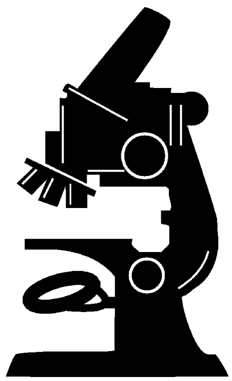
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

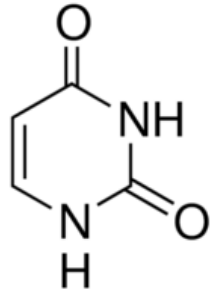
State • 2018



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. Where might you find the molecule in this image?



A) DNA
B) RNA
C) polypeptides
D) chitin
E) phospholipids

B02. Which of the following best represents reduced hybrid viability?
A) The shells of two *Bradybaena* species spiral in opposite directions.
B) Mules and hinnies.
C) The mating of first-generation hybrids yields second-generation hybrids that fail to thrive.
D) The production of polyploidy crop plants with decreased yields of product.
E) Different subspecies of *Ensatina* salamanders that interbreed in overlapping habitats, resulting in offspring that do not survive to adulthood.

B03. A population of diploid plants has a hypothetical gene, *ARA*, that exists as two alleles (*ARA1* and *ARA2*). Researchers determined that the frequency of *ARA1* was 0.13. Assuming the plant population is in Hardy-Weinberg equilibrium, what percent of the population is carrying both *ARA1* and *ARA2*?
A) 2.56%
B) 11.3%
C) 13.0%
D) 22.6%
E) 87.0%

B04. The main histone types found within the nucleosome (10-nm fiber) structure of eukaryotic chromatin includes all of the following *except*
A) H1.
B) H2A.
C) H2B.
D) H3.
E) H4.

B05. The vertebrate nervous system has a role in regulating endocrine pathways. In the vertebrate brain, the _______ receive(s) nervous system information and initiate(s) the appropriate endocrine response.
A) cerebellum
B) ventricles
C) brainstem
D) pituitary gland
E) hypothalamus

B06. Predict why microorganisms that only ferment would have membrane-bound ATPases.
A) Microorganisms use the ATPase to generate ATP during substrate-level phosphorylation in glycolysis.
B) The ATPase produces ATP through oxidative phosphorylation.
C) The ATPase can hydrolyze ATP and generate a proton motive force useful for other cellular work, including transport and motility.
D) The ATPase functions in the Krebs cycle.
E) The ATPase reoxidizes NADH to NAD^+ during fermentation.

B07. B lymphocytes are a type of immune system cell that are involved in the humoral (antibody-mediated) response of the adaptive immune system. If you were examining the organelles of an activated B-cell (produces antibodies), which organelle would you expect to be in abundance relative to the others listed below?
A) lysosome
B) nucleus
C) smooth endoplasmic reticulum
D) Golgi body
E) Mitochondrion

B08. Which structure on a plant root tip corresponds to an area where the cells are the most mitotically active to lengthen the root?
A) epidermis
B) root cap
C) apical meristem
D) lateral meristem
E) cortex

B09. When comparing and contrasting the process of transcription in eukaryotes and bacteria, which one of the following statements is *not* accurate?
A) Transcription factors must bind to eukaryotic promoters first, which then recruit RNA polymerase II to form the initiation complex.
B) Both bacteria and eukaryotes have TATA box.
C) RNA polymerase has helicase activity to unwind DNA.
D) Eukaryotic transcription termination involves formation of a polyadenylation signal.
E) The RNA polymerase involved in transcription for both eukaryotes and bacteria is a DNA-dependent RNA polymerase.

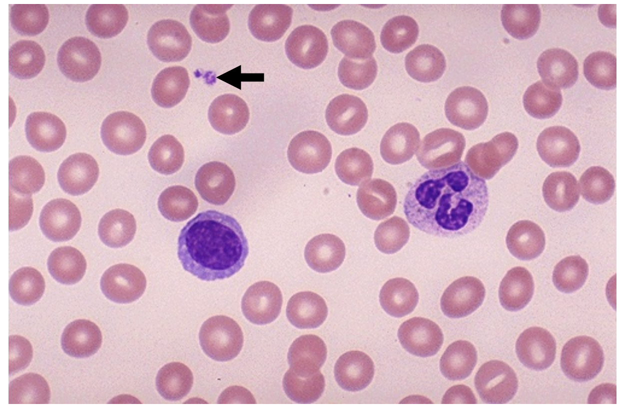
B10. MRSA is a ______ infection.
A) fungal
B) viral
C) bacterial
D) protozoal
E) helminth

B11. ________ control(s) primary production in terrestrial ecosystems.
A) Temperature and moisture
B) Amount of sunlight
C) Nonlimiting nutrient availability
D) The transfer of organic matter between producers and consumers
E) Trophic level

B12. Which of the following is a consequence of eutrophication?
A) Increased reproduction of fish and other aquatic species, due to increased nutrients.
B) More clarified water.
C) Higher dissolved oxygen concentrations.
D) Increased algal blooms.
E) Decreased plant growth.

B13. Which of the following is *not* an example of an evolutionary adaptation of a plant stem?
A) onion bulbs
B) rhizomes of iris plants
C) stolons of strawberry plants
D) tubers of potatoes
E) flower petals

B14. Examine the image of a blood smear. The arrow is pointing to a formed element involved in



A) immune defense.
B) osmoregulation.
C) blood clotting.
D) secreting antibodies.
E) respiratory gas exchange.

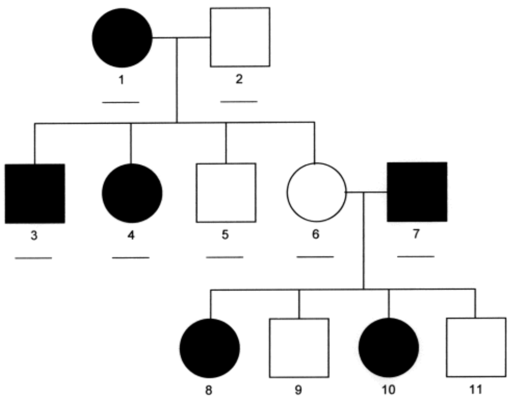
B15. If PCR began with one DNA target molecule, how many copies of the target molecule are present at the end of 25 cycles?
A) 25
B) 26
C) 1.6×10^7
D) 1.68×10^8
E) 3.35×10^7

B16. A hypothetical cell can respire using a combination of electron donors and acceptors. Given the following E_0' information from a redox tower, which pair from the answer choices would be most energetically favorable for a cell to use? Assume metabolic diversity in this hypothetical cell.

1. CO_2/glucose ($24e^-$): -0.43
2. NAD^+/NADH ($2e^-$): -0.32
3. Fumarate/succinate ($2e^-$): +0.03
4. NO_2^-/NO ($2e^-$): +0.36
5. $\frac{1}{2}O_2/H_2O$ ($2e^-$): +0.82

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

B17. Which inheritance pattern is represented by the human pedigree?



A) X-linked recessive
B) X-linked dominant
C) Y-linked recessive
D) Y-linked dominant
E) autosomal recessive
F) autosomal dominant

B18. RNA processing of pre-mRNA into mature transcript in eukaryotes involves three processes: addition of a 5' cap, 3'-poly(A) tail, and removal of the introns. Which statement about eukaryotic RNA processing is *incorrect*?
A) The poly(A) tail serves as a binding site for the ribosome.
B) The 5' cap is a modified guanine nucleotide.
C) Both the 5' cap and 3'-poly(A) tail assist with mRNA stability and resistance to degradation.
D) The spliceosome is comprised of snRNPs that recognizes sequences (splice sites) within the introns.
E) A single gene can encode more than one polypeptide due to alternative splicing.

B19. During nucleotide excision repair,
A) DNA polymerase III excises incorrect bases using its 3’→5’ exonuclease activity.
B) nucleases cut out the damaged DNA and the resulting gap is filled in and sealed with DNA polymerase and DNA ligase, respectively.
C) DNA polymerase III proofreads.
D) DNA polymerase I removes the incorrect base and adds the correct base.

