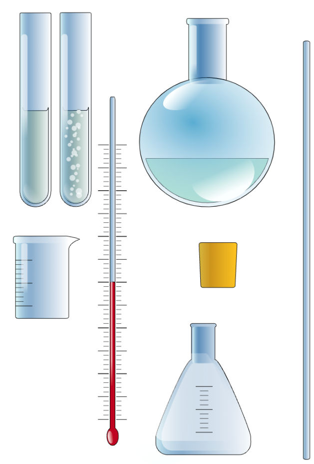
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

State • 2024



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. Two molecules moving in the same direction across a membrane through a transport protein against their concentration gradients would be termed _____ and an example of ____ transport.
A) antiport: active
B) symport: active
C) antiport: passive
D) symport: passive
E) antiport: osmosis
F) symport: osmosis

B02. Which of the following is not one of the four characteristics that all chordates have at some point in their life?
A) notochord
B) pharyngeal slits or clefts
C) muscular, post-anal tail
D) dorsal, hollow nerve cord
E) vertebrae

B03. A bacterial cell is infected with a bacteriophage. The bacteriophage injects its nucleic acid into the host cell. The injected nucleic acid enters the nucleoid region and integrates into the host DNA as a prophage. The prophage is replicated along and in sync with the cell's own replication processes and the prophage is passed down to each daughter cell. Which viral replicative cycle is described above?
A) Mitosis
B) Lytic
C) Lysogeny
D) Binary fission
E) Budding

B04. A microorganism that has nitrate reductase in place of cytochrome c oxidase in its electron transport chain is likely transforming energy via
A) anaerobic respiration.
B) aerobic respiration.
C) alcohol fermentation.
D) 2,3-butanediol fermentation.
E) homolactic acid fermentation.

B05. Which member of *Enterobacteriaceae* causes opportunistic urinary tract infections and produces an enzyme, called urease, that alkalinizes urine and can ultimately cause kidney and bladder stone formation due to pH changes?
A) *Escherichia coli*
B) *Shigella dysenteriae*
C) *Salmonella enterica* Typhi
D) *Klebsiella pneumoniae*
E) *Proteus vulgaris*

B06. Proteins that hold sister chromatids together at the centromeres until the right moment of separation during Meiosis II are specifically called
A) histones.
B) shugoshin.
C) cohesins.
D) adhesions.
E) chiasmas.

B07. Reproductive barriers are an important factor in the evolution of species. What happens when closely related species have incomplete reproductive barriers and can therefore mate and produce offspring in the areas where their ranges overlap?
A) A stable, hybrid zone can form.
B) Reproductive barriers can be strengthened when hybrids are less fit than their parent species.
C) Reproductive barriers can be weakened as gene flow occurs among the species.
D) All of the above can occur.
E) None of the above occurs.

B08. In the nitrogen biogeochemical cycle, the main reservoir of nitrogen, which contains 80% of free dinitrogen gas, is
A) the atmosphere.
B) soil.
C) water of oceans, lakes, rivers, and streams.
D) sediments.
E) biomass of living organisms.

B09. Examine the image. In which location would this cell produce pyruvate during aerobic respiration?

A) 2
B) 3
C) 9
D) 11
E) 13

B10. Translation of the mRNA for genes whose products are designed to be used in the extracellular environment would occur using ribosomes _______ of eukaryotic cells.
A) free-floating in the cytosol
B) present within the Golgi complex
C) embedded within the rough endoplasmic reticula
D) located within the mitochondrial matrix
E) found within the nucleolus

B11. According to the Centers for Disease Control and Prevention, which viral infection is currently being monitored across the United States, with the most cases being reported in Illinois, as of late March 2024?
A) mumps
B) rabies
C) smallpox
D) COVID-19
E) measles

B12. If red (R) is incompletely dominant over white (r), and tall (T) is completely dominant over short (t), what percent of the progeny will be both pink and short from the following genetic cross?

RrTt x RrTt

A) 0%
B) 6.25%
C) 10%
D) 12.5%
E) 24%
F) 50%

B13. Supergroup Opisthokonta includes all of the following except
A) amoebas.
B) choanoflagellates.
C) fungi.
D) animals.
E) nucleariids.

B14. The enzymes that catalyze the reactions of the Calvin-Benson cycle in plants are located within the
A) plant cell’s cytoplasm.
B) chloroplast's stroma.
C) thylakoid membranes.
D) grana.
E) thylakoid lumen/spaces.

B15. Assuming Hardy-Weinberg equilibrium, a population has 792 individuals that exhibit the dominant phenotype out of a total population of 926. What is the frequency of heterozygotes in the population?
A) 0.145
B) 0.380
C) 0.471
D) 0.620
E) 0.855

B16. Acetylcholine is released into the neuromuscular junction from motor neuron synapses to promote muscle contraction. Which of the following occurs *immediately* after the release of this neurotransmitter to promote muscle contraction?
A) Acetylcholine diffuses across the synaptic cleft and binds to ligand-gated ion channels on the muscle fiber.
B) Acetylcholinesterase degrades the acetylcholine in the synaptic cleft.
C) An action potential travels down the motor neuron and activates voltage-gated ion channels.
D) Voltage-gated calcium channels open in response to an action potential and release calcium.
E) An end plate potential is achieved, and muscle contraction occurs.

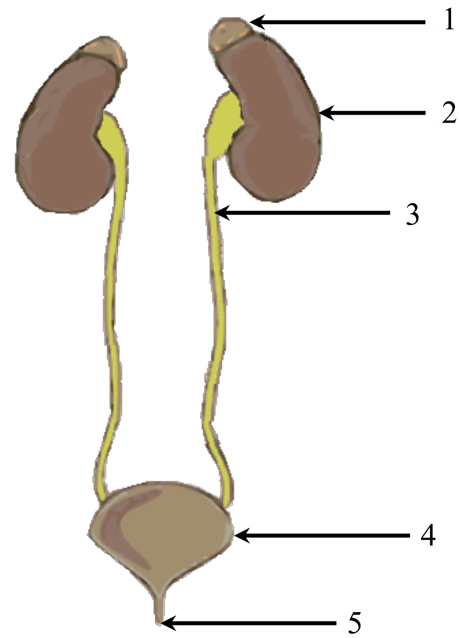
B17. A third copy of human chromosome 21 in a fertilized egg results in
A) Klinefelter syndrome.
B) Jacob syndrome.
C) Down syndrome.
D) deletion of human chromosome 1.
E) color blindness.

B18. The ABO gene locus encodes glycosyltransferases that produce type A and type B antigens on erythrocytes, which confer blood type. The H gene, also called FUT1 for fucosyl transferase, synthesizes the sugars (type H antigens) to which the type A or type B antigens are attached. The Bombay blood type (*hh*) results in type O but is still incompatible with non-Bombay type O blood as those who are genotype *hh* produce anti-H antibodies. Based upon this information, what percent of the progeny from the following cross would be considered type O?

I^AI^BHh x I^BiHh

A) 0%
B) 25%
C) 50%
D) 75%
E) 100%

B19. Examine the image. Where would transitional epithelium primarily be found?



