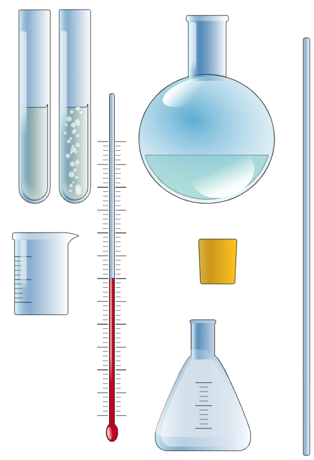
UNIVERSITY INTERSCHOLASTIC LEAGUE

# Science

## District • 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. Which of the following statements is true for lysogeny?
A) Lysogeny is a part of mitosis.
B) Lysogeny only occurs in eukaryotic cells.
C) The lysogenic cycle bursts the host cell without delay.
D) Lysogenic viruses use lysogeny to incorporate viral genome into host cell genome.
E) Lysogeny produces two identical cells.

B02. Acetylcholine is to _______ as estrogen is to _____.
A) nervous system; endocrine system
B) muscle; reproductive system
C) nerve fiber; pancreas
D) digestive system; respiratory system
E) integumentary system; reproductive system

B03. The member of *Enterobacteriaceae* that causes Typhoid fever is
A) *Klebsiella pneumoniae*.
B) *Escherichia coli*.
C) *Shigella dystenteriae*.
D) *Proteus vulgaris*.
E) *Salmonella enterica.*

B04. An organic macromolecule that contains a chain of C—C with C—H would best be classified into which major macromolecular group?
A) lipids
B) carbohydrates
C) amino acids
D) nucleic acids
E) proteins

B05. Humans, birds, lions, fish, and snakes all belong to
A) Domain Eukarya.
B) Supergroup Opisthokonta.
C) Kingdom Animalia.
D) Phylum Chordata.
E) All of the above.

B06. In a population at Hardy-Weinberg equilibrium, 330 organisms out of 1000 express the recessive phenotype. What is the frequency of the dominant allele?
A) 0.181
B) 0.330
C) 0.425
D) 0.574
E) 0.670

B07. Proteins designated for export from a eukaryotic cell are modified and packaged in the
A) nucleus.
B) peroxisome.
C) Golgi apparatus.
D) lysosome.
E) mitochondrion.

B08. Which of the following is not an example of macroevolution?
A) Elephant tusks evolving from canine teeth.
B) Resistance to antibiotics evolving in bacteria.
C) Insect wings evolving from limbs.
D) Feathers evolving from reptile scales.
E) New organs evolving from existing structures.

B09. If yellow (Y) is dominant over green (y) seeds and round (R) is dominant over wrinkled (r) seeds, what is the probability that seeds from the following cross would be both green and wrinkled s?

YyRr x YyRr

A) 1/32
B) 1/16
C) 3/16
D) 9/16
E) 13/16

B10. The type of epithelial cells found within the bladder that specifically function to slide across each other as the bladder fills and expands are called
A) cuboidal cells.
B) squamous cells.
C) transitional cells.
D) basal cells.
E) columnar cells.

B11. Which of the following is not an example of unity in diversity?
A) Characteristics of all mammals.
B) Insect wings and bird wings.
C) All organisms are made of cells.
D) The forelimbs of bats, humans, whales, and cats.
E) Ribosomes, cytosol, DNA, and plasma membranes as structures found in all cell types.

B12. Land plants belong to Supergroup
A) Opisthokonta.
B) Excavata.
C) Amoebozoa.
D) Rhizaria.
E) Archaeplastida.

B13. Per glucose, how many NADH are generated in aerobic respiration starting from glycolysis and ending after the Krebs cycle?
A) 2
B) 4
C) 6
D) 8
E) 10

B14. In January 2024, the Centers for Disease Control and Prevention issued a Food Safety Alert for the outbreak of _____, linked to charcuterie meats.
A) *Salmonella* sp.
B) MRSA
C) *Pseudomonas aeruginosa*
D) *Escherichia coli*.
E) *Mycobacterium tuberculosis*

B15. When a disease, such as Spanish flu, the plague, COVID, etc. is present across the entire planet at the same time, this is called a/an
A) transdemic.
B) epidemic.
C) pandemic.
D) endemic.
E) none of the above.

B16. The enzyme that catalyzes the carboxylation of ribulose-1,5-bisphosphate below during photosynthesis is
A) primase.
B) RuBisCO.
C) Phosphoglycerate kinase.
D) NaBisCO.
E) Glyceraldehyde-3-phosphate dehydrogenase.

B17. Primase, used in DNA replication, is a/an
A) RNA-dependent RNA polymerase.
B) RNA-dependent DNA polymerase.
C) DNA-dependent DNA polymerase.
D) DNA-dependent RNA polymerase.
E) none of the above.

B18. Given the following DNA *template* strand, what is the RNA sequence after transcription?

3’-GTAACATGC-5’

A) 3’-GUAACAUGC-5’
B) 5’-GUAACAUGC-3’
C) 3’-CAUUGUACG-5’
D) 5’-CAUUGUACG-3’
E) 5’-CGUACAAUG-3’

B19. If an antisense RNA binds to a messenger RNA and overlaps the start codon, the result would most likely be
- A) repression of translation.
- B) activation of translation.
- C) repression of transcription.
- D) activation of transcription.
- E) export the double-stranded RNA molecules from the cell.

B20. Which of the following techniques identifies whether a gene is expressed into mRNA?
- A) Western blot
- B) Southern blot
- C) CRISPR/Cas9
- D) Northern blot
- E) DNA sequencing

C01. If a helium-filled balloon at STP has a volume of 2.00 L and you add 0.35 grams of helium to the balloon, what will the new volume of the balloon be at STP?

A) 3.96 L
B) 0.875 L
C) 1.96 L
D) 2.00 L
E) 22.4 L

C02. What volume of liquid water would be produced by reacting 15.0 moles of $H_2$ gas with 15.0 moles of $O_2$ gas? Assume the density of liquid water is 1.0 gram per milliliter.

A) 270 mL
B) 540 mL
C) 30 mL
D) 510 mL
E) 480 mL

C03. While surfing chemistry websites, you see one that refers to $^{16}_{8}O$ and $^{18}_{8}O$. What is the difference between them?

