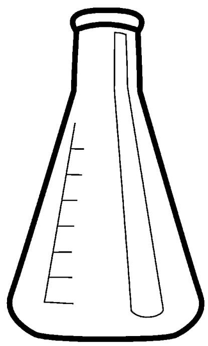
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

State • 2019



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. On 12 April 2019, the Centers for Disease Control and Prevention posted a food safety alert on a recall of pre-cut melons contaminated with
A) *Salmonella* Carrau.
B) *Salmonella* Typhimurium.
C) *Escherichia coli* O103.
D) Shiga-toxin-producing *E. coli*.
E) *Salmonella* Schwarzengrund.

B02. Which of the following statements could not be applied to both transcription and translation in prokaryotes?
A) Covalent bond formation between monomers releases water.
B) Ribonucleotides are involved.
C) Nucleic acid serves as a template.
D) Elongation is the movement of a catalytic complex along the template while generating the final product.
E) Topoisomerases relieve supercoiling.

B03. Examine this image of two eukaryotic cellular organelles that are continuous from left to right.

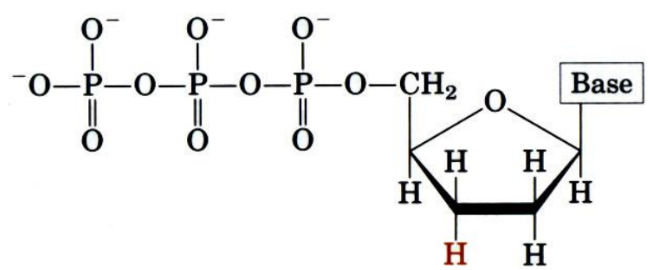
The organelle identified by the arrow functions in
A) DNA storage.
B) biosynthesis of secreted proteins.
C) energy transformation.
D) calcium storage, detoxification, and lipid synthesis.
E) posttranslational modification of secreted proteins.

B04. *Escherichia coli*, a bacterium, and *Balantidium coli*, a protozoan, belong to the same
A) species.
B) Genus.
C) Domain.
D) Kingdom.
E) None of the above answers are correct.

B05. California's giant sequoias and related coastal redwoods belong to Phylum Coniferophyta and are considered
A) angiosperms.
B) seedless plants.
C) gymnosperms.
D) deciduous.
E) non-vascular plants.

B06. Two different traits, A and B, both exhibit incomplete dominance. One parent strain is incompletely dominant for both traits and a second parent strain is homozygous recessive for both traits. What percent of the offspring would be incompletely dominant for trait A and completely dominant for trait B in this parental cross?
A) 0%
B) 25%
C) 50%
D) 75%
E) 100%

B07. Examine the image. This compound is often used in DNA sequencing. What would be the immediate result if this compound was accidentally added as a substrate during a Polymerase Chain Reaction?



A) A base deletion mutation would occur.
B) A frameshift mutation would occur.
C) Elongation would be terminated.
D) The PCR product would have one extra base.
E) Nothing would happen since this is an appropriate substrate for the enzyme.

B08. The first intermediate of the Krebs cycle is
A) citrate.
B) oxaloacetate.
C) acetate.
D) isocitrate.
E) Coenzyme A.

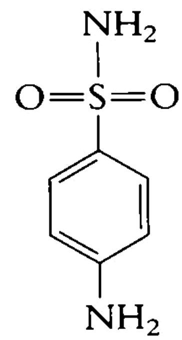
B09. All of the following are examples of reproductive barriers. Which of the following examples specifically reflects behavioral isolation?
A) Two species of snakes live in the same geographic area, but one mainly lives in the water and the other lives on land.
B) The elaborate courtship rituals of male birds-of-paradise in the *Paradisaeidae* family in dense rainforests of New Guinea.
C) Gamete surface proteins from closely-related aquatic animals fail to bind to each other.
D) Hybrid offspring of fertile parents are sterile.
E) *Spilogale putorius* mates during the late winter and the closely-related *Spilogale gracilis* mates in late summer.