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

B20. In the evolution of land plants, which structure evolved before the others in the list below?
A) pollen
B) flowers
C) roots
D) seeds
E) vascular tissue

C01. A standard latex party balloon is filled with a 50/50 mole to mole mixture of helium and argon to a volume of 14.5 L at 25 °C and 1 atm pressure. If the uninflated balloon weighs 36.2 grams, what is the overall density of the inflated balloon?

A) 0.85 g/L D) 2.96 g/L
B) 1.18 g/L E) 3.60 g/L
C) 3.22 g/L

C02. If you mix 7.70×10^{24} molecules of SF_4 with 770 grams of fluorine gas to produce SF_6 gas and the reaction goes to completion, what would the volume of the container be at 25°C and 1 atm pressure when the reaction is complete?

A) 496 L D) 1000 L
B) 316 L E) 770 L
C) 1232 L

C03. Which of these isotopes has the fewest neutrons?

A) C-14 D) F-19
B) N-14 E) Ne-20
C) O-18

C04. A gas sample has a volume of 10.0 L at 1.0 atm pressure and 25.6 °C. The volume of the container is expanded to 25.0 L and heated to 74.4°C, and then 50.0 grams of a mystery gas is added to the container. The new pressure is found to be 2.5 atm. Which of these gases could be the mystery gas?

A) CO_2 D) N_2
B) F_2 E) O_2
C) Ar

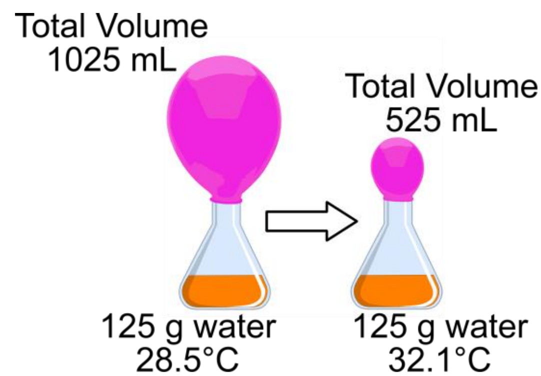
C05. According to molecular orbital theory, what is the bond order in a boron monoxide molecule?

A) ½ D) 2
B) 1 E) 2½
C) $^3/_2$

C06. Which of these compounds would you expect to have the largest lattice energy?

A) Na_3PO_4
B) $Cr(OH)_3$
C) $MgCl_2$
D) $(NH_4)_3AsO_4$
E) Ag_2S

C07. What is the change in internal energy for the reaction shown here at 1 atm pressure?



A) 1832 J D) –1832 J
B) 1888 J E) –1888 J
C) 1933 J F) –1933 J

C08. How many grams of barium chloride would you need to make up 1500 mL of solution with an osmotic pressure of 3.33 atm at 15°C?

A) 44.0 g D) 28.9 g
B) 104 g E) 98.2 g
C) 32.0 g

C09. For this equilibrium reaction

$$A_2 + 2B_2 \rightleftharpoons 2AB_2(g) \quad \Delta H_{rxn} = -30.4 \text{ kJ}$$

If the equilibrium constant is 3095 at 25°C, at what temperature will the equilibrium constant be equal to 500?

A) 55°C
B) 66°C
C) 77°C
D) 88°C
E) 99°C

C10. 5.00 grams of the salt of a monoprotic weak acid HA is dissolved in water to make 250 mL of solution and the pH of the solution is 9.67. If the salt has a molar mass of 144.11, what is the K_a of HA?

A) 6.34×10^{-7}
B) 1.58×10^{-8}
C) 4.68×10^{-5}
D) 2.14×10^{-10}
E) 3.31×10^{-9}

C11. If you had a 0.010 M solution of $NiCl_2$ and you started adding NaOH to the solution, at what pH would $Ni(OH)_2$ start to precipitate out? Assume no volume change as the NaOH is added.

A) 6.95
B) 7.00
C) 7.15
D) 7.22
E) 7.31

C12. What is the total charge on each side of the balanced net ionic equation for the redox reaction between the hypochlorite ion and the hydroxide ion? The products of the overall reaction are the chloride ion and oxygen gas.

A) 0
B) –1
C) –2
D) –4
E) –6

C13. When a certain reaction is heated from 20.0°C to 35.7°C, the reaction rate doubles. What is the activation energy for the reaction?

A) 328 J
B) 49.5 kJ
C) 13.6 kJ
D) 29.9 kJ
E) 33.2 kJ

C14. How many grams of copper are in a 500 gram sample of copper(II) sulfate pentahydrate?

A) 101 g
B) 127 g
C) 145 g
D) 182 g
E) 199 g

C15. If a photon of ultraviolet light strikes a potassium surface in a vacuum and ejects an electron with a velocity of 8.28×10^5 m/s, what is the wavelength of the ultraviolet photon? The work function for potassium is 2.3 eV.

A) 292 nm
B) 188 nm
C) 202 nm
D) 227 g
E) 345 g

C16. Five vanadium species are listed in the box below. Among these five species, the vanadium atom has the same oxidation state in two of them. What is that oxidation state?

$V(CO)_6$	VO_4^{3-}	VO_2
$VO(O_2)(H_2O)_4^+$	VO_2^-	

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

C17. The reaction between baking soda ($NaHCO_3$) and vinegar (~5% solution of acetic acid, CH_3COOH) is endothermic with a ΔH of 43.6 kJ/mol. An unknown mass of baking soda is added to 500 mL of vinegar in a lab that is at 23.5°C and 1 atm pressure and the temperature of the solution drops to 20.7°C. What volume of CO_2 gas is generated in this reaction? Assume the density and specific heat of the vinegar are the same as those of water.

A) 2.45 L
B) 2.66 L
C) 2.89 L
D) 3.01 L
E) 3.27 L

C18. A novice lab assistant is asked to make a 6.00 molar solution of NaCl, so he weighs out 6.00 moles of NaCl and adds it to 1.00 L of water. The density of the resulting solution is 1.194 g/mL. What is the actual molarity of the solution?

A) 5.30
B) 5.70
C) 6.00
D) 6.30
E) 6.70

C19. Which of these could be the correct name for an orbital in molecular orbital theory?

A) sp^3
B) $3p$
C) σ^*_{2p}
D) π^*_{2s}
E) π_{1s}

C20. The vapor pressure of water at 25°C is 0.0313 atm. What is the vapor pressure of water at 0°C?

A) 4.18 torr
B) 5.28 torr
C) 14.4 torr
D) 18.0 torr
E) 21.9 torr

P01. According to Guillen, while Albert Einstein was in school, he read many books on his own instead of doing his schoolwork. An example of a collection of volumes that inspired the young Einstein is…

A) *The Encyclopedia Brittanica*
B) *On the Origin of Species*
C) *English Men: their Nature and Nurture*
D) *Popular Books on Physical Sciences*
E) *The Principia Mathematica*

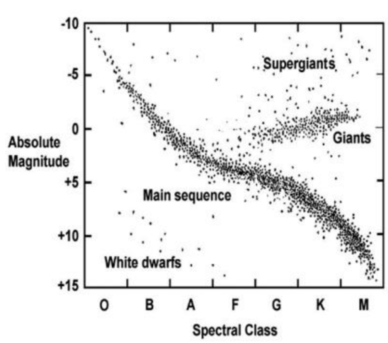
P02. According to Guillen, James Maxwell's hypothesis that electromagnetic ripples and light waves might be one and the same was confirmed by an experiment that used a spark generator to produce electromagnetic waves. Which scientist performed this experiment?