B20. Individuals who were infected by the measles virus prior to vaccine development, and actually survived the disease, retain lifelong immunity to measles. Which of the following types of immunity is produced in this situation?
A) naturally acquired active immunity
B) naturally acquired passive immunity
C) artificially acquired active immunity
D) artificially acquired passive immunity

C01. A 23.5 gram piece of copper metal is dropped into 155 ml of 6.00 M nitric acid and reacts according to the following reaction until one of the reactants is exhausted:

$3\ Cu(s) + 8\ HNO_3(aq) \rightarrow$

$3\ Cu(NO_3)_2(aq) + 4\ H_2O(\ell) + 2\ NO(g)$

If the excess reactant is Cu, how many grams are left? If the excess reactant is HNO_3, what is the final concentration of the solution? (Assume the volume of the solution does not change.)

A) HNO_3 is in excess, final conc is 3.61 M.
B) HNO_3 is in excess, final conc is 1.23 M.
C) HNO_3 is in excess, final conc is 0.930 M.
D) Cu is in excess, 22.1 grams remain.
E) Cu is in excess, 7.39 grams remain.
F) Cu is in excess, 1.34 grams remain.

C02. Which of the following sets of compounds (A – E) contains only compounds that are insoluble in water?

A)	BaS	AgOH	$PbCl_2$	$MnCO_3$
B)	FeS	$Mg(OH)_2$	AgCl	$CaCO_3$
C)	CuS	$Pb(OH)_2$	Hg_2Cl_2	Na_2CO_3
D)	NiS	$Al(OH)_3$	$FeCl_3$	$CdCO_3$
E)	ZnS	KOH	$PbCl_4$	$NiCO_3$

C03. MgO reacts with HCl according to the following equation:

$MgO(s) + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2O(\ell)$

Use the standard enthalpy of formation for each compound (on the data page) to determine the change in enthalpy for the reaction.

A) −291.2 kJ/mol
B) +291.2 kJ/mol
C) −151.0 kJ/mol
D) +151.0 kJ/mol
E) −124.0 kJ/mol
F) +124.0 kJ/mol

C04. What is the sum of the coefficients in the balanced equation for the following redox reaction, which takes place in *basic* solution?

$Cr(OH)_3(s) + ClO_3^-(aq) \rightarrow CrO_4^{2-}(aq) + Cl^-(aq)$

A) 11
B) 15
C) 19
D) 23
E) 27

C05. If 0.64 g of NaOH is added to 100.0 mL of 0.075 M H_2SO_4 and the solution is then diluted to 1.0 L, what is the pH of the final solution?

A) 11.93
B) 11.00
C) 7.00
D) 3.00
E) 2.07

C06. What is the kinetic energy of the photoelectron that is produced when a blue photon with a wavelength of 472 nm strikes a potassium surface in a vacuum? Potassium has a work function of 3.67×10^{-19} J.

A) 4.21×10^{-17} J
B) 3.67×10^{-19} J
C) 4.21×10^{-19} J
D) 5.4×10^{-20} J
E) 7.9×10^{-22} J

C07. Which of these electrochemical cells will generate the highest voltage?

A) $Zn\,|\,Zn^{2+}(aq,\ 1\ M)\ \|\ Cu^{2+}(aq,\ 1\ M)\,|\,Cu$
B) $Zn\,|\,Zn^{2+}(aq,\ 0.5\ M)\ \|\ Cu^{2+}(aq,\ 0.5\ M)\,|\,Cu$
C) $Zn\,|\,Zn^{2+}(aq,\ 0.5\ M)\ \|\ Cu^{2+}(aq,\ 1\ M)\,|\,Cu$
D) $Zn\,|\,Zn^{2+}(aq,\ 1\ M)\ \|\ Cu^{2+}(aq,\ 0.5\ M)\,|\,Cu$
E) They will all generate the same voltage.

C08. A student tries to make 1000 mL of 0.500 M $ZnCl_2$ by combining 100 mL of a 5.00 M stock solution with 1000 mL of water. He quickly realizes his mistake, and decides to add more stock solution to the new solution to bring the final concentration to 0.500 M. How much additional stock solution should he add?

A) 4.50 mL
B) 45.0 mL
C) 5.50 mL
D) 55.0 mL
E) 11.1 mL

C09. Given the gas phase equilibrium reaction $2\ NO_2 \rightleftharpoons N_2O_4$, use the thermodynamic data provided on the data sheet to determine the equilibrium constant for the reaction at 25°C.

A) 0.0121
B) 0.147
C) 1.00
D) 6.81
E) 82.9

C10. A chemist performs a crude titration by dropping NaOH pellets into a 50.0 mL solution of 2.24 M HNO_3 and counting how many pellets it takes to reach the phenolphthalein endpoint. If his NaOH is 96.7% pure and each NaOH pellet weighs 0.1602 grams, how many pellets will he have to add to make the solution turn pink?

A) 28
B) 29
C) 31
D) 35
E) 40

C11. The concentration unit *part per thousand* (ppt) is a mass-to-mass ratio of solute to solution. If a sample of surface water from the Gulf of Mexico at 25°C has a concentration of 36.0 ppt NaCl and a density of 1.027 g/mL, what is the molar concentration of NaCl in the sample?

A) 0.370 M
B) 0.494 M
C) 0.633 M
D) 0.924 M
E) 0.974 M

C12. A 300°C, the rate constant for the gas phase reaction

$$H_2(g) + I_2(g) \rightarrow 2HI(g)$$

is 1.32×10^{-4} L/mol·s.
At 400°C, the rate constant for the same reaction is 2.13×10^{-2} L/mol·s. What is the activation energy for the reaction?

A) 163 kJ/mol
B) 113 kJ/mol
C) 50.7 kJ/mol
D) 28.8 kJ/mol
E) 13.7 kJ/mol

C13. A chemist discovers a bottle in his lab labeled *sodium halide*, but he doesn't know which compound it is. He dissolves 3.04 grams of the solid in 100. g of water and measures the freezing point of the solution as –1.1°C. Which compound is in the bottle?

A) NaF
B) NaCl
C) NaBr
D) NaI
E) It is none of these compounds.

C14. If a molecule is made up of seven atoms and all of the bond angles are 90°, what is the most likely shape of the molecule?

A) Octahedron
B) Square Planar
C) Cubic
D) Zig-zag
E) Tesseract

C15. If five ice cubes, each at exactly 0°C and each weighing 16.5 grams, are added to 250. g of water at 65.0°C in an insulated container, what will the final temperature of the water be?

A) 38.7°C
B) 29.1°C
C) 26.3°C
D) 22.4°C
E) 19.9°C

C16. If 1.00 g of $FeCl_3$ is dissolved in 10.0 mL of water and added to 50.0 mL of 0.375 M $AgNO_3$, how many grams of AgCl(*s*) will be formed?

A) 0.188 g
B) 1.93 g
C) 2.65 g
D) 3.00 g
E) 26.7 g

C17. A scientist places a sample of water at 25°C in an insulated container at 760 torr and begins reducing the pressure in the container. At what pressure will the water begin to boil?

A) 24.5 torr
B) 27.9 torr
C) 30.3 torr
D) 33.5 torr
E) 36.9 torr

C18. In the van der Waals equation of state,

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

the correction factors applied to the pressure and volume terms are included in order to take into account which physical properties of real gases?

A) intermolecular forces that act between gas particles and the volume taken up by the gas particles
B) the density of the gas and isotopic variations that cause some particles of the gas to have more mass than others
C) quantum effects and non-Newtonian collisions between real gas molecules
D) the shape and polarity of molecules in a real gas
E) those terms have no physical significance and are merely empirical correction factors

C19. If 65.0 kJ of heat is added to 100.0 g of ethanol at 0°C in an open container and the vaporized ethanol is allowed to escape, how much ethanol will remain in the container?

A) 44.9 g
B) 55.1 g
C) 46.5 g
D) 18.9 g
E) 78.2 g

C20. Solid ammonium carbamate, $NH_4CO_2NH_2$, decomposes into $CO_2(g)$ and $NH_3(g)$. If 25.0 g of ammonium carbamate is placed in an evacuated container and the equilibrium pressure in the container is 0.121 atm, what is K_P for the decomposition reaction?