A) $^{18}_{8}O$ has two more electrons than $^{16}_{8}O$.
B) $^{18}_{8}O$ has two more protons than $^{16}_{8}O$.
C) $^{18}_{8}O$ has two more neutrons than $^{16}_{8}O$.
D) $^{18}_{8}O$ is a sample of 18 O atoms and $^{16}_{8}O$ is a sample of 16 O atoms.
E) $^{18}_{8}O$ is 18 moles of oxygen and $^{16}_{8}O$ is 16 moles of oxygen.

C04. Which of the compounds below is an ionic compound?

A) $NH_3$
B) $H_3PO_4$
C) $CH_3NH_2$
D) $(NH_4)_3PO_4$
E) These are all covalent compounds

C05. If the volume of a gas sample is tripled at the same time the number of moles is increased by 50%, what will the final pressure be compared to the initial pressure?

A) One third
B) Two thirds
C) One half
D) One and one third
E) One and one half

C06. Which of these liquids would have the lowest enthalpy of vaporization?

A) $CH_4$
B) $CH_3F$
C) $CH_3Cl$
D) $CH_3F_2$
E) $CH_3OH$

C07. Changes in the internal energy of a system show up in the form of heat (*q*) and work (*w*). When the system absorbs energy from the surroundings, the sign on the energy is positive and when the system loses energy to the surroundings the sign on the energy is negative. For this reaction, what are the signs on the heat and work for the system?

$$AX_3(g) + X(g) \rightarrow AX_4(g)$$

A) $q$ = (+) and $w$ = (+)
B) $q$ = (+) and $w$ = (–)
C) $q$ = (–) and $w$ = (–)
D) $q$ = (–) and $w$ = (+)
E) Not enough information is provided.

C08. What would the freezing point of the solution be if you dissolved 20.0 grams of $AlCl_3$ in 250 grams of water?

A) –2.23°C
B) –1.23°C
C) 0.00°C
D) –1.12°C
E) –4.46°C

C09. If the following gas-phase reaction is at equilibrium and you increase the temperature, how would the reaction respond?

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H_{rxn} = –196$ kJ

A) The equilibrium will shift forward to produce more product
B) The equilibrium will shift backward to produce more reactants
C) The reaction will go to completion
D) The reaction will go backward to completion
E) The equilibrium concentrations will remain the same but the molecules will be moving faster

C10. What is the pH of a $3.46 \times 10^{-4}$ M solution of HClO?

A) 3.46
B) 4.46
C) 5.46
D) 6.46
E) 7.46

C11. Which equation would you use to solve for the molar solubility ($x$) of iron(II) phosphate if you knew the $K_{sp}$?

A) $K_{sp} = 4x^3$
B) $K_{sp} = 4x^2$
C) $K_{sp} = 27x^3$
D) $K_{sp} = 27x^4$
E) $K_{sp} = 108x^5$

C12. What is the coefficient on $H_2O$ when the equation for the following redox reaction is balanced in acidic solution using the smallest whole number coefficients?

$Sn(s) + MnO_4^{-}(aq) \rightarrow Sn^{2+}(aq) + Mn^{2+}(aq)$

A) 10
B) 8
C) 6
D) 4
E) 2

C13. What happens to the rate constant of a chemical reaction when you increase the temperature of the reaction?

A) Nothing – rate constants are independent of temperature
B) Doubling the temperature doubles the rate constant
C) Doubling the temperature reduces the rate constant by half
D) The rate constant increases exponentially with temperature
E) The rate constant decreases exponentially with temperature

C14. A 100-gram sample of solid $CaBr_2$ contains

A) equal masses of calcium and bromine
B) about twice as many grams of bromine as calcium
C) about twice as many grams of calcium as bromine
D) about four times as many grams of bromine as calcium
E) None of the above answer choices is correct

C15. Which of these electron transitions in a hydrogen atom will result in the emission of a photon with the shortest wavelength?

A) $n$=4 to $n$=2
B) $n$=5 to $n$=4
C) $n$=3 to $n$=2
D) $n$=6 to $n$=5
E) $n$=1 to $n$=3

C16. In which of these phase changes does the system undergo the largest positive change in entropy?

A) condensation
B) vaporization
C) deposition
D) sublimation
E) melting (fusion)

C17. A chromium atom was walking down a busy tourist boulevard when he suddenly realized one of his electrons was missing! Pickpocketed, perhaps, by a passing non-metal. The police were called, and five of the chromium atom's remaining electrons were questioned as possible witnesses to the crime.

Detectives demanded identification from each of the five electrons, A–E, and each one responded by giving its set of four quantum numbers at the time of the missing electron's disappearance.

A) $n = 3$ $\ell = 2$ $m_\ell = -1$ $m_s = +½$
B) $n = 4$ $\ell = 0$ $m_\ell = 0$ $m_s = +½$
C) $n = 3$ $\ell = 1$ $m_\ell = 0$ $m_s = -½$
D) $n = 1$ $\ell = 0$ $m_\ell = 0$ $m_s = -½$
E) $n = 2$ $\ell = 1$ $m_\ell = 1$ $m_s = +½$

"Return those four electrons to their subshells," the chief detective said. "There is only one possible witness to the crime, and it is electron ____!"

Which electron did the detective identify?

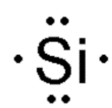
C18. 15.0 mL of a $2.0 \times 10^{-4}$ M solution of nitric acid is added to a 100 mL volumetric flask and the solution is diluted to the mark with water. What is the pH of the resulting solution?

A) 2.88
B) 4.88
C) 3.70
D) 7.00
E) 4.52

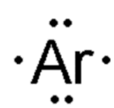
C19. When calcium carbonate is heated it decomposes into calcium oxide and carbon dioxide gas. How many grams of calcium carbonate would be needed to produce 10.0 L of carbon dioxide gas at 1 atm and 25°C?

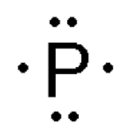
A) 40.93 g
B) 20.47 g
C) 44.68 g
D) 27.84 g
E) 55.68 g

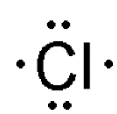
C20. Which of these Lewis dot structures for a neutral atom is correct?

A) 


B) 


C) 


D) 


E) 

# Chemistry

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

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

<u>Water Data</u>

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

<u>Constants</u>

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

<u>Acid Dissociation Constants</u>

HClO: $K_a = 3.5 \times 10^{-8}$.