A) Albert Einstein
B) Marie Curie
C) Heinrich Hertz
D) Thomas Young
E) Albert Michaelson

P03. According to Guillen, Einstein concluded that it was physically impossible for any material body to travel as fast as an electromagnetic wave. What mathematical result helped lead him to this conclusion?

A) mass goes to zero at the speed of light.
B) mass becomes infinite at the speed of light.
C) energy becomes zero at the speed of light.
D) energy is not conserved near the speed of light.
E) light slows down when passing through matter.

P04. You discover an average F-class main sequence star that has an apparent magnitude of +10.5. Use this HR diagram to determine the approximate distance to the star. Note: 1.0 parsec equals 3.26 light-years.



A) around 2000 light-years
B) around 700 light-years
C) around 200 light-years
D) around 50 light-years
E) around 10 light-years

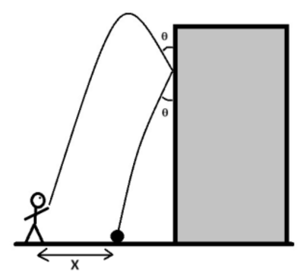
P05. What are the units of Z, which equals the square root of the product of the permittivity of free space and the permeability of free space?

$$Z = \sqrt{\varepsilon_0 \mu_0}$$

A) s/m (seconds per meter)
B) N (Newtons)
C) Js (Joule*seconds)
D) kg/C (kilograms per Coulomb)
E) C/J (Coulombs per Joule)

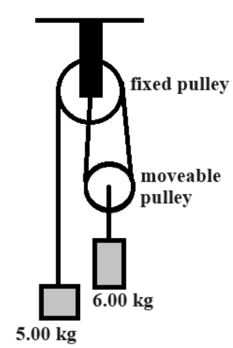
P06. You throw a tennis ball from a point that is 2.00m above the ground with a velocity of 16.0m/s at an angle of 56.0° above the horizontal. The ball hits the side of a brick building which is located 15.0m horizontally in front of you. After it hits the building, the tennis ball bounces back at the same speed with which it hit the building, and with a bounce angle that is the same as the impact angle (as shown). How far from you, horizontally, does the ball land on the ground (x)?

A) 0.514 m
B) 1.29 m
C) 2.90 m
D) 4.50 m
E) 5.78 m



P07. A pulley system is set up to give a mechanical advantage to an Atwood-type machine, as shown. The upper pulley is fixed in place, but the lower pulley is free to move. A 6.00kg mass is connected directly to the lower pulley and the mass and pulley move up and down together. A long rope connects to the fixed upper pulley, wraps around the lower pulley, goes over the top of the upper pulley, and is attached to a 5.00kg hanging mass. When the system is released, what is the acceleration of the 5.00kg mass? Assume the pulleys are frictionless and massless.

A) 0.891 m/s^2
B) 2.45 m/s^2
C) 3.02 m/s^2
D) 3.56 m/s^2
E) 4.90 m/s^2



P08. A variable force acts in the x-direction on a 4.50kg box, sliding it across the floor. The box slides from its starting location ($x = 0$) to a point six meters away ($x = 6.00$m). Along the way, the force decreases according to the equation $F = 72 - 2x^2$. What is the total work done by this force moving the box a distance of 6.00m?

A) 144 J
B) 288 J
C) 432 J
D) 648 J
E) 1296 J

P09. A merry-go-round is constructed by setting a 55.0kg solid disk with a radius of 1.44m on an axle with frictionless bearings. A person with a mass of 80.0kg starts at the exact center of the merry-go round, and the merry-go-round is given an initial angular velocity of 32.0 rad/s. The person then walks slowly to the edge of the merry-go-round. What is the angular velocity of the system after the person reaches the edge? Note: the moment of inertia of a solid disk is $I = \frac{1}{2}mr^2$.

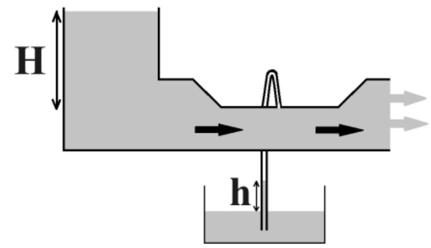
A) 22.0 rad/s
B) 17.5 rad/s
C) 13.0 rad/s
D) 11.0 rad/s
E) 8.18 rad/s

P10. A folk musician blows air across a 37.0cm-tall bottle that functions as an open-closed pipe. The sound resonates at a frequency of 652 Hz, which is one harmonic above the fundamental. What is the temperature of the air in and around the bottle?

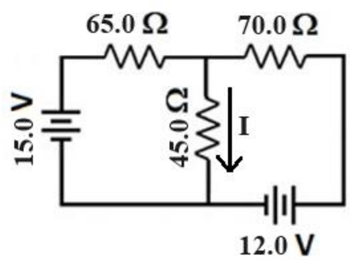
A) −15.2°C
B) −7.70°C
C) 0.00°C
D) 7.9°C
E) 16.1°C

P11. Oil with a density of 840kg/m^3 flows from an open container into a pipe. The level of oil in the container is $H = 1.50$m above the pipe (as shown). The pipe starts with a diameter of 16.0cm, narrows to a diameter of 14.0cm, and then returns to a diameter of 16.0cm before emptying the oil into an open-air pit. In the narrow section of the pipe, a small siphon tube containing air is connected to the pipe, and loops down into an open container of water. The entire setup is shown below. How far up into the siphon tube does the water rise (h)?

A) 179 cm
B) 150 cm
C) 126 cm
D) 106 cm
E) 89.0 cm



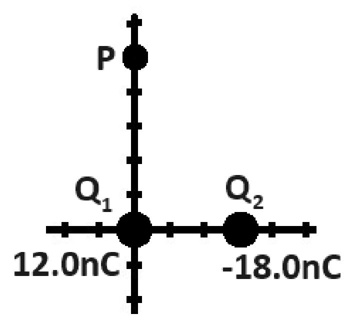
P12. In the circuit shown below, the current I is measured to be 104.3mA, which is not what we would expect. Which of these possible problems explains the erroneous current measurement?



A) The 70.0 Ω resistor is shorted (zero resistance)
B) The 70.0 Ω resistor is open (infinite resistance)
C) The 45.0 Ω resistor is shorted (zero resistance)
D) The 65.0 Ω resistor is shorted (zero resistance)
E) The 65.0 Ω resistor is open (infinite resistance)

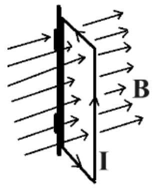
P13. Determine the magnitude of the electric field at the point P (0.0, 25.0cm) due to the two charges shown: Q_1 = 12.0nC located at (0.0, 0.0) and Q_2 = −18.0nC located at (16.0cm, 0.0)

A) 3567 N/C
B) 2523 N/C
C) 1728 N/C
D) 1006 N/C
E) 110.8 N/C



P14. A rectangular wire loop is 5.0cm wide and 8.0cm tall. One side of the loop is hinged to a post. A current of $I = 14.0$A flows in the loop, and a magnetic field of $B = 650$μT is directed perpendicular to the face of the loop. The setup is shown below. What is the net torque on the current-carrying loop due to the magnetic field?