A) 1.77×10^{-3} atm^3
B) 3.67×10^{-3} atm^3
C) 2.62×10^{-4} atm^3
D) 5.25×10^{-4} atm^3
E) 6.56×10^{-5} atm^3

P01. According to Tyson, given the rate at which we are discovering meteorites on Earth whose origin is Mars, we conclude that ____________ ton(s) of Martian rocks rain down on Earth each year.
A) about one
B) about ten
C) about a hundred
D) about a thousand
E) about a million

P02. According to Tyson, what would be the first and foremost visible feature of planet Earth if it were observed by aliens from the great beyond?
A) The lights from human cities
B) The blueness caused by water
C) The clouds and weather patterns
D) The polar ice caps
E) The largest human-built structures

P03. According to Tyson, using the latest estimates, how many Earth-like planets should exist in the Milky Way galaxy?
A) four million
B) forty million
C) three hundred million
D) three billion
E) forty billion

P04. A small galaxy is 220 million light-years from Earth, and is moving away from us at 7500 km/s. Another small galaxy is 340 million light-years from Earth. Using Hubble's Law, how fast would you expect that second galaxy to be moving away from us?
A) 4900 km/s
B) 6000 km/s
C) 9300 km/s
D) 11,600 km/s
E) 17,900 km/s

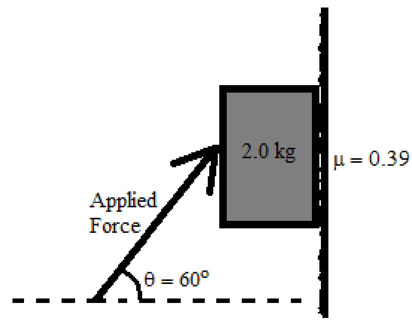
P05. For this formula, B is in units of Teslas, I is in units of Amperes, F is in Newtons, and V has units of Volts. What are the units of β?

$$\beta F = I^2 BV$$

A) N/Cs (Newtons per Coulomb-second)
B) N/m (Newtons per meter)
C) N/s (Newtons per second)
D) Nm/s (Newton-meters per second)
E) N^2/s (Newtons-squared per second)

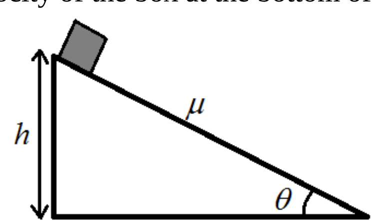
P06. A hawk, flying at a speed of 15.0m/s at an angle of 45.0° above the horizontal, accidentally releases a mouse held in its talons. The hawk is at a height of 80.0m when it releases the mouse. From the instant it is released, how much time passes until the mouse hits the ground? Ignore air resistance.
A) 5.85s
B) 5.27s
C) 4.18s
D) 3.10s
E) 2.79s

P07. A 2.00kg box is pushed against a vertical textured wall by a force angled at 60.0° above the horizontal (as shown). The coefficient of friction between the box and the wall is 0.390. At what magnitude of applied force will the box begin to slide up the wall?



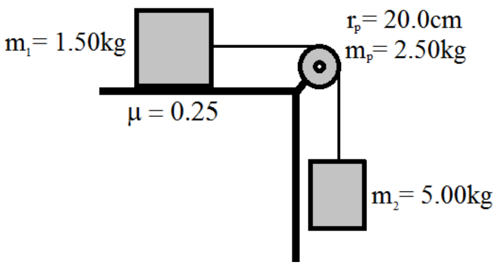
A) 50.3 N
B) 32.1 N
C) 29.2 N
D) 22.6 N
E) 19.6 N

P08. A box of bananas slides down a ramp inclined at an angle θ. The box is released from rest from a vertical height of *h*, and the coefficient of friction between the box and the ramp is μ. Which formula correctly gives the velocity of the box at the bottom of the ramp?



A) $\sqrt{2gh(1 - \mu cot\theta)}$
B) $\sqrt{2gh(1 - \mu tan\theta)}$
C) $\sqrt{2gh(1 - \mu cos\theta)}$
D) $\sqrt{2gh(1 + \mu cos\theta)}$
E) $\sqrt{2gh(1 + \mu tan\theta)}$

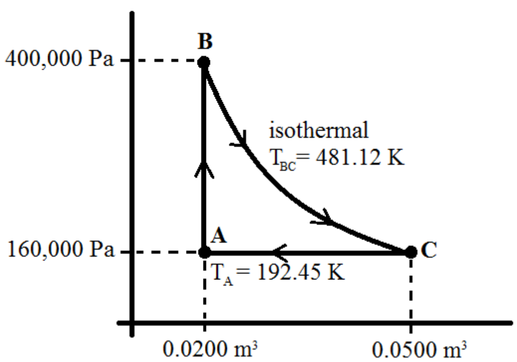
P09. A horizontal Atwood machine is constructed as shown, with a 1.50kg mass on the table and a 5.0kg hanging mass. The solid disk pulley has a mass of 2.50kg and a radius of 20.0cm, and the rope goes over the pulley without slipping. If the coefficient of friction between the table and the first mass is 0.25, what is the acceleration of the masses? The moment of inertia of a solid disk is $I = \frac{1}{2}mr^2$.



A) 5.04 m/s^2
B) 5.85 m/s^2
C) 6.32 m/s^2
D) 6.97 m/s^2
E) 7.54 m/s^2

P10. A travelling wave on a string has a wavelength of 2.20m and a frequency of 90.0Hz. The mass of 1.00m of the string is 1.50g. What is the tension in the string?
A) 0.297 N
B) 2.51 N
C) 58.8 N
D) 613 N
E) 2610 N

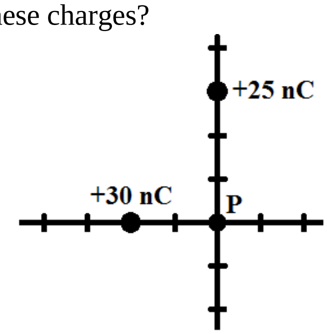
P11. Two moles of an ideal gas go through the cycle shown on the PV diagram below. The gas is diatomic, so $C_V = \frac{5}{2}R$ and $C_P = \frac{7}{2}R$. What is the efficiency of the cycle?



A) 7.00 %
B) 13.1 %
C) 28.6 %
D) 33.6 %
E) 60.0 %

P12. Two Capacitors, a 2.20μF and a 4.70μF, are connected in series to a 12.0V battery. The capacitors are carefully disconnected from the circuit without discharging them. The capacitors are then reconnected with their positive plates wired together (so that they are in parallel). After they are reconnected, what is the electric potential across the capacitors?
A) 2.61 V
B) 3.83 V
C) 5.22 V
D) 8.17 V
E) 11.1 V

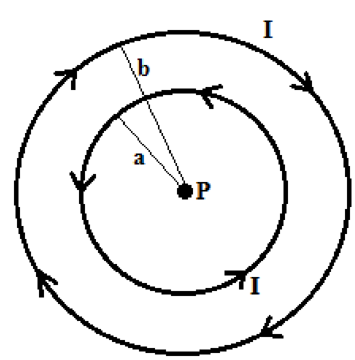
P13. Two charges are arranged as shown: a +25.0nC charge is placed at (0.00, 3.00cm) and a +30nC charge is placed at (−2.00cm, 0.00). What is the magnitude of the electric field at the origin (point P) due to these charges?



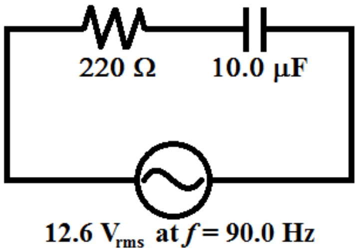
A) 2.50×10^5 N/C
B) 4.24×10^5 N/C
C) 6.74×10^5 N/C
D) 7.19×10^5 N/C
E) 9.24×10^5 N/C

P14. Two concentric wire circles each carry a current I, as shown. The radii of the wire circles are *a* and *b*. Which expression correctly represents the magnitude of the magnetic field at the center of the circles?