<u>Conversion factors</u>

*1 L·atm = 101.325 J*

P01. According to Guillen, Faraday worked at a bookbindery while he was young. His life changed forever when, while stitching together a copy of the *Encyclopedia Britannica*, he read the entry on ________________.

A) alchemy
B) chemistry
C) magnetism
D) electricity
E) relativity

P02. According to Guillen, after the publication of his first article, Faraday was falsely accused of having plagiarized the idea for the article from William Wollaston. What idea was Faraday accused of plagiarizing?

A) the compass
B) the liquification of chlorine
C) the dynamo
D) the electric motor
E) the telegraph

P03. According to Guillen, Faraday always was adamant about expressing his discovery in a way that ordinary people could understand. Decades later, another physicist would translate Faraday's discovery into a mathematical equation. Who was this physicist?

A) James Clerk Maxwell
B) Luigi Galvani
C) William Gilbert
D) Andre Ampere
E) Hans Christian Orsted

P04. Stars similar in mass to the Sun are too small to produce a supernova when they die. Instead, they gradually cast off gas during their red giant phase. What do we call the astronomical object formed by the ejected gas from a dying low-mass star?

A) a cold molecular cloud
B) a globular cluster
C) a coronal flare
D) a quasar
E) a planetary nebula

P05. A helicopter starting at Brenham flies 80.0 miles in a direction that is 60.0° south of east. It then flies another 50.0 miles due west before landing. How far from Brenham is the helicopter when it lands?

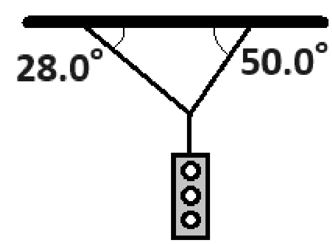
A) 30.0 miles
B) 70.0 miles
C) 94.3 miles
D) 113.6 miles
E) 130.0 miles

P06. You throw a dog toy with a velocity of 13.5m/s at an angle of 41.0° above the horizontal. The toy is released from a height of 3.30m above the ground. How far away from you, horizontally, does the toy land on the ground? Ignore air resistance.

A) 3.23 m
B) 8.37 m
C) 12.1 m
D) 18.9 m
E) 21.7 m

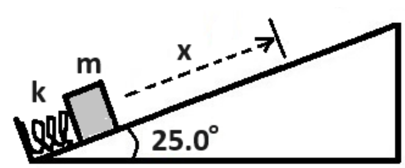
P07. A 22.0kg stoplight is suspended by three cables, as shown. The upper left cable makes an angle of 28.0° with respect to the horizontal, and the upper right cable makes an angle of 50.0° with respect to the horizontal. The lower cable is vertical, and the system is in equilibrium. What is the tension in the upper left cable?

A) 103 N
B) 125 N
C) 142 N
D) 168 N
E) 195 N



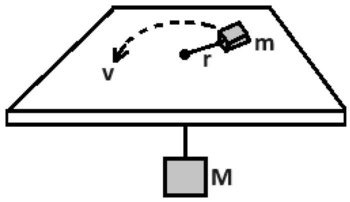

P08. A spring with a spring constant of 890.0 N/m is compressed by 15.0cm. A box of cat litter with a mass of 2.20kg is placed up against the compressed spring. The spring and box are placed at the bottom of a frictionless inclined plane that is angled at 25.0° above the horizontal (as shown). The spring is then released. How far up the plane (distance x) does the box of cat litter slide?

A) 110 cm
B) 92.8 cm
C) 72.0 cm
D) 51.2 cm
E) 46.4 cm

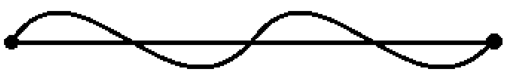


P09. A small, 350.0g block (m) is attached to a string, and is moving in a circle on a frictionless table, as shown. The string passes through a small hole in the table and a 1.20kg mass is hanging from the end of the string. The radius of the circle traced out by the small block is 24.0cm. If the system is stable, then what is the tangential velocity, v, of the small block?

A) 1.53 m/s
B) 2.84 m/s
C) 5.45 m/s
D) 8.06 m/s
E) 11.8 m/s




P10. A 42.0cm long guitar string has a mass of 1.90g. The resonant vibration of the string that is illustrated below oscillates at a frequency of 868.0Hz. What is the tension in the string?



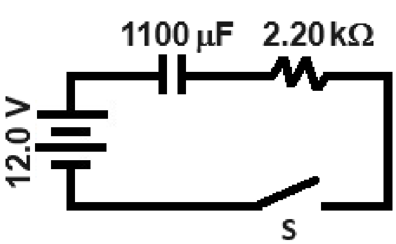
A) 601 N
B) 425 N
C) 338 N
D) 212 N
E) 150 N

P11. 250.0g of an unknown metal is heated to 100°C. The hot metal is placed in 200.0g of water that is initially at 10.0°C. The mixture of water and metal equilibrates to a final temperature of 24.2°C. What is the specific heat capacity of the unknown metal?

A) 1.07 J/kgK
B) 0.810 J/kgK
C) 0.627 J/kgK
D) 0.442 J/kgK
E) 0.150 J/kgK

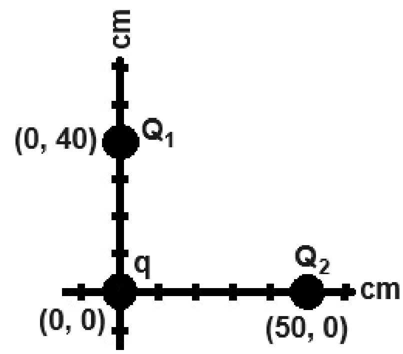
P12. For the RC-circuit shown, find the current flowing in the circuit exactly 1.90 seconds after the switch S is closed? Note: The capacitor is initially uncharged.

A) 2.49 mA
B) 4.28 mA
C) 4.98 mA
D) 5.45 mA
E) 10.9 mA



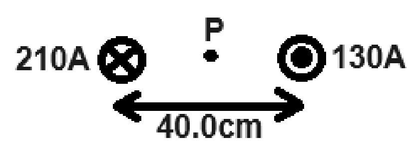

P13. Three charges are placed on a coordinate system as shown. The first charge, $Q_1 = 16.0\mu C$, is placed at (0.0, 40.0cm). The second charge, $Q_2 = 30.0\mu C$, is placed at (50.0cm, 0.0). Calculate the net force of these two charges acting on the third charge, $q = -5.00\mu C$, which is placed at the origin (0, 0).