A) 0.00 Nm
B) 3.64×10^{-5} Nm
C) 5.82×10^{-5} Nm
D) 4.55×10^{-4} Nm
E) 7.28×10^{-4} Nm

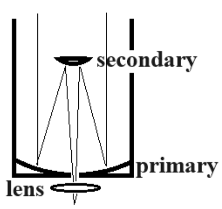


P15. A capacitor consists of two circular plates separated by 0.0200mm. The plates have a diameter of 2.50cm, and the voltage difference between the plates is 45.0V. The capacitor is rapidly discharged in a time of 4.20μs. What is the strength of the magnetic field induced along the edge of the capacitor's plates as a result of the discharge?

A) 2.93 nT
B) 18.6 nT
C) 37.3 nT
D) 42.1 nT
E) 149 nT

P16. A reflecting telescope is constructed with a concave primary mirror that has a radius of curvature of 96.0cm, a convex secondary mirror with a radius of curvature of 60.0cm, and a converging lens with a focal length of 15.0cm. The secondary mirror is placed 40.0cm in front of the primary mirror, and the lens sits 5.0cm behind the primary mirror. The telescope setup is illustrated below. Relative to the lens, where is the final image of a distant star located in this telescope?

A) 14.7 cm
B) 17.4 cm
C) 24.5 cm
D) 26.8 cm
E) 31.0 cm



P17. For the following wavefunction:

$$\Psi = A(1 + 2x) \quad 0 < x < 1$$

What is the expectation value of position, $\langle x \rangle$?

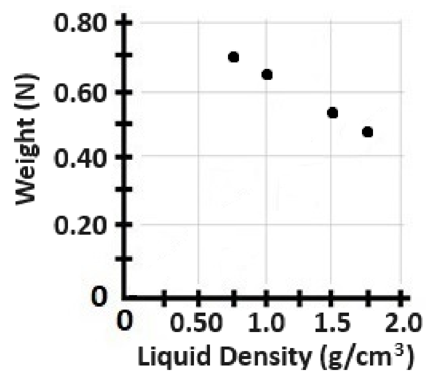
A) 0.231
B) 0.353
C) 0.500
D) 0.654
E) 0.769

P18. Two radioactive isotopes are combined together in a mixture. The first isotope has a half-life of 15.4minutes and an initial activity of 10.0μCi. The second isotope has a half-life of 24.8minutes and an initial activity of 20.0 μCi. After one hour, what is the total activity of the mixture?

A) 10.8 μCi
B) 8.19 μCi
C) 4.41 μCi
D) 3.21 μCi
E) 1.98 μCi

P19. An object made from an unknown metal is weighed while completely submerged in various liquids. The weight measurement is plotted against the density of the liquid in which the object is submerged when weighed. Based on these data, determine the approximate density of the unknown metal.

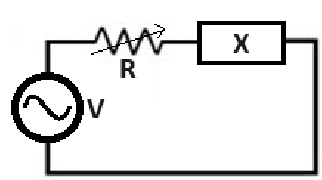
A) 2 g/cm^3
B) 4 g/cm^3
C) 6 g/cm^3
D) 8 g/cm^3
E) 10 g/cm^3



P20. A 12.0V$_{rms}$ AC power supply, a variable resistance, and an unknown reactance are connected in series (as shown). As the resistance is varied, the phase of the current relative to the voltage is measured. The data are tabulated below. Based on these data, what is the value of the reactance?

Resistance	Phase of the Current
80.0 Ω	61.9°
120 Ω	51.3°
220 Ω	34.3°
350 Ω	23.2°

A) |X| = 37.7 Ω
B) |X| = 75.0 Ω
C) |X| = 93.7 Ω
D) |X| = 124 Ω
E) |X| = 150 Ω



Chemistry

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

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

Water Data

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

Constants

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

Helpful Information

Density of water = 1.00 g/mL

K_{sp} for $Ni(OH)_2 = 2.8 \times 10^{-16}$

Conversion factors

1 atm = 760 torr
1 atm = 101325 Pa
1 atm = 1.01325 bar
1 L·atm = 101.325 J
1 eV = 1.602×10^{-19} J
1 in = 2.54 cm
1 ft = 12 in
1 cubic foot = 28.32 L

Physics

Useful Constants

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

DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!

UIL HIGH SCHOOL SCIENCE CONTEST
ANSWER KEY
2024 STATE

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

CHEMISTRY SOLUTIONS – UIL STATE 2024

C01. (E) First calculate how many moles of gas are in the balloon. Half of the moles are helium (molar mass 4.00 g/mol) and half of the moles are argon (39.95 g/mol). Determine the mass of the helium, the mass of the argon, and add that to the mass of the empty balloon, then divide by the volume to get density.

$PV = nRT$, so $n = PV/RT = (1 \cdot 14.5)/(0.08206 \cdot 298) = 0.59295$ moles.
Moles of each gas = 0.29648 mol.
Mass of helium = 0.29648 mol × 4.00 g/mol = 1.1859 g.
Mass of argon = 0.29648 mol × 39.95 g/mol = 11.8442 g.
Total mass of inflated balloon = 1.1859 + 11.8442 + 39.2 = 52.23 grams.
Density = mass/volume = 52.23 g/14.5 L = 3.30 g/L

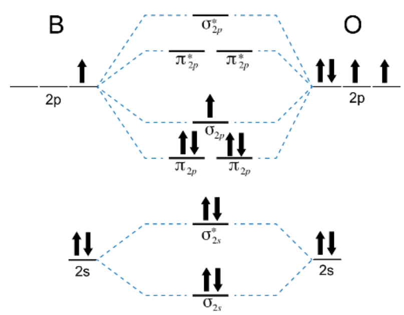
C02. (A) Calculate moles of SF_4 and moles of F_2. They will react according to the equation $SF_4(g) + F_2(g) \rightarrow SF_6(g)$ until one of them runs out. The total moles of gas in the sample will then be the moles of SF_4 formed plus the moles of the excess reactant.

Moles of SF_4 = $7.70 \times 10^{24} / 6.02 \times 10^{23}$ = 12.791 mol SF_4. Moles of F_2 = 770 g / 38 g/mol = 20.263 mol F_2. The SF_4 will run out first, producing 12.791 mol SF_6 and leaving an excess of 7.4725 moles of F_2. The total moles of gas at the end of the reaction is 12.790 + 7.4725 = 20.263 mol.
$V = nRT/P = (20.263)(0.08206)(298)/1 = 496$ L

C03. (B) N-14 has 7 protons and 7 neutrons. C-14 has 8 neutrons, and the others each have 10.