A) $\frac{\mu_0 I}{2}\left(\frac{b-a}{ab}\right)$
B) $\frac{\mu_0 I}{2}\left(\frac{b+a}{ab}\right)$
C) $\frac{\mu_0 I}{2\pi}\left(\frac{b-a}{ab}\right)$
D) $\frac{\mu_0 I}{4}\left(\frac{b+a}{ab}\right)$
E) $\frac{\mu_0 I}{4\pi}\left(\frac{b-a}{ab}\right)$

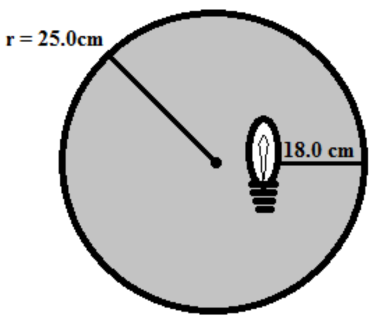


P15. What is the magnitude of the rms-current flowing in this AC circuit?



A) 11.1 mA
B) 31.7 mA
C) 44.6 mA
D) 57.3 mA
E) 71.2 mA

P16. A light source is embedded inside a solid sphere of glass. The sphere has a radius of 25.0cm and the light source is located 18.0cm from the surface of the sphere. As seen from outside the sphere, where does the image of the light source appear? The index of refraction of the glass is 1.57.



A) 47.9cm inside the sphere
B) 41.0cm inside the sphere
C) 20.0cm inside the sphere
D) 15.5cm inside the sphere
E) 9.09cm inside the sphere

P17. What is the proper normalization constant for this wavefunction for the domain given:

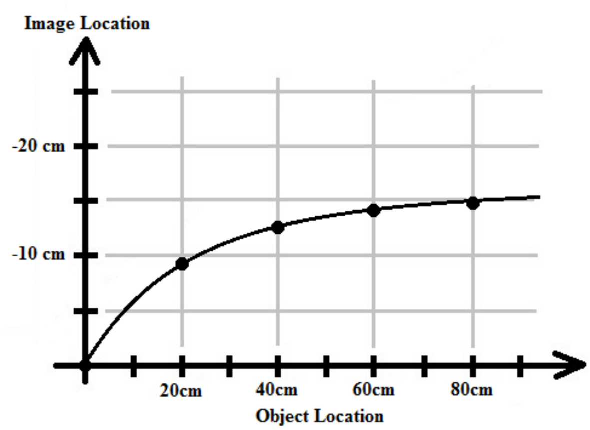
$$\Psi = Ae^{-kx} \quad 0 < x < \infty.$$

A) $A = \sqrt{2k}$
B) $A = \sqrt{k}$
C) $A = 2\sqrt{k}$
D) $A = \frac{1}{\sqrt{2k}}$
E) $A = \frac{1}{\sqrt{k}}$

P18. The quark structure of a D^+meson is $c\bar{d}$. It preferentially decays into a K-meson and two pions: $D^+ \to K^0 + \pi^+ + \pi^0$. To the nearest order of magnitude, what would be the mean lifetime of the D^+meson?
A) 10^{-31} seconds
B) 10^{-24} seconds
C) 10^{-18} seconds
D) 10^{-12} seconds
E) 10^{-2} seconds

P19. A varying horizontal force is used to push a 1.75kg cart. The force follows the equation: $F = 2.50x^2$ where x is the distance the cart has travelled in meters. If the cart is pushed for a total horizontal distance of 5.00m, what is the final velocity of the cart?
A) 8.45 m/s
B) 10.9 m/s
C) 13.4 m/s
D) 18.9 m/s
E) 24.4 m/s

P20. This graph shows the location of the image formed by a convex mirror as a function of the object location. All locations are measured relative to the surface of the mirror. What is the radius of curvature of the mirror?



A) -9.0cm
B) -12cm
C) -18cm
D) -24cm
E) -36cm

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 = 40.7 kJ/mol
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

Thermodynamic Data

Compound	ΔH_f^o (kJ/mol)
$MgCl_2(aq)$	–801.2
$H_2O(\ell)$	–285.8
$HCl(aq)$	–167.2
$MgO(s)$	–601.6
$N_2O_4(g)$	+9.16
$NO_2(g)$	+33.18

Compound	ΔS^o (J/mol·K)
$N_2O_4(g)$	+304
$NO_2(g)$	+240

Physical Data for Ethanol

T_{mp} = –114.14°C
T_{bp} = 78.24°C
ΔH_{fus} = 106.3 J/g
ΔH_{vap} = 836.8 J/g
$c_{liquid\ ethanol}$ = 2.420 J/g·°C
$c_{solid\ ethanol}$ = 2.439 J/g·°C
$c_{gaseous\ ethanol}$ = 1.699 J/g·°C

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	$1.67265 \times 10^{-27}\ kg$
Neutron mass	m_n	$1.67495 \times 10^{-27}\ kg$
Atomic Mass Unit	u	$1.66 \times 10^{-27}\ kg$
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	$8.314\ J/mol \cdot K$
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	$1.013 \times 10^{5}\ Pa$

DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!

UIL HIGH SCHOOL SCIENCE CONTEST
ANSWER KEY
2018 STATE

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

CHEMISTRY SOLUTIONS – UIL STATE 2018

C01. (F) First calculate how many moles of HNO_3 and how many moles of Cu we have to start with:

$$\text{moles } HNO_3 = 6.00\text{ M} \times 0.155\text{ L} = 0.9300\text{ mol } HNO_3$$

$$\text{moles Cu} = \frac{23.5\text{ g}}{63.55\text{ g/mol}} = 0.3698\text{ mol Cu}$$

According to the balanced equation, 0.9300 moles of HNO_3 is enough to react with

$$0.9300\text{ moles } HNO_3 \times \frac{3\text{ mol Cu}}{8\text{ mol } HNO_3} = 0.3488\text{ mol Cu}$$

We have more Cu than that, so HNO_3 is the limiting reagent.
Excess Cu = 0.3698 mol – 0.3488 mol = 0.02105 mol Cu
0.02105 mol Cu × 63.55 g/mol = 1.34 g Cu.

C02. (B) The soluble compounds are BaS, KOH, $FeCl_3$, and Na_2CO_3.

C03. (C) Use the standard enthalpy of formation for each compound to determine the change in enthalpy for the reaction.
$\Delta H_{rxn} = [\Delta H_f°(MgCl_2(aq)) + \Delta H_f°(H_2O(\ell))] - [2\Delta H_f°(HCl(aq)) - \Delta H_f°(MgO(s))]$
$\Delta H_{rxn} = [(-801.2) + (-285.8)] - [2(-167.2) + (-601.6)]$
$\Delta H_{rxn} = -801.2 - 285.8 + 334.4 + 601.6$
$\Delta H_{rxn} = -151.0$ kJ/mol

C04. (B) $2\ Cr(OH)_3 + ClO_3^- + 4\ OH^- \rightarrow 2\ CrO_4^{2-} + Cl^- + 5\ H_2O$

C05. (B) Calculate how many moles of OH^- and H^+ we have to start with:

$$\frac{0.64\text{ g}}{40.00\text{ g/mol}} = 0.016\text{ mol NaOH} = 0.016\text{ mol } OH^-$$

$$0.075\text{ M} \times 0.1000\text{ L} = 0.0075\text{ mol } H_2SO_4 \times \frac{2\text{ mol } H^+}{1\text{ mol } H_2SO_4} = 0.015\text{ mol } H^+$$

OH^- is in excess. Excess OH^- = 0.016 mol – 0.015 mol = 0.0010 mol. Now dilute to 1 L:

$$\frac{0.0010\text{ mol } OH^-}{1.0\text{ L}} = 0.0010\text{ M } OH^-$$

–log(0.0010) = pOH = 3.00
pH = 14 – pOH = 14 – 3.00 = 11.00

C06. (D) First calculate the energy of the photon from its wavelength. $E = h\nu$ and $\nu\lambda = c$. Combine these equations to get $E = hc/\lambda$, then calculate E.

$$E = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\ \mathrm{J \cdot s})(2.998 \times 10^{8}\mathrm{m/s})}{4.72 \times 10^{-7}\mathrm{m}} = 4.21 \times 10^{-19}\ \mathrm{J}$$

The kinetic energy of the electron is equal to the energy of the photon minus the energy required to free the electron:

$$KE = h\nu - \varphi = 4.21 \times 10^{-19}\ \mathrm{J} - 3.67 \times 10^{-19}\ \mathrm{J} = 5.4 \times 10^{-20}\ \mathrm{J}$$

C07. (C) A student might rationalize an answer based on LeChatlier's Principle – the reaction is $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$, so increasing the amount of reactant (Cu^{2+}) or reducing the amount of product (Zn^{2+}) should make the forward reaction more favorable. And this is correct.