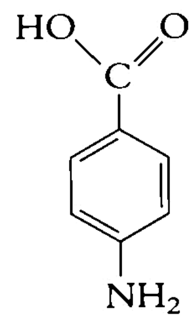
B10. An unvaccinated patient presents to a clinic with fever, headache, muscle aches, fatigue, and loss of appetite. On further examination, a physician finds that the patient has puffy cheeks, a tender and swollen jaw, and swollen parotid salivary glands. Laboratory tests indicate that no bacteria are present. Which of the following is the correct diagnosis?
A) Measles
B) Mumps
C) Strep throat
D) Diphtheria
E) Meningitis

B11. When similar environmental pressures and natural selection produce similar adaptations in organisms that do not share evolutionary lineage, this is referred to as
A) speciation.
B) homology.
C) analogy.
D) divergent evolution.
E) morphological homology.

B12. The photic and aphotic zones of aquatic biomes together form the ________ zone.
A) pelagic
B) benthic
C) abyssal
D) limnetic
E) oceanic

B13. Examine the image of two analogs. PABA is the natural substrate for the enzyme dihydropteroate synthase (DHPS) and is involved in folic acid biosynthesis in bacteria. Sulfa drugs, such as sulfanilamide, are important antibiotics that inhibit DHPS. Based on the images presented below, by which mechanism would you highly anticipate DHPS is being inhibited?


Sulfanilamide


PABA

A) PABA is binding to the active site of DHPS.
B) Sulfanilamide is binding to the allosteric site of DHPS.
C) PABA is competitively inhibiting DHPS.
D) Sulfanilamide is competitively inhibiting DHPS.
E) Both PABA and sulfanilamide are binding simultaneously to the active site of DHPS.

B14. Molecular biologists often move specific genes from one bacterial strain to another (same or closely-related) bacterial strain using a bacteriophage. This genetic technique is called
A) conjugation.
B) transformation.
C) transduction.
D) transfection.
E) lysogenic conversion.

B15. In the nitrogen cycle, some microbes reduce nitrates to nitrogen gas in a process called
A) nitrogen fixation.
B) ammonification.
C) nitrification.
D) assimilation.
E) denitrification.

B16. Cells have a resting potential across their cellular membranes, which means that the cytosolic side of the membrane is more negative than the extracellular side of the membrane. In excitable cells, such as neurons and muscle fibers, this resting membrane potential can be converted into an action potential. What process is primarily responsible for maintaining and/or reestablishing a resting membrane potential in excitable cells?
- A) The active transport of sodium ions outside the cell and potassium ions inside the cell by the sodium-potassium pump.
- B) The diffusion of sodium ions towards the outside of the cell.
- C) The diffusion of potassium ions towards the inside of the cell.
- D) The active transport of anions towards the inside of the cell.
- E) The secondary active transport of substrates, such as glucose, with sodium-glucose cotransporters.

B17. The _______ anchors epithelial cells to the loose connective tissue of the dermis and also serves as a physical barrier to prevent malignant cells that have formed in the epithelial layers from invading deeper tissue. These types of early stage cancers are called carcinoma *in situ.*
- A) epithelium
- B) interstitial matrix
- C) lamina propria
- D) basement membrane
- E) epidermis

B18. In the signaling process for skeletal muscle contraction, a neurotransmitter is released from the terminal ends of axons and diffuses across the synaptic cleft to bind to receptors on skeletal muscle cells. The events described above are occurring at the neuromuscular junction to promote muscle contraction. The most important neurotransmitter for the process described is
- A) glycine.
- B) acetylcholine.
- C) calcium.
- D) GABA.
- E) glutamate.

B19. The production of gametes within larger structures called gametangia distinguishes land plants from algal ancestors. The female gametangia of land plants are specifically called
- A) apical meristems.
- B) gametophytes.
- C) sporophytes.
- D) antheridia.
- E) archegonia.

B20. If an anticodon on a tRNA reads 5'-UAG-3', what amino acid is coded at that position?

	U	C	A	G	
U	Phe	Ser	Tyr	Cys	U
	Phe	Ser	Tyr	Cys	C
	Leu	Ser	STOP	STOP	A
	Leu	Ser	STOP	Trp	G
C	Leu	Pro	His	Arg	U
	Leu	Pro	His	Arg	C
	Leu	Pro	Gln	Arg	A
	Leu	Pro	Gln	Arg	G
A	Ile	Thr	Asn	Ser	U
	Ile	Thr	Asn	Ser	C
	Ile	Thr	Lys	Arg	A
	Met	Thr	Lys	Arg	G
G	Val	Ala	Asp	Gly	U
	Val	Ala	Asp	Gly	C
	Val	Ala	Glu	Gly	A
	Val	Ala	Glu	Gly	G

- A) Aspartic acid
- B) Methionine
- C) Isoleucine
- D) Leucine
- E) None. This encodes a stop codon.