C04. (D) Initial gas moles: $n = PV/RT = (1.0)(10.0)/(0.08296)(298.6) = 0.4081$ moles
Final gas moles: $n = PV/RT = (2.5)(25.0)/(0.08296)(347.4) = 2.1924$ moles
Moles added = 2.1924 – 0.4081 = 1.7843 moles. 50.0 g/1.7843 mol = 28.02 g/mol, which is N_2.

C05. (E) The total number of valence electrons in B–O is 6 + 3 = 9. There are 7 electrons in bonding orbitals and 2 electrons in anti-bonding orbitals, so the bond order is (7 – 2)/2 = 2½.



C06. (B) Lattice energy depends on the magnitude of the ionic charges and the size of the ions. Higher charges and smaller ionic radii result in a higher the lattice energy. Answer choices A, B, and D all have ions with charges of 1 and 3 (the signs don't matter), whereas C and E only have charges of 1 and 2, so to break the tie among A, B, and D you look at the ion size. A and D both have large polyatomic –3 anions, whereas B has a much smaller hydroxide ion along with a very small Cr^{3+} ion, so $Cr(OH)_3$ will have the strongest attractions between the ions and therefore the highest lattice energy.

C07. (D) $\Delta U = q + w$ $q = mc\Delta T$ and $w = -P\Delta V$. m = 125 g, c = 4.184 J/c°C, ΔT = 3.6°C.
q = (125)(4.184)(3.6) = 1882.8 J, but heat is given off so this has to be negative: q = –1882.8 J
$w = -P\Delta V$ = –(1 atm)(0.525 L –1.025 L) = 0.500 L·atm. 0.500 L·atm × 101.325 J/L·atm = 50.66 J
$\Delta U = q + w$ = –1882.8 J + 50.66 J = –1832 J

C08. (A) $\Pi V = nRT = (g/MM)\cdot RT$, so $g = \Pi V\cdot MM/RT$. Π = 3.33 atm, V = 1.500 L, T = 288K, R = 0.08206L·atm/mol·K,. The molar mass of $BaCl_2$ is 208.23 g/mol. Plug the numbers in and g = 44.01 g

C09. (C) Equilibrium constants have an exponential dependence on temperature, so K and T are related by the van't Hoff equation.

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

K_2 = 500, K_1 = 3095, T_1 = 298 K, T_2 = ? K, ΔH_{rxn} = –30,400 J, R = 8.314 J/mol·K

$$\ln\left(\frac{500}{3095}\right) = \frac{-30400}{8.314}\left(\frac{1}{298} - \frac{1}{T_2}\right)$$

T_2 = 350.0 K = 77°C

C10. (A) Since it is a weak base in solution, assume K_b is small and the answer will be found somewhere in the equation $[\mathrm{OH}^-] = \sqrt{K_b C_{\text{base}}}$. If we know K_b we can solve for K_a using $K_a \times K_b = K_w$

At pH 9.67 $[OH^-] = 4.677\times10^{-5}$ M. $C_{base} = (g/MM)/V$ = (5.00/144.11)/0.250 = 0.13878 M
$K_b = [OH^-]^2/C_{base} = 1.5762 \times 10^{-8}$. K_b is in fact very small, so our initial assumption is good.
Therefore $K_a = 1 \times 10^{-14} / 1.5762 \times 10^{-8} = 6.34 \times 10^{-7}$.

C11. (D) K_{sp} for $Ni(OH)_2$ is $2.8 \times 10^{-16} = [Ni^{2+}][OH^-]^2$. $[OH^-]^2 = 2.8 \times 10^{-16}/0.010 = 2.8 \times 10^{-14}$, so $[OH^-] = 1.67 \times 10^{-7}$. pOH = 6.78 and pH = 7.22

C12. (C) The skeletal equation is ClO^- (*aq*) + OH^- (*aq*) → Cl^- (*aq*) + O_2 (*g*)

The unbalanced half reactions are $ClO^- \rightarrow Cl^-$ and $OH^- \rightarrow O_2$
When balanced in basic solution the half-reactions are $ClO^- + H_2O + 2e^- \rightarrow Cl^- + 2OH^-$ and $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ Double the reduction half-reaction to equalize the electrons and then add, and the overall balanced net ionic equation becomes

$2ClO^- + 2H_2O + 4e^- \rightarrow 2Cl^- + 4OH^-$
$\underline{4OH^- \rightarrow O_2 + 2H_2O + 4e^-}$
$2ClO^- \rightarrow O_2 + 2Cl^-$

The charge on each side of the balanced overall net ionic equation is –2. (Yes, one of the reactants is not in the net ionic equation! OH^- is still a reactant and is not a catalyst because the product O_2 comes from the OH^- reactant. A catalyst comes out of a reaction unchanged.)

C13. (E) Rate constants, and by extension reaction rates, have an exponential dependence on temperature, with the activation energy as part of the equation. The Arrhenius equation is used to solve this. Since the reaction rate is proportional to the rate constant, you can use the ratio of reaction rates in place of the ratio of rate constants.

$$\ln\left(\frac{k_2}{k_1}\right) = \ln\left(\frac{rate_2}{rate_1}\right) = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$rate_2/rate_1 = 2$, $R = 8.314$ J/mol·K, $T_1 = 293$ K, $T_2 = 308.7$ K

$$\ln(2) = \frac{E_a}{8.314}\left(\frac{1}{293} - \frac{1}{308.7}\right)$$

Solving for E_a, $E_a = 33200$ J = 33.2 kJ

C14. (B) The formula for copper(II) sulfate pentahydrate is $CuSO_4 \cdot 5H_2O$. The overall molar mass of the compound is 249.72 g/mol and the molar mass of Cu is 63.55 g/mol, so the mass of copper in 500 grams of the compound is (63.55/249.72) × 500 g = 127 g

C15. (A) $KE = hv - \varphi = hc/\lambda - \varphi$. $\lambda = hc/(KE + \varphi)$ $h = 6.626 \times 10^{-34}$ J·s, $c = 3.0 \times 10^8$ m/s,
$\varphi = 2.3$ eV × $(1.602 \times 10^{-19}$ J/eV$) = 3.6846 \times 10^{-19}$ J
$KE = \frac{1}{2}mv^2 = \frac{1}{2}(9.11 \times 10^{-31}\text{ kg})(8.28 \times 10^5\text{ m/s})^2 = 3.1228 \times 10^{-19}$ J
$\lambda = (6.626 \times 10^{-34})(3.0 \times 10^8)/(3.1228 \times 10^{-19} + 3.6846 \times 10^{-19}) = 2.92 \times 10^{-7}$ m = 292 nm

C16. (D)

Species	$V(CO)_6$	VO_4^{3-}	VO_2	$VO(O_2)(H_2O)_4^+$	VO_2^-
V oxidation number	0	+5	+4	+3	+3

C17. (E) This is a stoichiometry problem relating the heat of the reaction to the moles of CO_2 produced. The balanced equation is $CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2(g)$
ΔH = 43,600 J/mol

The heat lost by the surroundings is $q = mc\Delta T$ = (500)(4.184)(20.7 – 23.5) = –5857.6 J. so the heat absorbed by the reaction is 5857.6 J.