The voltage of the cell can also be calculated using the Nernst equation,

$$E_{\mathrm{cell}} = E°_{\mathrm{cell}} - \frac{0.0591}{n}\log Q$$

In this case $n = 2$ and $Q = \frac{[\mathrm{Zn}^{2+}]}{[\mathrm{Cu}^{2+}]} = \frac{0.5}{1} = 0.5$

Plugging these values into the Nernst equation yields

$$E_{\mathrm{cell}} = E°_{\mathrm{cell}} - \frac{0.0591}{2}\log 0.5 = E°_{\mathrm{cell}} - (0.0296\ \times -0.301)$$

$E_{\mathrm{cell}} = E°_{\mathrm{cell}} + 0.009\ V$. The other cell choices are all at or below $E°_{\mathrm{cell}}$.

C08. (E) The most straightforward way to do this problem is also the most difficult, but there are a few shortcuts clever students might use to bypass the rigorous chemistry calculations. First the straightforward method:

Use the dilution equation $M_1V_1 = M_2V_2$ to calculate the concentration of the first solution he made:

$$M_1V_1 = M_2V_2 \text{ so } M_2 = \frac{M_1V_1}{V_2} = \frac{(5.00\ \mathrm{M})(0.100\ \mathrm{L})}{1.100\ \mathrm{L}} = 0.4545\ \mathrm{M}$$

You can't use the dilution equation to get to the final solution because when he adds more stock solution to the solution he just made, the number of moles of $ZnCl_2$ is changing:

Moles of $ZnCl_2$ in this solution + moles of $ZnCl_2$ added = moles of $ZnCl_2$ in the final solution
$M_2V_2 + M_1V_{\mathrm{added}} = M_{\mathrm{final}}V_{\mathrm{final}}$
$V_{\mathrm{final}} = V_2 + V_{\mathrm{added}}$
$M_2V_2 + M_1V_{\mathrm{added}} = M_{\mathrm{final}}(V_2 + V_{\mathrm{added}})$

M_{final} = 0.500 M, so rearrange to solve for V_{added}:
$M_2V_2 + M_1V_{\text{added}} = M_{\text{final}}V_2 + M_{\text{final}}V_{\text{added}}$
$M_2V_2 - M_{\text{final}}V_2 = M_{\text{final}}V_{\text{added}} - M_1V_{\text{added}}$
$M_2V_2 - M_{\text{final}}V_2 = (M_{\text{final}} - M_1)(V_{\text{added}})$

$$V_{\text{added}} = \frac{M_2V_2 - M_{\text{final}}V_2}{M_{\text{final}} - M_1}$$

$$V_{\text{added}} = \frac{(0.4545\text{ M})(1.100\text{ L}) - (0.500\text{ M})(1.100\text{ L})}{(0.500\text{ M}) - (5.00)} = \frac{-0.05005}{-4.50} = 0.0111\text{ L} = 11.1\text{ mL}$$

That's the hard way. Students might also realize that the final concentration is 1/10 that of the stock solution, so the volume of the final solution has to be 10× the total volume of stock solution used:

Total stock solution added = 100 mL + V_{added}
Final volume = 1000 + 100 + V_{added}
$V_{\text{final}} = 10 \times (100 + V_{\text{added}})$
$V_{\text{final}} = 1000 + 10V_{\text{added}}$
$1100 + V_{\text{added}} = 1000 + 10V_{\text{added}}$
$100 = 9V_{\text{added}}$
V_{added} = 100/9 = 11.1 mL

Another method is to use the dilution equation for the entire two-step dilution process as one step, since the total moles of $ZnCl_2$ added must be equal to the number of moles of $ZnCl_2$ in the final solution:

$M_1(100 + V_{\text{added}}) = M_{\text{final}}V_{\text{final}}$
$5.00 \times (100 + V_{\text{added}}) = 0.500\,(1100 + V_{\text{added}})$
$500 + 5.00\,V_{\text{added}} = 550 + 0.500\,V_{\text{added}}$
$4.5\,V_{\text{added}} = 50$
V_{added} = 11.1 mL

A sneakier alternative is to solve this by trial and error by multiplying the initial concentration by the initial-to-final volume ratio, and plugging in the volumes given in answers A – E for V_{added} until the calculated result is equal to the final concentration of 0.500 M:

$$5.00\text{ M} \times \frac{100 + V_{\text{added}}}{1100 + V_{\text{added}}} = 0.500\text{ M}$$

I put the correct answer last in case anyone thought to do the problem this way.

C09. (D) $\Delta G = \Delta H - T\Delta S$ and $\Delta G = -RT \ln K$, so first calculate ΔG, then use that to calculate K. Using the values for ΔH_f^o and ΔS^o for N_2O and N_2O_4 as given on the data sheet,

$\Delta H = \Delta H_f^o(N_2O_4) - 2 \times \Delta H_f^o(NO_2) = 9.16$ kJ/mol – 2(33.18 kJ/mol) = –57.20 kJ/mol = –57,200 J/mol
$\Delta S = \Delta S^o(N_2O_4) - 2 \times \Delta S^o(NO_2) = 304$ J/mol·K – 2(240 J/mol·K) = –176 J/mol·K

$\Delta G = \Delta H - T\Delta S$
$\Delta G = -57{,}200$ J/mol – (298 K × –176 J/mol·K) = –4752 J/mol

$\Delta G = -RT \ln K$, so $\ln K = -\Delta G/RT$
$\ln K$ = (4752 J/mol) / (8.314 J/mol·K × 298 K) = 1.918
$K = e^{1.918} = 6.81$

C10. (B) First calculate how many moles of H^+ are in the acid solution, and how many moles of NaOH are in each pellet:

$$\text{moles of H}^+ = 2.24\text{ M} \times 0.050\text{ L} = 0.112\text{ mol H}^+$$

$$0.1602\text{ grams/pellet} \times 0.967 \times \frac{1\text{ mole NaOH}}{40.00\text{ g}} = 0.003873\text{ mol NaOH/pellet}$$

Divide the moles of H^+ by the moles per pellet of NaOH to determine how many pellets are required to neutralize the acid:

$$\frac{0.112\text{ mol H}^+}{0.003873\text{ mol OH}^-\text{/pellet}} = 28.92\text{ pellets}$$

So the 29th pellet will result in an excess of NaOH and the solution will turn pink.

C11. (C) Assume a 1000 g sample. In that case the mass of NaCl in the sample is 36.0 g, and the sample volume is (1000 g)/(1.027 g/ml) = 973.7 mL = 0.9737 L.
(36.0 g NaCl)/(58.44 g/mol) = 0.616 mol NaCl
(0.616 mol)/(0.9737 L) = 0.633 M

C12. (A) The two-point Arrhenius equation relates the activation energy and rate constants at two different temperatures:

$$\ln\left(\frac{k_1}{k_2}\right) = \frac{-E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Rearrange to solve for activation energy:

$$E_a = -R \times \frac{\ln(k_1/k_2)}{\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

T_1 = 300°C = 573 K, T_2 = 400°C = 673 K
$k_1 = 1.32 \times 10^{-4}$ L/mol·s, $k_2 = 2.13 \times 10^{-2}$ L/mol·s
R = 8.314 J/mol·K

$$E_\mathrm{a} = -8.314\ \mathrm{J/mol \cdot K} \times \frac{\ln(1.32 \times 10^{-4}/2.13 \times 10^{-2})}{\left(\frac{1}{373} - \frac{1}{473}\right)}$$

$$E_\mathrm{a} = -8.314\ \mathrm{J/mol \cdot K} \times \left(\frac{-5.084}{0.0002593}\right) = 163{,}010\ \mathrm{J/mol} = 163\ \mathrm{kJ/mol}$$

C13. (C) Use the freezing point depression to calculate moles of particles in the solution:
$\Delta T_\mathrm{f} = K_\mathrm{f}\, m$
ΔT_f = 1.1°C
K_f = 1.86°C/m

$$m = \frac{\Delta T_f}{K_f} = \frac{1.1\text{°C}}{1.86\ \text{°C}/m} = 0.5914\ \mathrm{mol/kg}$$

Assume the density of water is 1.00 kg/L, then 0.5914 mol/kg × 0.100 kg = 0.05914 mol. This is the number of moles of *particles* in the solution, but since there are two moles of particles for every mole of sodium halide that dissolves, the number of moles of *compound* dissolved is 0.05914 / 2 = 0.02957 moles. The molar mass of the compound is therefore 3.04 g / 0.02957 mol = 102.8 g/mol. This is close to the molar mass of 102.89 for NaBr.