C01. Which of these is the predominant force controlling interactions among atoms and molecules?

A) Electrostatics
B) Gravity
C) The strong nuclear force
D) The weak nuclear force
E) The unified field force
F) The Force, Luke!

C02. When 186.58 grams of a metal carbonate is heated, it forms CO_2 gas and 127.17 grams of the metal oxide. Which metal oxide is it?

A) Na_2O
B) K_2O
C) CaO
D) BaO
E) CuO

C03. 100 grams of A_2B_3 reacts in a double replacement reaction with 250 mL of 2.75 M CD_2, to form C_2B_3 and AD_2. If the molar mass of A is 56.5 g/mol, what is the molar mass of B? (A, B, C, and D are fictional elements and are not on the periodic table.)

A) 156.3 g/mol
B) 59.3 g/mol
C) 85.6 g/mol
D) 34.6 g/mol
E) 20.4 g/mol

C04. What is the maximum wavelength of a photon that is capable of ionizing a hydrogen atom whose electron is in a 5*p* orbital?

A) 2.28×10^{-6} m
B) 1.14×10^{-5} m
C) 3.28×10^{-3} m
D) 2.10×10^{-5} m
E) 6.33×10^{-7} m

C05. What is E_{cell} for this electrochemical cell at 25 °C?

$$Zn \mid Zn^{2+}(0.15\ M) \parallel Cu^{2+}(0.75) \mid Cu(s)$$

A) 1.099 V
B) 1.058 V
C) 1.139 V
D) 1.069 V
E) 1.120 V

C06. 2.0 L of propane gas is mixed with 5.0 L of oxygen in a flexible-walled container at 25 °C and 1.0 atm, and ignited. If the container is allowed to cool back down to 25 °C and 1.0 atm, what will the final volume of the container be?

A) 3.0 L
B) 4.0 L
C) 6.0 L
D) 8.0 L
E) 14 L

C07. Which of these is not part of the five-step sequence for calculating the lattice energy of one mole of NaCl(*s*) from its elements in their standard states?

A) Allow $Na^+(g)$ and $Cl^-(g)$ to form NaCl(*s*)
B) Dissociate Cl_2(g) into 2Cl(*g*)
C) Evaporate $Cl_2(\ell)$ to $Cl_2(g)$
D) Sublime Na(*s*) to Na(*g*)
E) Convert Cl(*g*) to $Cl^-(g)$
F) Ionize Na(*g*) to $Na^+(g)$

C08. What is the change in internal energy when one mole of helium gas in a flexible-walled container at STP is heated to 100°C? ($c_{He(g)}$ = 5.30 J/g·K)

A) 843 J
B) 981 J
C) 1290 J
D) 2110 J
E) 2951 J

C09. A long time ago in a galaxy far, far away, a Mandalorian chemist carried out a titration using Imperial acid, $H_3⊛_3$, and rebel hydroxide base, $Ѱ_2(OH)_5$. The unbalanced equation for the reaction is

$$H_3⊛_3 + \quad Ѱ_2(OH)_5 \rightarrow \quad Ѱ_2⊛_5 + \quad H_2O$$

If the titration required 12.70 ml of 1.50 M Imperial acid to neutralize a 2.500 gram sample of rebel base, what is the molar mass of rebel hydroxide?

A) 131.2 g/mol
B) 78.70 g/mol
C) 421.0 g/mol
D) 218.7 g/mol
E) 113.8 g/mol

C10. 1.0 mole of A and 3.0 moles of B are dissolved in water to a final volume of 2.0 L, and the following reaction occurs

$$A(aq) + 2B(aq) \rightleftharpoons C(aq) + D(aq)$$

When the system reaches equilibrium, [B] = 1.25 M. What is the equilibrium concentration of D?

A) 0.625 M
B) 1.25 M
C) 0.125 M
D) 0.075 M
E) 1.50 M

C11. What is the molar solubility of CoS in a 1.0 M solution of H_2S at pH 4.5?

A) 6.8×10^{-6} M
B) 2.1×10^{-4} M
C) 2.1×10^{-8} M
D) 4.5×10^{-8} M
E) 4.5×10^{-4} M

C12. An insane alchemist invents his own temperature scale (degrees athanor, °A) on which lead freezes at 0 °A and gold boils at 333 °A. What is the value of absolute zero measured on the athanor scale?