A) 0.899 N
B) 3.24 N
C) 4.50 N
D) 7.02 N
E) 9.89 N



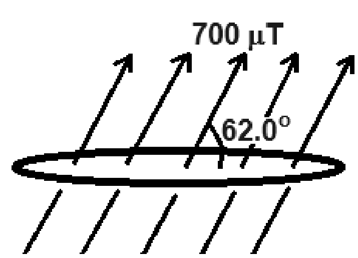

P14. Two long, straight, current carrying wires run parallel to one another in the z-direction, as illustrated. The first wire carries a current of 130.0A in the +z direction (out of the page) and the second wire carries a current of 210.0A in the −z direction (into the page). The wires are separated by 40.0cm. What is the strength of the magnetic field halfway between the wires, at the point P?

A) 40.0 µT
B) 80.0 µT
C) 170 µT
D) 340 µT
E) 400 µT




P15. A 2.5Ω wire is curled into a single circular loop with a diameter of 30.0cm. The loop is placed flat (horizontal) on a table. A 700.0µT magnetic field passes through the loop at an angle of 62.0° with respect to the horizontal, as shown. If the magnetic field vanishes to zero in a time of 0.75ms, what current is induced in the wire loop?

A) 106 mA
B) 93.2 mA
C) 59.8 mA
D) 26.4 mA
E) 23.3 mA



P16. A single dog hair is illuminated by a 530nm laser, producing a diffraction pattern on a screen located 1.30m away from the hair. The diffraction fringes on the screen are separated by 2.20cm. What is the diameter of the dog hair?

A) 15.7 μm
B) 31.3 μm
C) 53.0 μm
D) 61.6 μm
E) 89.7 μm

P17. The atoms in a Bose-Einstein Condensate have been cooled to the point that their velocities are extremely low. Suppose atoms of sodium (mass $3.82 \times 10^{-26}$ kg) are slowed to a speed of 0.250mm/s. To what minimum physical size do the wavefunctions of these very cold atoms extend?

A) 5.5 μm
B) 3.4 μm
C) 2.2 μm
D) 1.4 μm
E) 0.88 μm

P18. You observe the following fusion reaction. How much energy is released by this reaction?

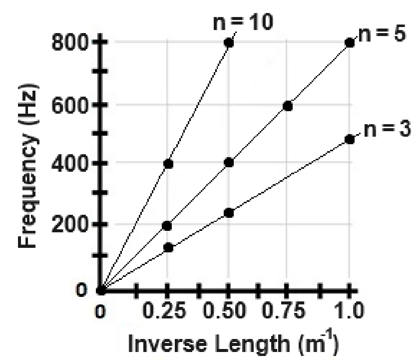
$$^{21}_{10}Ne + ^{4}_{2}He \rightarrow ^{24}_{12}Mg + n^0$$

The mass of Neon-21 is 20.9938467u, the mass of Helium-4 is 4.002603u, and the mass of Magnesium-24 is 23.98504170u.

A) 1.01 MeV
B) 2.56 MeV
C) 2.99 MeV
D) 5.15 MeV
E) 9.32 MeV

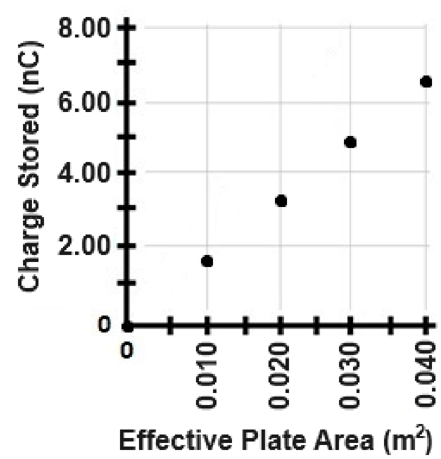
P19. While playing a trombone, you adjust the extension of the slide to produce specific frequencies, recording the total pipe length and harmonic for each frequency produced. You plot the frequency, $f$, versus the inverse of the pipe length, $L^{-1}$, for each harmonic (shown below). Based on these data, what is the speed of sound in the trombone?

A) 380 m/s
B) 360 m/s
C) 340 m/s
D) 320 m/s
E) 300 m/s




P20. You sandwich a sheet of glass between two metal plates to form a capacitor. The plates are fixed at a separation of 1.25cm (the thickness of the glass), and you can vary the effective area of the capacitor by changing the alignment of the two plates. For different alignments, you measure the effective area, as well as the total charge stored on the capacitor when it is connected to a 12.0V battery. The data are plotted below. Based on the data, determine the dielectric constant of the glass.

A) 12
B) 16
C) 19
D) 23
E) 27



# Physics

## Useful Constants

| quantity | symbol | value |
|---|---|---|
| Free-fall acceleration | g | $9.80\ m/s^2$ |
| Permittivity of Free Space | $\varepsilon_0$ | $8.854 \times 10^{-12}\ C^2/Nm^2$ |
| Permeability of Free Space | $\mu_0$ | $4\pi \times 10^{-7}\ Tm/A$ |
| 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 | $m_p$ | $1.67265 \times 10^{-27}\ kg$<br>$1.007276 amu$ |
| Neutron mass | $m_n$ | $1.67495 \times 10^{-27}\ kg$<br>$1.008665 amu$ |
| Atomic Mass Unit | amu | $1.66 \times 10^{-27}\ kg$<br>$931.5\ MeV/c^2$ |
| 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 | $8.314\ J/mol \cdot K$<br>$0.082057\ L \cdot atm/mol \cdot K$ |
| 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 | $R_\infty$ | $1.097 \times 10^{7}\ m^{-1}$ |
| Standard Atmospheric Pressure | 1 atm | $1.013 \times 10^{5}\ Pa$ |
| Density of Pure Water | $\rho_{water}$ | $1000.0\ kg/m^3$ |
| Specific Heat Capacity of Water | $c_{water}$ | $4.186\ J/kg \cdot K$ |

**DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!**

# UIL HIGH SCHOOL SCIENCE CONTEST
# ANSWER KEY
# 2024 DISTRICT

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

## CHEMISTRY SOLUTIONS – UIL DISTRICT 2024

C01. (A) First calculate how many moles of gas are in the balloon to start with, then add the number of moles added and calculate the new volume. $PV = nRT$, so $n = PV/RT$. At STP $P$ = 1.00 atm and $T$ = 273 K, and RT = 22.4 L/mol. $n$ = (1.00)(2.00)/(22.4) = 0.08929 mol. 0.35 g/4.00 g/mol = 0.0875 mol. Total moles now = 0.08929 + 0.875 = 0.1768 mol. V = nRT/P = (0.1768)(22.4)/1.00 = 3.96 L

C02. (A) $2\ H_2(g) + O_2(g) \rightarrow 2H_2O(\ell)$. Therefore 15 mol $H_2$ will produce 15 mol $H_2O(\ell)$, and 7.5 mol of $O_2$ is in excess. 15 mol $H_2O\ (\ell)$ × 18.02 g/mol = 270.3 grams = 270 mL $H_2O$.

C03. (C) The left superscript is the number of protons plus neutrons, and since all oxygen atoms have 8 protons, O-18 has two more neutrons than O-16.

C04. (D) This is an ionic compound made up of two different polyatomic ions, $NH_4^+$ and $PO_4^{3-}$. $H_3PO_4$ does ionize in water, but it is a covalent compound that forms individual molecules and does not form an extended three-dimensional ionic lattice the way ionic compounds do.

C05. (C) $P_1V_1/P_2V_2 = n_1/n_2$, so $P_2 = (P_1V_1/V_2)(n_2/n_1)$ Let $P_1 = 1$, $V_1$=1, and $n_1$=1. Then $P_2$ = (1× 1/3)(1.5/1) = 0.5. The final pressure is therefore ½ of the initial pressure. Alternatively you can apply the changes one at a time: increasing the moles by 50% will increase the pressure by 50% (to 1.5 time the original), and then expanding the volume to 3 times will reduce the pressure to 1/3, and 1/3 of 1.5 = 0.5 times the original pressure.

C06. (A) $CH_4$ is non-polar and has only dispersion forces, compounds B-D all have dipole-dipole forces in addition to dispersion forces, and methanol $CH_3OH$ has hydrogen bonding as well. The weaker the intermolecular forces the lower the enthalpy of vaporization ($\Delta H_{vap}$), and the more easily the liquid vaporizes.

C07. (D) In this reaction a bond is being formed but no bonds are being broken. Forming a bond gives off heat, so $q$ = (–). The reactants are two moles of gas and the products are only one mole of gas, so the volume of the system is getting smaller, which means the surroundings are pushing in on the system and therefore $w$ = (+).

C08. (E) $\Delta T_{FP} = -ik_fm$ molality (m) = moles solute/kg solvent = 20.0 g / 133.33 g/mol = 0.150 mol. 0.150 mol/0.25 kg $H_2O$ = 0.600 molal. $\Delta T_{FP} = -ik_fm$ = 4×1.86×0.600 = –4.46°C. $T_{BP}$ = 0°C – 4.46°C = –4.46°C

C09. (B) Since this is an exothermic reaction, heat is a product. LeChatelier's Principle says that adding more heat will therefore cause the equilibrium to shift backward, consuming products and producing more reactant gases.

C10. (C) For a weak acid, $[\mathrm{H}^+] = \sqrt{K_a C_{\mathrm{acid}}}$ as long as the concentration of the weak acid dissociated (which is equal to $[H^+]$) is less than 5% of the initial concentration $C_{acid}$.

$[\mathrm{H}^+] = \sqrt{(3.5 \times 10^{-8})(3.46 \times 10^{-4}}$ = $3.480 \times 10^{-6}$ M This is about 1% of the initial acid concentration, so we do not need to use the quadratic formula to solve for $[H^+]$.

pH = $-\log[H^+]$ = 5.46

C11. (E) Iron(II) phosphate is $Fe_3(PO_4)_2$, which has five ions, so the equation is $K_{sp} = 108x^5$

C12. (B) Oxidation half-reaction: $Sn(s) \rightarrow Sn^{2+}(aq) + 2\ e^-$

Reduction half-reaction: $MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow 4H_2O(\ell) + Mn^{2+}(aq)$

Multiply ox × 5 and red × 2 to equalize the electrons and then add:

$$5Sn(s) + 2MnO_4^-(aq) + 16H^+(aq) \rightarrow 5Sn^{2+}(aq) + 2Mn^{2+}(aq) + \mathbf{8}H_2O(\ell)$$

C13. (D) Kinetic rate constants, chemical equilibrium constants, and vapor pressure all increase exponentially with temperature, which is why the Arrhenius equation for rate constants, the van't Hoff equation for equilibrium constants, and the Clausius-Clapeyron equation for vapor pressures all look nearly identical.

C14. (D) The percent composition of $CaBr_2$ is: Calcium (40.08/(40.08 + 79.90×2)) × 100 = 20.05% calcium and 79.95% bromine, so in a 100 gram sample there would be about 20 grams of Ca and 80 grams of Br, or about four times as many grams of bromine as calcium.

C15. (A) The transition from $n$=4 to $n$=2 is the green visible emission line in a hydrogen emission spectrum, and $n$=3 to $n$=2 is the (longer wavelength) red emission line. Transitions ending in a higher energy level than $n$=2 are lower energy transitions with longer wavelengths (in the IR or microwave region). The transition from $n$=1 to $n$=3 is the highest energy transition, but that would require the electron to absorb a photon as it goes to a higher energy level, not emit a photon and drop to a lower energy level.

C16. (D) Sublimation, going from solid to gas, would be the largest positive change in entropy for the system. Vaporization would be second, and melting would be third. The other answer choices, deposition and condensation, are negative changes in entropy for the system.

C17. (B) Transition metals lose their first electrons from their outermost *s* subshell, meaning that the missing electron must have come from the chromium atom's 4*s* subshell. Electron B had quantum numbers $n$ = 4 and $\ell$ = 0 at the time of the disappearance, meaning that electron B was the other electron in the 4*s* orbital when the missing electron disappeared, and therefore was the only possible witness when his orbitalmate disappeared. All of the other electrons were in different energy levels from the electron that vanished.