C14. (A)

C15. (B) Melting the ice requires 334 J/g × 16.5 g/cube × 5 cubes = 27,555 J
Removing that much heat from the water will lower its temperature by an amount ΔT:
$q = mc\Delta T$, so $\Delta T = q/mc$ = 27,555/(250 × 4.184) = 26.34°C

So now we're mixing 82.5 g of water at 0°C (the melted ice cubes) with 250 g of water at a new temperature of 65.0 – 26.34 = 38.66°C, and we have to calculate the final temperature.

T_Final can be calculated using the calorimetry equation or by using a shortcut. First we'll do it the long way, by rearranging the calorimetry equation to solve for T_Final:

$m_\mathrm{C}c_\mathrm{C}\Delta T_\mathrm{C} = -m_\mathrm{H}c_\mathrm{H}\Delta T_\mathrm{H}$
$m_\mathrm{C}c_\mathrm{C}(T_\mathrm{Final} - T_\mathrm{C}) = -m_\mathrm{H}c_\mathrm{H}(T_\mathrm{Final} - T_\mathrm{H})$
$m_\mathrm{C}c_\mathrm{C}T_\mathrm{Final} - m_\mathrm{C}c_\mathrm{C}T_\mathrm{C} = -m_\mathrm{H}c_\mathrm{H}T_\mathrm{Final} + m_\mathrm{H}c_\mathrm{H}T_\mathrm{H}$
$m_\mathrm{C}c_\mathrm{C}T_\mathrm{Final} + m_\mathrm{H}c_\mathrm{H}T_\mathrm{Final} = m_\mathrm{H}c_\mathrm{H}T_\mathrm{H} + m_\mathrm{C}c_\mathrm{C}T_\mathrm{C}$
$T_\mathrm{Final}(m_\mathrm{C}c_\mathrm{C} + m_\mathrm{H}c_\mathrm{H}) = m_\mathrm{H}c_\mathrm{H}T_\mathrm{H} + m_\mathrm{C}c_\mathrm{C}T_\mathrm{C}$

$$T_{\text{Final}} = \frac{m_{\text{H}}c_{\text{H}}T_{\text{H}} + m_{\text{C}}c_{\text{C}}T_{\text{C}}}{m_{\text{C}}c_{\text{C}} + m_{\text{H}}c_{\text{H}}}$$

$$T_{\text{Final}} = \frac{(250\text{ g})(4.184)(38.66) + (82.5\text{ g})(4.184)(0)}{(82.5\text{ g})(4.184) + (250)(4.184)} = 29.07 = 29.1℃$$

Shortcut: since the hot material and the cold material are the same substance, the specific heat capacity cancels out, and T_{Final} can be calculated by ignoring the calorimetry equation and simply taking a weighted average of the two temperatures:

$$T_{\text{Final}} = \frac{m_{\text{H}}T_{\text{H}} + m_{\text{C}}T_{\text{C}}}{m_{\text{H}} + m_{\text{C}}} = \frac{(250\text{ g})(38.66) + (82.5\text{ g})(0)}{(82.5\text{ g}) + (250)} = 29.07 = 29.1℃$$

C16. (C) Determine the limiting reactant by calculating how much product can be formed from the amounts of each reactant available:

1.00 g $FeCl_3$ / 162.20 g/mol = 0.006165 mol $FeCl_3$

$$0.006165\text{ mol FeCl}_3 \times \frac{3\text{ mol AgCl}}{1\text{ mol FeCl}_3} = 0.01850\text{ mol AgCl}$$

0.375 M × 0.050 L = 0.01875 mol $AgNO_3$

$$0.1875\text{ mol AgNO}_3 \times \frac{3\text{ mol AgCl}}{3\text{ mol AgNO}_3} = 0.01875\text{ mol AgCl}$$

$AgNO_3$ is in excess, and $FeCl_3$ is the limiting reagent. The mass of AgCl formed is 0.01850 mol × 143.32 g/mol = 2.65 g AgCl

(The volume of the $FeCl_3$ solution is not needed in this problem.)

C17. (B) Since a liquid boils when its vapor pressure is equal to the surrounding pressure, the water will boil when the pressure inside the container is equal to the vapor pressure of water at 25°C. The Clausius-Clapeyron equation relates vapor pressure at one temperature to vapor pressure at another temperature, using the molar heat of vaporization.

$$\ln\left(\frac{P_1}{P_2}\right) = \frac{-\Delta H_{\text{vap}}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln(P_1) - \ln(P_2) = \frac{-\Delta H_{\text{vap}}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln(P_1) = \ln(P_2) - \frac{\Delta H_{\text{vap}}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

The calculations can be done using any pressure units, but since the answers are given in torr, the problem provides atmospheric pressure in torr in hopes that the students will start with torr and not have to convert pressure units at the end. The *1* and *2* subscripts can be assigned to either condition; I'm assigning 760 torr and 100°C as P_2 and T_2 to make it easier to solve for P as P_1.

P_1 = ??? torr P_2 = 760 torr
T_1 = 25°C = 298 K T_2 = 100°C = 373 K
H_{vap} = 40700 J/mol (H_{vap} must be J/mol because R uses units of joules and moles)
R = 8.314 J/mol·K

$$\ln(P_1) = \ln(760) - \frac{40700}{8.314}\left(\frac{1}{298} - \frac{1}{373}\right)$$

$$\ln(P_1) = 6.633 - (4895.4)(6.747 \times 10^{-4})$$

$$\ln(P_1) = 6.633 - 3.303 = 3.330$$

$$P_1 = e^{3.33} = 27.9 \text{ torr}$$

C18. (A)

C19. (A) First determine how much energy is required to heat the ethanol from 0°C to its boiling point of 78.24°C, then see how many grams of ethanol can be vaporized with the remaining energy.

Heat 100.0 g of ethanol from 0°C to 78.24°C: $c_{\text{liquid ethanol}}$ = 2.420 J/g·°C
$q = mc\Delta T$ = 100.0 g × 2.420 J/g·°C × 78.24°C = 18.93 kJ
Heat remaining = 65.0 kJ – 18.93 kJ = 46.07 kJ
ΔH_{vap} for ethanol = 836.8 J/g
46,070 J / 836.8 J/g = 55.05 grams vaporized
100.0 g – 55.05 g = 44.9 g of ethanol remain

C20. (C) $NH_2CO_2NH_4(s) \rightleftharpoons CO_2(g) + 2\ NH_3(g)$

$P_{\text{total}} = 0.121$ atm

$$P_{CO_2} = \frac{1}{3}(0.121 \text{ atm}) = 0.04033 \text{ atm}$$

$$P_{NH_3} = \frac{2}{3}(0.121 \text{ atm}) = 0.08067 \text{ atm}$$

$$K_P = (P_{CO_2})(P_{NH_3})^2 = (0.04033 \text{ atm})(0.08067 \text{ atm})^2 = 2.62 \times 10^{-4} \text{atm}^3$$

PHYSICS SOLUTIONS – UIL STATE 2018

P01. (D) page 167-168: "At the rate we are discovering meteorites on Earth whose origin is Mars, we conclude that about a thousand tons of Martian rocks rain down on Earth each year."

P02. (B) page 181: "What visible features of planet Earth might they detect? Blueness would be first and foremost. Water covers more than two-thirds of Earth's surface…."

P03. (E) page 192: "Latest estimates, extrapolating from the current catalogs, suggest as many as forty billion Earth-like planets in the Milky Way alone."

P04. (D) When dealing with galaxies this far away, their recession velocity is governed primarily by Hubble's Law. Fortunately, Hubble's Law is linear: $v = H_0 d$, where v is the velocity of the galaxy, H_0 is Hubble's constant, and d is the distance from Earth to the galaxy. When we compare two galaxies, we can just use the ratio: $\frac{v_1}{d_1} = H_0 = \frac{v_2}{d_2}$. So, using the data given: $\frac{7500\ km/s}{220\ Mly} = \frac{v_2}{340\ Mly}$, which gives: $v_2 = 11600\ km/s$.