5857.6 J × (1 mol CO_2 / 43,600 J) = 0.13432 moles CO_2 produced.
$V = nRT/P$ = (0.13432)(0.08206)(296.8)/1 atm = 3.27 L

C18. (A) The lab assistant has made up a 6 *molal* solution (6 mol solute per 1 kg solvent), not a 6 *molar* solution (6 moles of solute in 1 L of solution). To know the molarity you need to figure out how many liters of solution this is. The entire solution has a mass equal to the mass of the NaCl plus the mass of the water. 6 moles × 58.44 g/mol = 350.64 grams NaCl. The density of water on the data sheet is given as 1.00 g/mL, so the mass of solvent is 1000 g. 350.64 g + 1000 g = 1350.64 g of solution. From the density of the solution, 1350.64g / 1.194 g/mL = 1131.19 mL = 1.13119 L.
6 mol / 1.13119 L = 5.30 M

C19. (C) Molecular orbital theory does not use atomic orbitals with names like *s* and *p*, and instead uses molecular orbitals with names like σ, σ*, π, and π*. *s* orbitals can only form σ and σ* molecular orbitals, and atomic *p* orbitals can form σ, σ*, π, and π* molecular orbitals. So answer choices D and E that are π* and π molecular orbitals derived from atomic *s* orbitals are impossible.

C20. (B) Vapor pressure has an exponential dependence on temperature, so use the Clausius-Clapeyron equation to solve this. The heat of vaporization for water is on the data page as 2260 J/g, so multiply that by 18.02 to get ΔH_{vap} in J/mol. 2260 J/g × 18.02 g/mol = 40,725 J/mol.

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

P_2 = ?, P_1 = 0.0313 , ΔH_{vap} = 40,725 J/mol, R = 8.314 J/mol·K, T_1 = 298 K, T_2 = 273 K

$$\ln\left(\frac{P_2}{0.0313}\right) = \frac{40{,}725}{8.314}\left(\frac{1}{298} - \frac{1}{273}\right)$$

P_2 comes out to be 0.00695 atm × 760 torr/atm = 5.28 torr.

PHYSICS SOLUTIONS – UIL STATE 2024

P01. (D) page 223: "…he had learned far more from his books than from his militaristic teachers at school. During his first year at Luitpold, for example, Einstein cuddled up to *Popular Books on Physical Sciences,* an engaging collection of volumes written by one Aaron Bernstein."

P02. (C) page 239: "Maxwell leapt to the conclusion that his hypothetic electromagnetic ripples and Young's light waves had to be one and the same thing. In 1888, Maxwell's mathematical conjecture was confirmed when German physicist Heinrich Hertz used a giant spark generator to produce an effusion of electromagnetic waves."

P03. (B) page 250: "This meant for a person travelling at the speed of light… the person's mass and energy appeared to expand up to infinity…. He interpreted these outrageous predictions to mean that his new theory was trying to tell him something, namely that it was physically impossible for any material body to travel as fast as an electromagnetic wave…"

P04. (B) From the HR diagram, an average F-class star has an absolute magnitude of about $M = +4$. We are given the apparent magnitude of $m = +10.5$. The distance to the star can then be calculated using $d = 10 \times 10^{(m-M)/5} = 10 \times 10^{(10.5-4)/5} = 10 \times 10^{1.3} = 200$parsec. Converting to light years, we get $d = 200 parsec * 3.26 = 650 \approx 700$ light years.

P05. (A) The units of ε_0 are C^2/Nm^2 and the units of μ_0 are Tm/A as given in the table of constants. Recall a few conversions: $1\ A = 1\ C/s$ and $1\ T = 1\ kg/Cs$. Multiplying this all together, we get $\varepsilon_0\mu_0 \rightarrow \frac{TmC^2}{ANm^2}$. Putting in the conversions: $\frac{TmC^2}{ANm^2} \rightarrow \frac{kgmC^2s}{CsCNm^2} \rightarrow \frac{kg}{Nm}$. Finally, recall that $1\ N = 1\frac{kgm}{s^2}$. This leads to $\varepsilon_0\mu_0 \rightarrow \frac{kg}{Nm} \rightarrow \frac{kgs^2}{kgmm} \rightarrow \frac{s^2}{m^2}$. Thus, the quantity $Z = \sqrt{\varepsilon_0\mu_0}$ has units of $\sqrt{\frac{s^2}{m^2}} = \frac{s}{m}$.

P06. (D) Find initial velocity components: $v_{ix} = v_i \cos\theta = (16.0)\cos(56.0) = 8.95 m/s$, and $v_{iy} = v_i \sin\theta = (16.0)\sin(56.0) = 13.26 m/s$. Find the time to reach the building: $x = x_i + v_{ix}t \rightarrow 15.0m = (8.95)t \rightarrow t = 1.677s$. Find the height of impact on the building: $y = y_i + v_{iy}t + \frac{1}{2}a_y t^2 \rightarrow y = 2 + (13.26)(1.68) + (0.5)(-9.80)(1.68)^2 = 10.466m$. Find the vertical velocity at the time of impact with the building: $v_y = v_{iy} + a_y t = 13.26 - 9.80(1.677) = -3.165 m/s$. Since the speed and angle stay the same after bouncing from the building, the vertical velocity remains the same. The horizontal velocity stays the same magnitude but reverses sign. That is, after bouncing, we have $v_{x2} = -8.95 m/s$ and $v_{y2} = -3.165 m/s$. We are also located at the point $x_2 = 15.0m$ and $y_2 = 10.465m$. Now we find the time needed to reach the ground from the point of impact: $y_f = y_2 + v_{y2}T + \frac{1}{2}a_y T^2 \rightarrow 0 = 10.466 - 3.165T + (0.5)(-9.80)T^2 \rightarrow$ $4.90T^2 + 3.165T - 10.466 = 0$. Solving the quadratic gives: $T = 1.17s, -1.82s$. We ignore the negative result, so $T = 1.17s$. Finally, we find the horizontal location when the ball hits the ground: $x_f = x_2 + v_{x2}T = 15.0 + (-8.95)(1.17) = 4.50m$. This is the distance from you to the place where the ball hits the ground.