C18. (E) $M_1V_1 = M_2V_2$, so the new concentration is (15.0/100.0)($2.0 \times 10^{-4}$) = $3.0 \times 10^{-5}$ M.
pH = –log[$H^+$] = –log($3.0 \times 10^{-5}$) = 4.52

C19. (A) $CaCO_3 \rightarrow CaO + CO_2(g)$ One mole of $CaCO_3$ produces one mole of $CO_2$ gas, so however many moles of $CO_2$ gas you have, that's how many moles of $CaCO_3$ you need. Moles of $CO_2$ gas = $PV/RT$ = (1)(10.0)/(0.08206)(298) = 0.40893 moles $CO_2$ = 0.40893 moles $CaCO_3$ × 100.09 g/mol = 40.93 g $CaCO_3$.

C20. (B) Se is the only one that has the correct number of valence electrons for a neutral atom.

**PHYSICS SOLUTIONS – UIL DISTRICT 2024**

P01. (D) page 128: "One day, while stitching together the newest edition of the *Encyclopedia Britannica*, Faraday's life changed forever. In reading its 127-page entry on electricity, Faraday learned that, though natural philosophers had known about this invisible phenomenon for centuries, they still had not figured it out."

P02. (D) page 152: "… days after the publication of Faraday's *Journal* article. The young man began hearing rumors accusing him of having plagiarized the idea for the electric motor from William Hyde Wollaston, a manager at the Royal Institution."

P03. (A) page 158: "In 1865, a young Scottish physicist, James Clerk Maxwell, would publish his landmark *A Dynamical Theory of the Electromagnetic Field*, in which he would translate Faraday's simply stated discovery into a mathematical equation."

P04. (E) The ejected gas around a dying low-mass star is both illuminated and ionized by the star. This produces a glowing region of nebulosity that astronomer William Herschel labelled a 'planetary nebula' (through a telescope he thought these nebulae resembled planets). Planetary nebulae come in a dazzling array of shapes and colors, but they have absolutely nothing to do with planets or planetary formation.

P05. (B) This problem is simply the addition of two vectors. In order to add the vectors, we must reduce them to their components – horizontal (East-West) and vertical (North-South). The first vector has a magnitude of $|A| = 80.0$ miles and a direction of $\theta_A = 60.0°$ South of East. The components of this vector are: $A_x = (80.0)\cos(60.0) = 40.0$ miles East, and $A_y = (80.0)\sin(60.0) = 69.3$ miles South. The second vector is already horizontal, with $B_x = B = 50.0$ miles West. For this vector, there is no vertical component ($B_y = 0$). Combining these components gives the components of the resultant vector: $C_x = A_x + B_x = 40.0East + 50.0West = 10.0$ miles West, and $C_y = A_y + B_y = 69.3South + 0 = 69.3$miles South. Thus, the resultant vector has a magnitude of $|C| = \sqrt{C_x^2 + C_y^2} = \sqrt{(10.0)^2 + (69.3)^2} = 70.0$ miles. Incidentally, though not needed, the direction of the resultant vector is $\theta_c = \tan^{-1}\left(\frac{C_y}{C_x}\right) = \tan^{-1}\left(\frac{69.3}{10.0}\right) = 81.8°$ South of West.

P06. (E) We begin with the components of the initial velocity: the initial velocity component in the horizontal direction is $v_{ix} = v_i \cos\theta = (13.5)\cos 41.0 = 10.2$ m/s and the initial velocity component in the vertical direction is $v_{iy} = v_i \sin\theta = (13.5)\sin 41.0 = 8.86$ m/s. We take the ground level to be $y = 0$, which gives an initial vertical height of $y_i = 3.30$m. Now we find the time of flight by using $y = y_i + v_{iy}t + \frac{1}{2}a_y t^2 \;\rightarrow\; 0 = 3.30 + (8.86)t + (0.5)(-9.8)t^2 \;\rightarrow\; 0 = 3.30 + 8.86t - 4.9t^2$. Solving this quadratic gives $t = \frac{-886 \pm \sqrt{(8.86)^2 - 4(-4.9)(3.30)}}{2(-4.9)} = -0.317s, 2.13s$. We can ignore the negative result for time, so the time of flight is $t = 2.13s$. Using this, and knowing that there is no horizontal acceleration, we can determine the horizontal distance traveled by the toy: $x = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = 0 + (10.2)(2.13) + (0.5)(0)(2.13)^2 = 21.7$m.

P07. (C) The system is in equilibrium, so we know that the forces acting at any point sum to zero. We will consider the knot where the three cables come together. We label the tension in the upper left cable as $T_1$ and the tension in the upper right cable as $T_2$. The tension in the lower cable, which we label $T_3$, will, under these circumstances, equal the weight of the stoplight: $T_3 = mg = (22.0)(9.80) = 216$N.

For the knot in equilibrium, we know $\sum F_x = 0$ and $\sum F_y = 0$. To finish these equations, we must determine the components of the tensions. For the upper left cable, we have $T_{1x} = T_1 \cos(28.0) = 0.8829T_1$ and $T_{1y} = T_1 \sin(28.0) = 0.4695T_1$. For the upper right cable, we find $T_{2x} = T_2 \cos(50.0) = 0.6428T_2$ and $T_{2y} = T_2 \sin(50.0) = 0.7660T_2$. For the lower cable, because it is vertical, we have $T_{3x} = 0$ and $T_{3y} = 216$N. Forces on the knot that are directed left or downward will be considered negative, while those forces directed to the right or upward will be positive. Thus, we have $\sum F_x = T_{2x} - T_{1x} = 0.6428T_2 - 0.8829T_1 = 0$. This leads to $0.6428T_2 = 0.8829T_1 \;\rightarrow\; T_2 = 1.374T_1$. For the vertical, we have $\sum F_y = T_{1y} + T_{2y} - T_{3y} = 0.4695T_1 + 0.7660T_2 - 216 = 0$. Now, using the substitution for $T_2$ from the first equation, we find $0.4695T_1 + 0.7660(1.374T_1) - 216 = 0$. This gives $(0.4695 + 1.052)T_1 = 1.522T_1 = 216 \;\rightarrow\; T_1 = 142$N, which is the tension in the upper left cable.