A) –41.3 °A
B) –75.7 °A
C) –38.1 °A
D) –273 °A
E) –112 °A

C13. Atmospheric pressure on the surface of Mars is about 600 pascals. What is the boiling point of liquid water on the surface of Mars?

A) 20 °C
B) 10 °C
C) 5 °C
D) –5 °C
E) –10 °C
F) –20 °C

C14. Which of these equations is not valid for First Order kinetics for a reactant *A*?

A) rate = $k[A]$
B) rate = $-\frac{d[A]}{dt}$
C) $\ln\left(\frac{[A]}{[A]_0}\right) = -kt$
D) $\frac{1}{[A]} = \frac{-kt}{[A]_0}$
E) $[A] = [A]_0 e^{-kt}$

C15. Combustion of a 100.0 mL sample of a liquid hydrocarbon compound yields 287.0 g of CO_2. A gaseous sample of the same hydrocarbon at 725 torr and 298 °C has a density of 2.20 g/L. What is the chemical formula for the compound? The liquid hydrocarbon has a density of 0.882 g/mL

A) C_2H_3
B) C_4H_6
C) C_6H_9
D) C_8H_{12}
E) $C_{10}H_{15}$

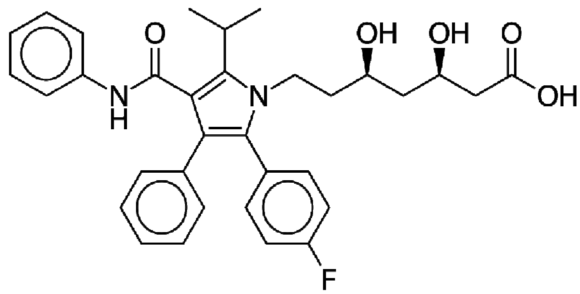
C16. A Jawa must quickly electroplate a stolen droid with a thin layer of copper metal to disguise it from Imperial stormtroopers. If he needs to plate a total of 500 grams of copper onto the droid from a solution of Cu^{2+} ions, and his electroplating system operates at 5.0 amps, how long will it take him to electroplate the entire droid?

A) 1 week
B) 3.5 days
C) 13 hours
D) 5.5 days
E) 11 days

C17. The reaction $2W + X \rightarrow 3Y + Z$ gives a 75% yield. If the reaction is run and 12 moles of Y are produced, how many moles of Z will be produced?

A) 15
B) 9
C) 12
D) 3
E) 4

C18. What is the molar mass of atorvastatin, better known as the cholesterol-fighting drug Lipitor, shown below?



A) 527.39 g/mol
B) 549.61 g/mol
C) 561.73 g/mol
D) 558.70 g/mol
E) 580.40 g/mol

C19. How many delocalized electrons are there in the Lipitor molecule shown in question C18?

A) 18
B) 3
C) 12
D) 9
E) 6

C20. In *The Empire Strikes Back*, Han Solo is encased in a fictional material called carbonite. On Earth we have phosphate and phosphite, sulfate and sulfite, and nitrate and nitrite, so why do we have carbonate but not carbonite?

A) O_2 in the atmosphere reduces all the carbonite to carbonate.
B) Due to its small size and –2 charge, the carbonite ion has an unstable charge density.
C) There aren't enough electrons in a carbonite ion for each atom to have an octet, so carbonite would be unstable and highly reactive.
D) The central carbon atom would have to have an expanded octet to form carbonite, but $n = 2$ elements can't form expanded octets.
E) The –2 charge on the ion means the central carbon must be in a –2 oxidation state, but the Pauli exclusion principle doesn't allow this for an atom with 4 valence electrons.
F) We do have carbonite, but it's known instead by the common name carbon dioxide.

P01. According to Natarajan, gravitational lensing occasionally produces multiple magnified images of the same background galaxy. We know that the numerous images are of the same background galaxy because…
A) the spectra of the images are all identical.
B) the shapes of the images are all identical.
C) the luminosities of the images are all identical.
D) the velocities of the images are all identical.
E) the dark matter profiles of the images are all identical.

P02. According to Natarajan, data released in 1998 indicate that the rate of expansion of the universe is accelerating. This provides evidence for…
A) the decay of dark matter particles.
B) black hole evaporation through Hawking Radiation.
C) a non-zero Cosmological Constant.
D) the non-zero mass of neutrinos.
E) the inflationary model of the Big Bang.