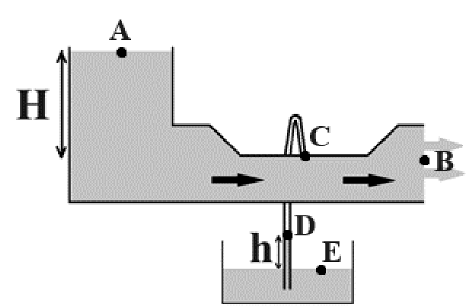
P07. (C) The forces acting on the 5.00kg mass are Tension (T, upward) and gravity ($m_1 g$, downward). We treat the moveable pulley and the 6.00kg mass as a single unit since they are fixed together. The forces acting on the moveable pulley-6.00kg mass unit are two tensions, one for the rope on each side (2T, upward), and gravity ($m_2 g$, downward). This simple block-and-tackle system gives a mechanical advantage, but also results in the moveable pulley-6.00kg mass unit moving at half the rate of the 5.00kg mass. Thus, if the acceleration of the 5.00kg mass is a, then the acceleration of the moveable pulley-6.00kg mass unit is only $\frac{1}{2}a$. Now we can use Newton's second law. For the 5.00kg mass: $\sum F = T - m_1 g = m_1(-a)$. The acceleration is negative since the mass is falling downward. This gives: $T - (5.00)(9.80) = -5.00a \rightarrow T = 49.0 - 5.00a$. For the moveable pulley-6.00kg mass unit, we get: $\sum F = 2T - m_2 g = m_2\left(\frac{1}{2}a\right)$. The acceleration is half as much, but it is positive since this unit is moving upward. This gives: $2T - (6.00)(9.80) = (6.00)(0.5)a \rightarrow 2T - 58.8 = 3.00a$. Plugging the result from the first equation into this second equation, we get: $2(49.0 - 5.00a) - 58.8 = 3.00a \rightarrow 98.0 - 10.0a - 58.8 = 3.00a \rightarrow 39.2 = 13.0a$. Thus, the acceleration of the 5.00kg mass is $a = 3.02 m/s^2$.

P08. (B) The mass of the box really doesn't matter – what matters is the force. Work is defined as $W = \int F \cdot dr$. Since this problem takes place in one dimension, we don't need to worry about the dot product: $W = \int F dx$. Putting in the force equation and the starting and ending points, we have $W = \int_0^6 (72 - 2x^2)dx = \left(72x - \frac{2}{3}x^3\right)\Big[_0^6 = 72(6) - \frac{2}{3}(6)^3 - 0 + 0 = 432 - 144 = 288$ J.

P09. (E) The inertia of the merry-go-round is $I_{disk} = \frac{1}{2}(55.0)(1.44)^2 = 57.0$ kgm^2. Initially, the person standing at the exact center of the merry-go-round does not contribute to the inertia of the system. Thus $I_0 = I_{disk} = 57.0$ kgm^2. After walking to the edge, the person contributes to the inertia with an additional $I_{person} = Mr^2 = (80.0)(1.44)^2 = 166$ kgm^2. This gives a total final inertia for the system of $I_f = I_{disk} + I_{person} = 57.0 + 166 = 223$ kgm^2. Rotational momentum is conserved, so we have $L_0 = L_f \rightarrow I_0\omega_0 = I_f\omega_f \rightarrow (57.0)(32.0) = (223)\omega_f \rightarrow \omega_f = 8.18\, rad/s$.

P10. (A) For an open-closed pipe, the frequencies are $f = \frac{nv}{4L}$ where n is an odd integer. One harmonic above the fundamental would be $n = 3$. Now we can get the speed of sound: $652 = \frac{3v}{4(0.37)} \rightarrow$ $v = 321.7$m/s. From this we can use: $v(T) = (331 m/s)\sqrt{T/273}$ where T is temperature in Kelvin. From this: $321.7 = 331\sqrt{T/273} \rightarrow (0.97176)^2 = T/273 \rightarrow T = 257.8K$. Converting to Celsius gives $T = 257.8 - 273 = -15.2$℃.

P11. (E) This solution references the points A-E as indicated on the diagram. Using Bernoulli's equation with points A and B, we get $P_A + \rho g H = P_B + \frac{1}{2}\rho v_B^2$. P_A and P_B both equal atmospheric pressure, so they cancel. Thus, $\rho g H = \frac{1}{2}\rho v_B^2 \rightarrow$ $v_B = \sqrt{2gH} = \sqrt{2(9.8)(1.50)} = 5.422$m/s.



Using the continuity equation with points B and C:
$A_B v_B = A_C v_C \rightarrow \pi r_B^2 v_B = \pi r_C^2 v_C$.
This gives $(8.0cm)^2(5.422) = (7.0cm)^2 v_C \rightarrow v_C = 7.082$m/s. Using Bernoulli's equation with points B and C, we can find the air pressure in the siphon tube: $P_B + \frac{1}{2}\rho v_B^2 = P_C + \frac{1}{2}\rho v_C^2$. This gives $P_{atm} + (0.5)(840)(5.422)^2 = P_C + (0.5)(840)(7.082)^2 \rightarrow P_C = P_{atm} - 8718$. Because the air in the siphon tube connects points C and D, we know that $P_D = P_C = P_{atm} - 8718$. One last application of Bernoulli's equation, this time in the water with points D and E: $P_D + \rho g h = P_E \rightarrow$ $P_{atm} - 8718 + (1000)(9.8)h = P_{atm}$. This gives $9800h = 8718 \rightarrow h = 0.890m = 89.0cm$.

P12. (E) The voltage drop across the 45.0Ω resistor is $V_{45} = IR = (0.1043A)(45.0\Omega) = 4.694V$. We'll do some calculations assuming that nothing has actually failed. Looking at the left loop, we get $15.0 - 65I_{65} - 4.694 = 0 \;\rightarrow\; 10.3 = 65I_{65} \;\rightarrow\; I_{65} = 0.1586A$. Examining the right loop, we get $12.0 - 70I_{70} - 4.694 = 0 \;\rightarrow\; 7.31 = 70I_{70} \;\rightarrow\; I_{70} = 0.1043A$. We can see that this violates the node rule at the top node. We should have $I_{65} + I_{70} = I$. However, $I_{65} + I_{70} = 0.1586 + 0.1043 = 0.2629 \neq I = 0.1043$. That said, it is obvious that $I_{70} = 0.1043 = I$. This implies that the failure, whatever it is, has caused $I_{65} = 0$. The only choice that would cause that to be true is E, that the 65.0Ω resistor is open. Note: you can solve for I for each of the failure choices, and choice E is the only one that gives a value of 0.1043A for the current I.

P13. (D) For Q_1 we find E_1: $E_1 = \frac{kQ_1}{r_1^2} = \frac{(8.99 \times 10^9)(12.0 \times 10^{-9})}{(0.25)^2} = 1726$ N/C, directed entirely in the +y direction. So, $E_{1x} = 0$ and $E_{1y} = 1726$ N/C. For Q_2, we first need the distance from the charge to the point P: $r_2 = \sqrt{(0.25)^2 + (0.16)^2} = 0.2968$m. Now we can find E_2: $E_2 = \frac{kQ_2}{r_2^2} = \frac{(8.99 \times 10^9)(-18.0 \times 10^{-9})}{(0.2968)^2} = -1837$ N/C. The sign indicates the field points towards the charge; thus, $|E_2| = 1837$ N/C directed down and right. The angle at which it is directed is $\theta_2 = \tan^{-1}\left(-\frac{0.250}{0.160}\right) = -57.38°$. The electric field from the second charge must be broken into components: $E_{2x} = |E_2|\cos\theta_2 = (1837)\cos(-57.38) = 990.2$ N/C, and $E_{2y} = |E_2|\sin\theta_2 = (1837)\sin(-57.38) = -1547$ N/C. Adding the components to get the total electric field at the point P, we obtain: $E_x = E_{1x} + E_{2x} = 0 + 990.2 = 990.2$ N/, and $E_y = E_{1y} + E_{2y} = 1726 - 1547 = 178.7$ N/C. This gives a magnitude for the total electric field of $|E| = \sqrt{E_x^2 + E_y^2} = \sqrt{(990.2)^2 + (178.7)^2} = 1006$ N/C.