P08. (A) We can use conservation of energy to solve this problem. Initially, energy is stored in the compressed spring. The amount of elastic potential energy stored is $E = \frac{1}{2}kx^2 = (0.5)(890)(0.150)^2 = 10.0$J. Because the inclined plane is frictionless, there is no energy converted to heat. Therefore, all of the original elastic potential energy is converted into gravitational potential energy once the box slides to its highest point. That is, $mgh = 10.0 \;\rightarrow\; (2.20)(9.80)h = 10.0 \;\rightarrow\; h = 0.464$m. This is a purely vertical height, so we must use trigonometry to find the distance x: $\sin(25.0) = \frac{h}{x} = \frac{0.464}{x}$. This gives a distance up the plane of $x = \frac{0.464}{\sin(25.0)} = 1.10m = 110cm$.

P09. (B) The system is effectively in equilibrium, so the forces on the hanging mass sum to zero. Those forces are entirely vertical: tension (upward) and gravity (downward). Thus, for the hanging mass, we have $\sum F_y = 0 = T - Mg \;\rightarrow\; T = Mg = (1.20)(9.80) = 11.76$N. For the small block, there are three forces: gravity (downward), the normal force (upward) and tension (towards the center of the circle). Both gravity and the normal force are vertical – they balance one another and really do not contribute to the solution of the problem. The tension, however, provides the centripetal force needed to keep the small block moving in a circle. Thus, $T = \frac{mv^2}{r} \;\rightarrow\; 11.76 = \frac{(0.350)v^2}{(0.24)} \;\rightarrow\; v^2 = 8.064$. Thus, the tangential velocity of the small block is $v = 2.84$m/s.

P10. (E) The resonant vibration shown in the illustration of the string has four anti-nodes, thus, it represents the $n = 4$ resonance of the string. This allows us to determine the wavelength of this oscillation: $\lambda = \frac{2L}{n} = \frac{2(0.420)}{4} = 0.210$m. Now we can find the velocity of the resonant wave on the string: $v = f\lambda = (868.0)(0.210) = 182.3$m/s. This velocity, in turn, is related to the tension on the string: $v = \sqrt{\frac{T}{\mu}}$. Here, $\mu$ is the mass per length of the string, which we can calculate:

$\mu = \frac{m}{L} = \frac{1.90 \times 10^{-3}}{0.420} = 0.00452$kg/m.

Putting it together: $182.3 = \sqrt{\frac{T}{0.00452}} \;\rightarrow\; T = (0.00452)(182.3)^2 = 150$N.

P11. (C) Assuming that any heat lost by the system is negligible, then the heat energy that leaves the metal must equal the heat energy that enters the water. Mathematically, $Q_{from\ metal} + Q_{into\ water} = 0$. There are no phase changes occurring in this problem, so the heat energies are entirely related to changes in temperature: $M_{metal}c_{metal}\Delta T_{metal} + M_{water}c_{water}\Delta T_{water} = 0$. Plugging in the given values, we obtain:
$(0.250kg)(c_{metal})(24.2℃ - 100℃) + (0.200kg)(4.186\,J/kg \cdot K)(24.2℃ - 10.0℃) = 0$. This gives: $-18.95c_{metal} + 11.89 = 0 \;\rightarrow\; c_{metal} = 0.627\,J/kg \cdot K$. Note: since we only use changes in temperature ($\Delta T$) we do not need to convert Celsius to Kelvin.

P12. (A) For a charging RC-circuit, the equation describing the current is $I = \frac{V}{R}e^{-t/RC}$. All of the quantities are given, so $I = \frac{12.0V}{2200\Omega}e^{-1.90/(0.0011)(2200)} = (0.00545)e^{-0.785} = 0.00249A = 2.49mA$.

P13. (D) The magnitude of the force exerted by one charge on another is given by Coulomb's Law: $|F| = \left|\frac{kQ_1Q_2}{r^2}\right|$. So, for the first charge, we get a force magnitude of $|F_1| = \left|\frac{kQ_1q}{r_1^2}\right| = \left|\frac{(8.99 \times 10^9)(16.0 \times 10^{-6})(-5.00 \times 10^{-6})}{(0.400)^2}\right| = 4.495\text{N}$. Because $q$ and $Q_1$ are opposite in sign, this force will be attractive. Thus, this first force acting on the charge $q$ will be directed in the positive y-direction. Similarly, for the second charge, we obtain a force magnitude of $|F_2| = \left|\frac{kQ_2q}{r_2^2}\right| = \left|\frac{(8.99 \times 10^9)(30.0 \times 10^{-6})(-5.00 \times 10^{-6})}{(0.500)^2}\right| = 5.394\text{N}$. Again, the charges are opposite in sign, so this force will be attractive, meaning that it will act on the charge $q$ in the positive x-direction. The two forces acting on the charge $q$ are perpendicular to one another ($F_1$ in the positive y-direction and $F_2$ in the positive x-direction). Thus, we combine them by using a Pythagorean sum. So, the magnitude of the net force acting on the charge $q$ is: $|F| = \sqrt{F_1^2 + F_2^2} = \sqrt{(4.495)^2 + (5.394)^2} = 7.02\text{N}$.

P14. (D) The magnitude of the magnetic field produced by a long straight wire carrying current $I$, at a distance $r$ from the wire, is given by $|B| = \left|\frac{\mu_0 I}{2\pi r}\right|$. Thus, the magnitude of the field produced at point P by the first wire is $|B_1| = \left|\frac{\mu_0 I_1}{2\pi r_1}\right| = \frac{(4\pi \times 10^{-7})(130)}{2\pi(0.200)} = 1.30 \times 10^{-4}T = 130\mu T$. Similarly, the magnitude of the magnetic field produced at the point P by the second wire is $|B_2| = \left|\frac{\mu_0 I_2}{2\pi r_2}\right| = \frac{(4\pi \times 10^{-7})(210)}{2\pi(0.200)} = 2.10 \times 10^{-4}T = 210\mu T$. Now we need to determine the direction of these two fields. Using a version of the right had rule, we point our thumb in the direction of the current and look at the curl of our fingers to show the direction of the circular magnetic fields around the wires. Doing this, we see that the magnetic field around the first wire goes in counterclockwise circles. Thus, at point P, the first wire's field points downward, in the negative y-direction. Using the same right-hand rule with the second wire, we see that the magnetic field around the second wire goes in clockwise circles. Therefore, the second wire's field also points downward (in the negative y-direction) at the point P. Since the two fields point in the same direction at the point P, we simply add their magnitudes to find the strength of the total magnetic field at P:
$|B| = |B_1| + |B_2| = 130\mu T + 210\mu T = 340\mu T$.