P05. (C) Solving for β, we get $\beta = \frac{I^2BV}{F}$. Converting everything to units and utilizing the relationships between different units: $\beta = \frac{[A]^2[T][V]}{[N]} = \frac{[C]^2}{[s]^2}\frac{[s][N]}{[m][C]}\frac{[J]}{[C]}\frac{1}{[N]} = \frac{[J]}{[s][m]} = \frac{[N][m]}{[s][m]} = \frac{[N]}{[s]} = \frac{Newtons}{seconds}$.

P06. (B) We first need to find the initial velocity of the mouse, which equals the velocity of the hawk. We need to break this velocity into horizontal and vertical components: $v_{ix} = v_i cos\theta = (15)\cos(45) = 10.6\ m/s$, and $v_{iy} = v_i sin\theta = (15)\sin(45) = 10.6\ m/s$. To get the time, we only need the vertical component, because now we can write an equation describing the vertical motion of the mouse and it will give us the answer. Using the initial position to be where the mouse is released, the final position being the ground ($y = 0$), and noting that the acceleration is due to gravity, we can write: $y_f = y_i + v_{iy}t + \frac{1}{2}a_y t^2 = 0 = 80 + (10.6)t + \frac{1}{2}(-9.8)t^2$. This gives us a quadratic equation in time: $t^2 - 2.165t - 16.33 = 0$. The solutions to this quadratic are $t = -3.10s, 5.27s$. Since negative time is nonsense, we know the answer must be $t = 5.27$s.

P07. (C) In order to slide up the wall, the vertical component of the force must overcome both gravity and friction. However, the frictional force will increase as the applied force increases, since the horizontal component of the applied force will result in an increased normal force. A force diagram reveals two horizontal forces (the horizontal component of the applied force to the right, and the normal force to the left). We also have three vertical forces (gravity downward, friction downward, and the vertical component of the applied force upward). At the instant the box begins to slide up the wall, the forces will all exactly balance; so we can write horizontal and vertical equations: $\sum F_x = F_h - F_N = Fcos(60) - F_N = 0$, and $\sum F_y = F_v - mg - F_f = Fsin(60) - mg - F_f = 0$. From these equations, we can see $F_N = Fcos(60)$, which leads to $F_f = \mu F_N = (0.39)Fcos(60) = 0.195F$. Plugging this into the vertical equation gives $Fsin(60) - mg - 0.195F = 0 = 0.866F - 0.195F - mg = 0$. This leads us to $0.671F = mg = (2)(9.8) = 19.6$, and finally $F = \frac{19.6}{0.671} = 29.2\ N$.

P08. (A) Since we know the vertical height and are seeking a velocity, this can easily be solved using conservation of energy. The box starts with only gravitational potential energy, mgh. At the bottom, the box only has kinetic energy $\frac{1}{2}mv^2$. In between, some energy is converted into heat by friction. This work done by friction equals the frictional force multiplied by the distance travelled. The distance is easy – it is the length of the incline, the hypotenuse of the triangle: $sin\theta = \frac{h}{d}$, so $d = \frac{h}{sin\theta}$. To get the magnitude of the frictional force, we need to consider the force diagram. We take "down the incline" to be the positive x-direction and upwards, perpendicular to the incline, to be the positive y-direction. The forces are the gravitational force (down), the normal force (+y direction), and the frictional force (-x direction). The gravitational force has to be divided into components: in the positive x-direction is $mgsin\theta$, and in the negative y-direction is $mgcos\theta$. At this point we can write the force equation for both the x and y directions: $\sum F_x = mgsin\theta - F_f = ma_x$ and $\sum F_y = F_N - mgcos\theta = 0$. The forces in the y-direction sum to zero since there is no acceleration perpendicular to the incline. It is the y-direction equation that will help us: we can see from it that $F_N = mgcos\theta$. We also know that the frictional force depends on the normal force: $F_f = \mu F_N$. This gives us $F_f = \mu mgcos\theta$. Finally, we can get the work done by friction: $W = F_f d = \mu mgcos\theta \frac{h}{sin\theta}$. This simplifies to $W = \mu mghcot\theta$.

Now we can return to conservation of energy. Taking the initial energy, subtracting the work done by friction, and setting it equal to the final energy, we get: $mgh - \mu mghcot\theta = \frac{1}{2}mv^2$. Mass cancels, and we simplify to acquire the velocity: $v^2 = 2gh - 2\mu ghcot\theta = 2gh(1 - \mu cot\theta)$, or $v = \sqrt{2gh(1 - \mu cot\theta)}$.

P09. (B) To begin this problem, we must start with a force diagram for each mass, as well as for the pulley. Let's start by analyzing the mass on the table: The first mass has four forces – gravitation (m_1g, down), a normal force (F_N, up), tension (T_1, right), and friction (F_f, left). This mass accelerates to the right, so the force equations are: $\sum F_y = F_N - m_1 g = 0$, and $\sum F_x = T_1 - F_f = m_1 a$. This leads to $F_N = m_1 g = (1.50)(9.8) = 14.7$ N. From this we can get the frictional force: $F_f = \mu F_N = (0.25)(14.7) = 3.675$ N. Thus, we can solve for the tension: $T_1 = 1.50a + 3.675$.

For the hanging mass, we only have forces in the y-direction: gravitation (m_2g, down), and tension (T_2, up). The acceleration is downward, so the force equation becomes: $\sum F_y = m_2 g - T_2 = m_2 a$. Solving for tension gives: $T_2 = m_2 g - m_2 a$, or $T_2 = (5)(9.8) - 5a = 49 - 5a$.

Lastly, we must consider the torque on the pulley. It is a solid disk that rotates about its center, so the only forces that contribute to the torque are the two tensions, T_1 and T_2. All other forces (gravitation and normal forces) are centered on the axis of the pulley and, thus, have a torque arm of zero. The torque arm for the both tensions is just the radius of the pulley. Conveniently, the tensions are also perpendicular to the torque arms (this is usually true for a pulley). The two tensions cause torques in opposite directions, so we consider the direction of acceleration to be positive, and can write the torque equation as $\sum \tau = T_2 r - T_1 r = I\alpha = \frac{1}{2} m_p r^2 \alpha$. Since the rope does not slip, we know that the angular acceleration and the linear acceleration are related: $a = r\alpha$. Using this and simplifying the torque equation gives: $T_2 r - T_1 r = \frac{1}{2} m_p r a$. Cancel out the remaining r, and we get $T_2 - T_1 = \frac{1}{2} m_p a = (0.5)(2.50)a = 1.25a$. Now we combine all of the tension equations together: $T_2 - T_1 = (49 - 5a) - (1.50a + 3.675) = 1.25a = 45.325 - 6.50a$. This simplifies to: $7.75a = 45.325$, which gives the acceleration: $a = \frac{45.325}{7.75} = 5.85\ \frac{m}{s^2}$.

P10. (C) We can get the speed of the traveling wave from the frequency and wavelength: $v = f\lambda = (2.20)(90.0) = 198$m/s. Now we also know the wave velocity is related to the tension in the string by: $v = \sqrt{\frac{T}{\mu}}$, where μ is the mass per length of the string. Since we know the mass of 1.00m of string, we can get the mass per length easily: $\mu = \frac{m}{L} = \frac{1.50g}{1m} = 1.50\ \frac{g}{m} = 0.00150\ \frac{kg}{m}$. So, $v = 198 = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{T}{0.0015}}$, or $\frac{T}{0.0015} = (198)^2 = 39204$, which gives the tension as: $T = (0.0015)(39204) = 58.8$ N.

P11. (B) Since we have the pressure, volume, and temperature at every vertex, we only need to consider the work done and heat flow for each process. The process A→ B is isovolumetric; thus $W = 0$ and the heat flow is $Q = nC_V\Delta T = (2)\left(\frac{5}{2}R\right)(481.12 - 192.45) = (5)(8.314)(288.67) = 12000$ J. The second process is isothermal, so $W = Q = nrT\ell n\left(\frac{V_f}{V_i}\right) = (2)(8.314)(481.12)\ell n\left(\frac{0.0500}{0.0200}\right) = 7330$ J. The final process is isobaric, for which $W = P\Delta V = (160{,}000)(0.02 - 0.05) = -4800$ J, and for which the heat flow is: $Q = nC_P\Delta T = (2)\left(\frac{7}{2}R\right)(192.45 - 481.12) = (7)(8.314)(-288.67) = -16800$ J.