P14. (A) Although this arrangement is in an unstable equilibrium, it is in equilibrium, nonetheless. The torque is given by $\tau = IAB\sin\theta$, where θ is the angle between the magnetic field direction and the normal line from the loop area A. In the setup described and shown, the magnetic field is parallel to the normal line from the loop area (the normal line is perpendicular to the face of the loop). Thus, the angle is zero, $\theta = 0°$, and the torque on this loop is also zero: $\tau = IAB\sin(0°) = 0.00$ Nm.

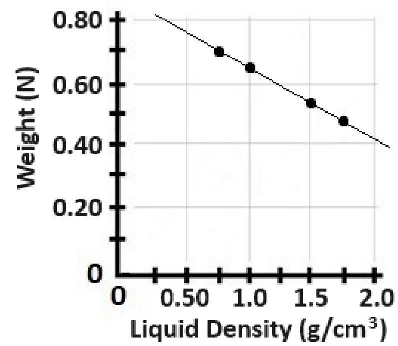
P15. (C) First, we find the electric field between the plates: $E = \frac{V}{d} = \frac{45.0}{0.020 \times 10^{-3}} = 2.25 \times 10^6$ N/C. Now we find the total electric field flux between the plates: $\Phi_E = EA = (2.25 \times 10^6)\pi r^2 = (2.25 \times 10^6)\pi(0.0125)^2 = 1104.5$ Nm^2/C. Turning to the Ampere-Maxwell equation and relying on the cylindrical symmetry of the problem, we find: $Bs = \mu_0\varepsilon_0\frac{d\Phi_E}{dt} \;\rightarrow\; B(2\pi r) = (4\pi \times 10^{-7})(8.854 \times 10^{-12})\frac{(1104.5-0)}{4.20 \times 10^{-6}} \;\rightarrow$
$B(2\pi)(.0125) = 2.926 \times 10^{-9}$.
This gives an induced magnetic field of $B = 3.725 \times 10^{-8}\,T = 37.3$ nT.

P16. (D) Since the star is very far away it has an object distance of $p_1 = \infty$. The focal length of the primary mirror is $f_1 = \frac{96}{2} = 48.0$cm. Thus, the primary image is located at $\frac{1}{p_1} + \frac{1}{q_1} = \frac{1}{f_1} \;\rightarrow$ $\frac{1}{\infty} + \frac{1}{q_1} = \frac{1}{48.0} \;\rightarrow\; q_1 = 48.0$cm. This image becomes the object for the secondary mirror: $p_2 = D_{ps} - q_1 = 40.0 - 48.0 = -8.0$cm. The focal length of the secondary mirror is $f_2 = \frac{-60}{2} = -30.0$cm. The secondary image is then found at $\frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f_2} \;\rightarrow\; \frac{1}{-8.0} + \frac{1}{q_2} = \frac{1}{-30.0} \;\rightarrow$ $q_2 = 10.91$cm. Now, this image becomes the object for the eyepiece lens: $p_3 = D_{sl} - q_2 = 45.0 - 10.91 = 34.09$cm. The final image is located at $\frac{1}{p_3} + \frac{1}{q_3} = \frac{1}{f_3} \;\rightarrow$ $\frac{1}{34.09} + \frac{1}{q_3} = \frac{1}{15.0} \;\rightarrow\; q_3 = 26.8$cm relative to the lens.

P17. (D) First, we normalize the wavefunction: $\int_{-\infty}^{\infty} \Psi^* \Psi dx = 1 \ \rightarrow$
$\int_0^1 A^2(1+2x)^2 dx = A^2 \int_0^1 (1+4x+4x^2)dx = 1.$
This gives: $A^2\left(x + 2x^2 + \frac{4}{3}x^3\right)\Big|_0^1 = A^2\left(\frac{13}{3}\right) = 1 \ \rightarrow \ A = \sqrt{\frac{3}{13}}$ as the normalization constant. For the expectation value, we have: $\langle x \rangle = \int_{-\infty}^{\infty} \Psi^* x \Psi dx = \int_0^1 \frac{3}{13} x(1+2x)^2 dx$. This gives:
$\langle x \rangle = \frac{3}{13}\int_0^1 (x + 4x^2 + 4x^3)dx = \frac{3}{13}\left(\frac{1}{2}x^2 + \frac{4}{3}x^3 + x^4\right)\Big|_0^1 = \frac{3}{13}\left(\frac{17}{6}\right)$. Thus, $\langle x \rangle = \frac{17}{26} = 0.654$.

P18. (C) The decay constant for the first isotope is $\lambda_1 = \frac{\ell n(2)}{15.4} = 0.0450\text{min}^{-1}$ and the decay constant for the second isotope is $\lambda_2 = \frac{\ell n(2)}{24.8} = 0.02795\text{min}^{-1}$. Thus, the combined activity after 60.0 minutes would be given by $A = (10.0\mu Ci)e^{-(0.0450 min^{-1})(60.0\text{min})} + (20.0\mu Ci)e^{-(0.02795 min^{-1})(60.0\text{min})}$.
This gives $A = (10.0)(0.0672) + (20.0)(0.1869) = 4.41\mu\text{Ci}$.

P19. (B) The weight for an individual point would be given by the difference between the gravitational force and the buoyant force. This can be written as $W = Mg - \rho V g$. We cannot see the y-intercept, which would give the mass of the object, but we can use the slope of the best fit line to find the volume of the object. From the equation, we see $slope = -Vg$. To find the slope, I'll use two points on the best fit line. Specifically, I'll use (0.50, 0.75) and (1.25, 0.60). This gives:



$$slope = \frac{0.60N - 0.75N}{1.25g/cm^3 - 0.50g/cm^3} = \frac{-0.15N}{0.75g/cm^3} = \frac{-0.15N}{750kg/m^3} = -0.0002\frac{m^4}{s^2}.$$

So, $-Vg = -0.0002 \ \rightarrow \ V = 2.04 \times 10^{-5} m^3$. Now we use one of the data points to find the mass of the object. I'll use the point (0.75, 0.70). From our initial equation
$W = 0.70N = Mg - \left(\frac{0.75g}{cm^3}\right)Vg = M(9.8) - (750kg/m^3)(2.04 \times 10^{-5})(9.8)$. This gives
$0.70 = 9.8M - 0.15 \ \rightarrow \ M = 0.08673kg$. Finally, the density of the metal object is
$\rho_M = \frac{M}{V} = \frac{0.08673kg}{2.04 \times 10^{-5} m^3} = 4251kg/m^3 = 4.251g/cm^3 \approx 4\ g/cm^3$.

P20. (E) The relationship between the phase angle, the resistance, and the reactance is quite simple: $\tan\phi = \frac{X}{R}$. For the first data point, this gives: $\tan(61.9) = \frac{X}{80.0} \ \rightarrow \ X = (80.0)(1.873) = 150\ \Omega$.
The other data also give the same result.