P03. According to Natarajan, no element heavier than __________ could form in the primordial fireball at the beginning of the universe.
A) Hydrogen
B) Helium
C) Lithium
D) Carbon
E) Iron

P04. You discover a new planet, called Planet Z, orbiting the Sun in a circular orbit at a distance of 52.0 A.U. (note: 1 A.U. is the distance from the Earth to the Sun). Approximately what is the orbital period of Planet Z?
A) 13.9 years
B) 91.1 years
C) 149 years
D) 252 years
E) 375 years

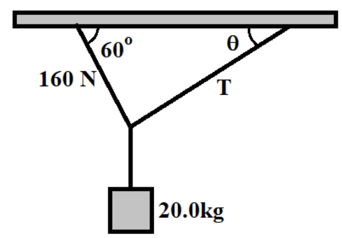
P05. In this formula, c is the speed of light and ϵ_0 is the permittivity of free space. E is an electric field in Volts/meter and B is a magnetic field in Teslas. What are the units of the quantity Z?

$$Z = c\epsilon_0 EB$$

A) Pascals
B) Watts
C) Amperes
D) Newtons
E) Joules

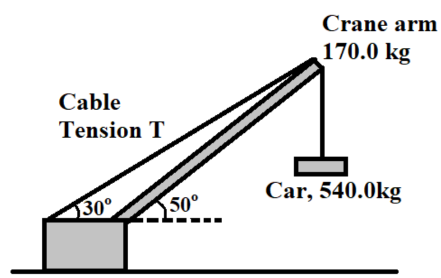
P06. A football is kicked so that it passes directly between two goal posts. The kick is from 37.0m away from the goal posts and the football passes between the posts at a height of 8.50m above the ground. If the football was kicked at an angle of 28.4°, what was the magnitude of the initial velocity of the football?
A) 17.4 m/s
B) 22.2 m/s
C) 24.7 m/s
D) 27.4 m/s
E) 38.8 m/s

P07. A 20.0kg crate is held aloft by a set of ropes, as shown. The leftmost rope is angled at 60.0° relative to horizontal and has a tension of 160.0N. What is the tension, T, in the rightmost rope?
A) 92.4 N
B) 98.5 N
C) 104 N
D) 125 N
E) 137 N



P08. A ball with a mass of 60.0g is moving at 1.25 m/s when it collides head-on with a second ball. The second ball has a mass of 40.0g and is at rest before the collision. If the collision is perfectly elastic, then what is the velocity of the second ball after the collision?
A) 0.250 m/s
B) 0.500 m/s
C) 1.25 m/s
D) 1.50 m/s
E) 1.69 m/s

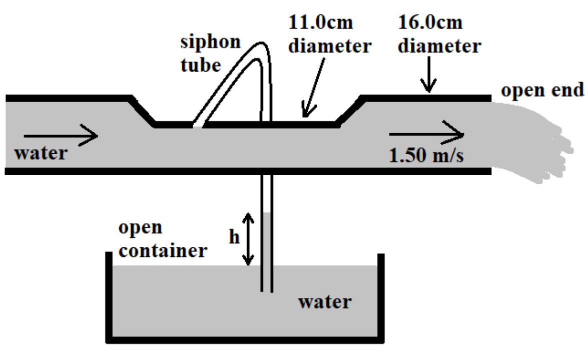
P09. A crane has an arm length of 250.0m and an evenly-distributed arm mass of 170.0kg. A car that has a mass of 540.0kg is hooked on the end of the crane arm. A cable is attached, also at the end of the arm, to help hold up the crane. Given the angles shown, determine the tension in the cable.
A) 7870 N
B) 8950 N
C) 11500 N
D) 13700 N
E) 16200 N



P10. A police car has a siren that produces a single, constant sound at 630.0Hz. While riding in a taxi, you hear the police car come up behind you, and see it pass you. While it is approaching (from behind) you hear the siren sound at 767.0Hz. After it passes, you hear the siren at 524.0Hz. What is the speed of the police car? Assume the air temperature is 20°C.