Now we can calculate the total work done by this cycle: $W = 0 + 7330 - 4800 = 2530$ J. And, using only positive heat flow, we can find the total heat added to the gas during one cycle: $Q_{in} = 12000 + 7330 = 19330$ J. Thus, the efficiency is $\eta = \frac{W}{Q_{in}} = \frac{2530}{19330} = 0.131 = 13.1\%$.

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P12. (C) First, we need to find the original charge stored on the capacitors, while they are in series. To do this, we need the total capacitance of the series connection. We get $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{2.2\mu F} + \frac{1}{4.7\mu F} = 0.667\frac{1}{\mu F}$, which gives $C_T = 1.5\mu F$. Now, the charge stored on each capacitor is the same as the charge stored on the combined capacitance. In other words, $Q_1 = Q_2 = Q_T = C_T V_T = (1.5\mu F)(12V) = 18\mu C$. Once the capacitors are disconnected, they each still contain 18μC of charge.

Now we reconnect the capacitors so that they are in parallel, which means their charges will rearrange so that the voltage across the capacitors is equal. No charge is lost, so $Q_1 + Q_2 = 36\mu C$; and, since they are in parallel, we have $V_1 = V_2$. Recalling that $Q = CV$, we get: $C_1V_1 + C_2V_2 = (C_1 + C_2)V = (2.2\mu F + 4.7\mu F)V = 36\mu C = (6.9\mu F)V$. This gives $V = \frac{36\mu C}{6.9\mu F} = 5.22$ V.

P13. (D) The net electric field will be the vector sum of the fields produced by each individual charge. Consider the +30nC charge: $\vec{E}_1 = \frac{kQ}{r^2}\hat{r} = \frac{(8.99 \times 10^9)(30 \times 10^{-9})}{(0.02)^2}(+\hat{\imath}) = 6.743 \times 10^5\hat{\imath}$. Notice that this field is directed entirely in the x-direction ($\hat{\imath}$). Now consider the +25nC charge: $\vec{E}_2 = \frac{kQ}{r^2}\hat{r} = \frac{(8.99 \times 10^9)(25 \times 10^{-9})}{(0.03)^2}(-\hat{\jmath}) = -2.497 \times 10^5\hat{\jmath}$. Notice that this field is entirely in the negative y-direction $(-\hat{\jmath})$. The total electric field is the sum of these two individual fields, or $\vec{E} = \vec{E}_1 + \vec{E}_2 = 6.743 \times 10^5\hat{\imath} - 2.497 \times 10^5\hat{\jmath}$. The magnitude of this field is the Pythagorean sum of the two directional vector components:
$|E| = \sqrt{(6.743 \times 10^5)^2 + (-2.497 \times 10^5)^2} = \sqrt{5.17 \times 10^{11}} = 7.19 \times 10^5\ \frac{N}{C}$.

P14. (A) The magnitude of the magnetic field at the center of a circular current is given by the equation: $|B| = \frac{\mu_0 I}{2R}$, while the direction is in the z-direction (+z for a counterclockwise current, and -z for a clockwise current). Thus, the magnetic field for the small circular current is $B_1 = \frac{\mu_0 I}{2a}(+z)$ and the field due to the larger circular current is $B_1 = \frac{\mu_0 I}{2b}(-z)$. The net magnetic field (which is entirely in the z-direction) is then $|B| = \frac{\mu_0 I}{2a} - \frac{\mu_0 I}{2b} = \frac{\mu_0 I}{2}\left(\frac{1}{a} - \frac{1}{b}\right)$. By getting a common denominator for the terms in parentheses, we get:$|B| = \frac{\mu_0 I}{2}\left(\frac{b}{ab} - \frac{a}{ab}\right) = \frac{\mu_0 I}{2}\left(\frac{b-a}{ab}\right)$.

P15. (C) First, we need to find the capacitive reactance: $X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(90)(10 \times 10^{-6})} = 176.8\ \Omega$. Now we can get the total impedance: $Z = \sqrt{R^2 + X_C^2} = \sqrt{(220)^2 + (176.8)^2} = \sqrt{79658} = 282.2\ \Omega$. Since we already have the rms-voltage, we can get the rms-current easily: $I_{rms} = \frac{V_{rms}}{Z} = \frac{12.6}{282.2} = 0.0446\ A = 44.6\ mA$.

P16. (D) The light emitted from the light source encounters a single refracting surface on the way out. The refracting surface (as seen by the light source) is concave, so it has a negative radius of curvature. The magnitude of the radius of curvature of the refracting surface is simply the radius of the sphere. This gives $R = -25.0$cm. The equation for image formation by a refracting surface is $\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$. Here n_1 is the index of refraction for where the light starts (in the glass) and n_2 is the index of refraction for where the light ends up (in the air). Working in cm, we get: $\frac{1.57}{18} + \frac{1.00}{q} = \frac{1.00-1.57}{-25} = 0.08722 + \frac{1}{q} = 0.0228$. Solving for the image location gives: $q = -15.5$cm. That is, 15.5cm inside the sphere.

P17. (A) Normalization is a fundamental step in doing quantum mechanics, but it does require integral calculus: We want to choose the constant A so that $\int \Psi^*\Psi dx = 1$ when integrated over the entire domain. So, for this entirely real wavefunction and domain, we get: $\int_0^\infty (Ae^{-kx})(Ae^{-kx})dx = \int_0^\infty (A^2 e^{-2kx})dx = A^2 \int_0^\infty (e^{-2kx})dx = 1$
Integrating gives us: $A^2 \frac{1}{-2k} e^{-2kx} \mid_0^\infty = \frac{A^2}{-2k}(e^{-\infty} - e^0) = \frac{A^2}{-2k}(0-1) = \frac{A^2}{2k} = 1$. Thus, we get $A^2 = 2k$, or $A = \sqrt{2k}$.

P18. (D) The mean lifetime of a particle is determined in large part by the strength of the fundamental force responsible for the decay. Strong decays happen in 10^{-22} to 10^{-24} seconds, while electromagnetic decays take longer – about 10^{-16} to 10^{-18} seconds. Weak force decays are slow – usually around 10^{-8} to 10^{-12} seconds. The D-meson is a *charmed* meson (contains a charm quark), but its decay products are not. The Kaon is a *strange* meson (contains a strange quark), while the pions contain only ordinary up and down quarks. It is obvious, then, that the charm quark must change flavor into either a strange quark (most likely) or into an up or down quark. Flavor changes can only happen through a weak force decay. Therefore, the decay of this D-meson must be a weak force decay – and the only appropriate choice for the lifetime of a weak force decay is 10^{-12} seconds

P19. (B) This is best solved using energy, so first we need to determine the work done on the cart by the varying force. Since the force is not constant, we will need to integrate over the distance. In general: $W = \int F(x)dx$. More specifically for this problem: $W = \int_0^{5.00}(2.50x^2)dx = (2.50)\frac{1}{3}x^3 \Big|_0^5 = (2.50)\frac{1}{3}5^3 = 104.2$ J. The work done by the force converts entirely into kinetic energy, so $W = KE = \frac{1}{2}mv^2 = 104.2$. Then, $v^2 = \frac{(2)(104.2)}{1.75} = 119.0$, which leads to $v = \sqrt{119} = 10.9$ m/s.

P20. (E) This graph shows that there is a horizontal asymptote, which happens to occur at an image location equal to the focal length of the mirror; but it is also easy enough to read a point from the curve and use those values to estimate the focal length of the mirror: using the data point (p = 40cm, q = -12.5cm) we can calculate the focal length of the mirror: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{1}{40} + \frac{1}{-12.5} = -0.055\text{cm}^{-1}$. Then we get a focal length of $f = \frac{1}{-0.055} = -18.2$cm. The radius of curvature is twice the focal length, so $R = 2f = 2(-18.2) = -36.4 \approx -36$cm.