P15. (E) To begin, we need to find the magnetic flux through the loop. To find the flux, we first need the area of the circular loop of wire: $A = \pi r^2 = \pi\left(\frac{0.300}{2}\right)^2 = \pi(0.150)^2 = 0.0707\text{m}^2$. We also need the angle of the magnetic field passing through the loop, but we need the angle with respect to the normal line from the face of the loop. That is, in this case, we need the angle with respect to vertical: $\theta = 90 - \phi = 90° - 62° = 28°$. Initially, the magnetic flux is $\Phi_i = B_i A \cos\theta = (700\mu T)(0.0707m^2)\cos(28°) = 43.7\mu Wb$. Since the field vanishes entirely, the final flux is zero. That is, $\Phi_f = 0$. Now, we can calculate the voltage induced in the loop by the changing magnetic flux: $\mathcal{E} = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Phi_f - \Phi_i}{\Delta t} = -\frac{0 - 43.7\mu Wb}{0.75ms} = \frac{43.7\times 10^{-6}}{0.75\times 10^{-3}} = 0.0583V$. Finally, we can find the current induced in the loop: $I = \frac{\mathcal{E}}{R} = \frac{0.0583V}{2.5\Omega} = 0.0233A = 23.3mA$.

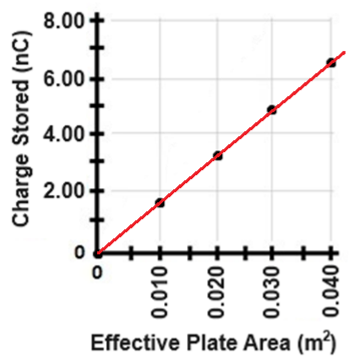
P16. (B) We start by finding the angle subtended by a single diffraction fringe. Using the distance from the hair to the screen and the separation of the diffraction fringes, we find that $\theta = \tan^{-1}\left(\frac{y}{L}\right) = \tan^{-1}\left(\frac{0.0220}{1.30}\right) = 0.9695°$. Now we use the single-slit diffraction equation: $a\sin\theta = m\lambda$. Here we'll use $m = 1$ since we are using the angle subtended by a single (one) fringe. Putting in all the known quantities, we get $a\sin(0.9695°) = (1)(530\times 10^{-9}m) \rightarrow a = 3.13\times 10^{-5}m = 31.3\mu m$.

P17. (A) At the extremely low temperatures of a Bose-Einstein Condensate, the Heisenberg uncertainty principle dictates the physical size of the atoms. Their wavefunctions expand according to the minimum uncertainty in their position. To begin, we find the average momentum of these cooled atoms: $p = mv = (3.82\times 10^{-26}kg)(0.000250m/s) = 9.55\times 10^{-30}kgm/s$. If we consider the total momentum equal to the uncertainty in the momentum (this is the largest the uncertainty in momentum could be) then we can find the minimum uncertainty in position. From the Heisenberg uncertainty principle, we have $\Delta p\Delta x \geq \frac{h}{4\pi}$. We use the equality to find the minimum uncertainty, and we will take $\Delta p = p = 9.55\times 10^{-30}kgm/s$. This gives $(9.55\times 10^{-30})\Delta x = \frac{(6.626\times 10^{-34})}{4\pi}$, which leads to a minimum position uncertainty of $\Delta x = 5.5\times 10^{-6}m = 5.5\mu m$. Note: other, less common, variants of the Heisenberg Uncertainty Principle all give larger results for the position uncertainty.

P18. (B) To find the energy released, we need to determine the mass difference between the left and right sides of the reaction equation. On the left side, we have a total mass of $M_L = M_{Ne} + M_{He} = 20.9938467 + 4.002603 = 24.9964497u$. On the right side, we have a total mass of $M_R = M_{Mg} + m_n = 23.985041 + 1.008665 = 24.993706u$. The difference, then is $\Delta M = M_L - M_R = 24.9964497 - 24.993706 = 0.0027437u$. Converting this mass difference into energy, we find the energy released by this fusion reaction: $E = (0.0027437u)(931.5MeV/u) = 2.56MeV$.

P19. (D) A brass instrument, like a trombone, is effectively an open-open pipe. The equation relating frequency to pipe length in an open-open pipe is $f_n = \frac{nv}{2L} = \left(\frac{nv}{2}\right)\frac{1}{L}$. From this we can see that the slopes of the lines on the plot are $slope = \frac{nv}{2}$. We need only use a single one of these harmonic lines to solve the problem, so I'll choose the middle line. Using the points (1.0, 800) and (0, 0) to estimate the slope, we obtain: $slope = \frac{800-0}{1-0} = 800\text{Hzm}$. Putting the known and calculated values into the slope formula we derived, we get $slope = 800 = \frac{(5)v}{2} \rightarrow v = 320\text{m/s}$. This is the speed of sound in the trombone.

P20. (C) The effective area and total charge of a capacitor are related to one another via two different equations: $Q = CV$ and $C = \frac{\kappa \varepsilon_0 A}{d}$. Putting these together, we obtain $Q = \frac{\kappa \varepsilon_0 A}{d} V = \left(\frac{\kappa \varepsilon_0 V}{d}\right) A$. From this we can see that our plot should be a straight line (it is), and it should have a slope of $slope = \frac{\kappa \varepsilon_0 V}{d}$. On the plot, we will add a best-fit line to clarify things:




We now must find the slope of the best-fit line. Two points on the best-fit line that I will use to calculate the slope are (0.025, 4.00) and (0, 0). Using these points, we obtain a slope of $slope = \frac{4.00-0}{0.025-0} = 160 \text{nC/m}^2 = 1.60 \times 10^{-7} \text{C/m}^2$. Plugging in the known values and equating this to the slope equation we derived earlier gives:

$slope = 1.60 \times 10^{-7} = \frac{\kappa (8.854 \times 10^{-12})(12.0)}{1.25 \times 10^{-2}} = \kappa (8.50 \times 10^{-9})$.

This leads to a dielectric constant for the glass of $\kappa = 18.8 \approx 19$.