A) 21.6 m/s
B) 36.3 m/s
C) 43.8 m/s
D) 50.9 m/s
E) 64.5 m/s

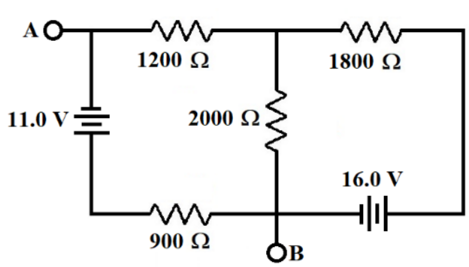
P11. Water is flowing through a large pipe at a velocity of 1.50 m/s, before emptying into an open pond. The main pipe has a diameter of 16.0cm, but in a portion of the pipe the diameter narrows to 11.0cm. In the narrow portion is connected an air-filled siphon tube. The siphon tube wraps down into an open container, also full of water (as shown). How high, h, into the siphon tube does the water from the open container rise?



A) 5.43cm
B) 11.5cm
C) 24.3cm
D) 39.9cm
E) 51.4cm

P12. Determine the magnitude of the voltage difference between points A and B in this circuit.

A) 5.26 V
B) 5.74 V
C) 6.69 V
D) 7.65 V
E) 9.08 V



P13. A solid cylinder has a total charge Q distributed uniformly throughout its volume. The radius of the cylinder is R and it has length L. The cylinder is very long, so that L >> R. Which formula correctly gives the magnitude of the electric field at a distance r from the axis of the cylinder, where r < R (as shown).

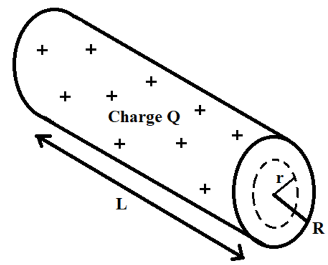
A) $|E| = \frac{r^2 Q}{4\pi\epsilon_0 R^2 L}$

B) $|E| = \frac{r^2 Q}{2\pi\epsilon_0 R^2 L}$

C) $|E| = \frac{rQ}{2\pi\epsilon_0 RL}$

D) $|E| = \frac{rQ}{4\pi\epsilon_0 R^2 L}$

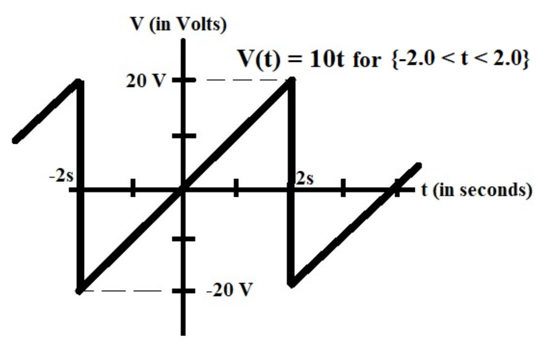
E) $|E| = \frac{rQ}{2\pi\epsilon_0 R^2 L}$



P14. A loop of wire with a diameter of 16.0cm and a resistance of 1.50 Ω is placed in a region of changing magnetic field. The face of the coil is perpendicular to the direction of the field. If the magnetic field strength varies according to the equation $B(t) = 0.10t^2 + 0.20t$, then what is the induced current in the loop at $t = 2.00$s?

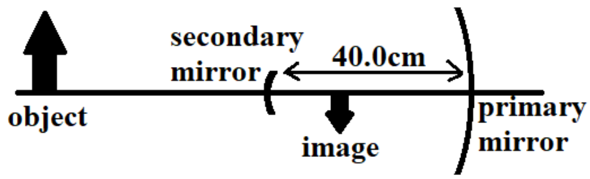
A) 8.04 mA
B) 10.7 mA
C) 24.6 mA
D) 32.2 mA
E) 42.9 mA

P15. For the voltage waveform shown (a sawtooth wave), what is the rms (root-mean-square) voltage magnitude? Note: the period of the waveform is $T = 4.00$s, and the function of the waveform is given on the graph.



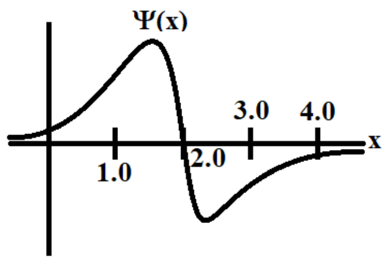
A) 14.1 V
B) 11.5 V
C) 10.0 V
D) 7.07 V
E) 5.77 V

P16. A reflecting telescope has a primary mirror with a focal length of +80.0cm and a secondary mirror with a focal length of +25.0cm. The secondary mirror is located 40.0cm in front of the primary (as shown). If an object is located 1.80m in front of the primary mirror, what is the final image location (relative to the primary mirror)?



A) 7.10cm in front of the primary.
B) 10.5cm in front of the primary.
C) 18.0cm in front of the primary.
D) 19.8cm in front of the primary.
E) 30.5cm in front of the primary.

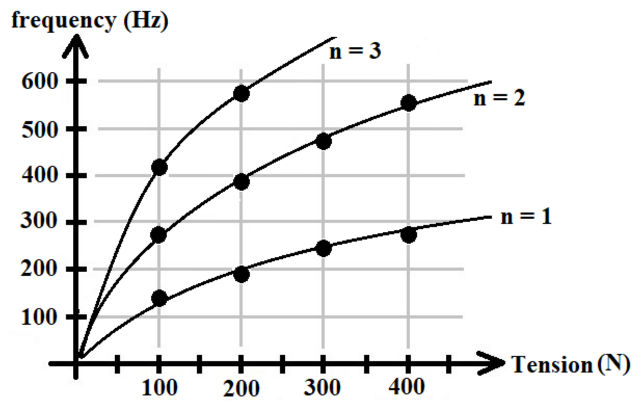
P17. The quantum state of a particle is given by the wavefunction shown. What can be deduced regarding the node of the wavefunction located at $x = 2.0$?



A) The particle can be found at $x < 2.0$ or at $x > 2.0$, but will never be found at $x = 2.0$.
B) The particle can only be found at locations where $x < 2.0$.
C) The particle can only be found at locations where $x > 2.0$.
D) The most probable position of the particle is at $x = 2.0$.
E) The momentum of the particle can be known exactly only when the particle is at $x = 2.0$.

P18. A subatomic particle with a rest mass of 106.0MeV/c^2 has a kinetic energy of 24.0MeV. What is the velocity of this particle?
A) 0.521c
B) 0.579c
C) 0.673c
D) 0.801c
E) 0.974c

P19. You collect data on the frequency of standing waves on a guitar string as a function of the tension in the string. The graph below shows data for the first three harmonics. Knowing that the length of the string is 65.0cm, use the data to determine the mass per length of the string.



A) 0.77 g/m
B) 1.7 g/m
C) 3.0 g/m
D) 5.6 g/m
E) 12 g/m

P20. A simple AC circuit has a single resistance in series with a single reactance. When connected to a $12.0V_{rms}$ supply at 60.0Hz, the current in the circuit is $110mA_{rms}$, and the current leads the voltage by a phase of 21.5°. What is the identity of the reactance and what are the values of the two components in the circuit?

A) Capacitance, C = 26.1μF, R = 40.0Ω
B) Inductance, L = 269mH, R = 40.0Ω
C) Capacitance, C = 417μF, R = 102Ω
D) Inductance, L = 667mH, R = 102Ω
E) Capacitance, C = 66.3μF, R = 102Ω
F) Inductance, L = 106mH, R = 102Ω

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
Density: assume 1.00 g/mL

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
$\mathcal{R}_H = 2.178 \times 10^{-18}$ J
$m_e = 9.11 \times 10^{-31}$ kg

Conversion Factors

1 amp = 1 C/s
1 mol e$^-$ = 95,485 C
1 atm = 101.325 kPa
1 L·atm = 101.325 J
1 Pa·m^3 = 1 J
1 kPa·L = 1 J

Ionization constants for H_2S

K_{a1} 8.9×10^{-8}
K_{a2} 1.0×10^{-19}

Cobalt Sulfide solubility

K_{sp} 4.0×10^{-21}

Standard Reduction Potentials

$Zn^{2+} + 2\,e^- \rightleftharpoons Zn(s)$ $E° = -0.762$ V
$Cu^{2+} + 2\,e^- \rightleftharpoons Cu(s)$ $E° = +0.337$ V

Lead and Gold Properties

Pb melting point = 327.5 °C
Au boiling point = 2970 °C

Physics

Useful Constants

quantity	symbol	value
Free-fall acceleration	g	$9.80\ m/s^2$
Permittivity of Free Space	ε_0	$8.854 \times 10^{-12}\ C^2/Nm^2$
Permeability of Free Space	μ_0	$4\pi \times 10^{-7}\ Tm/A$
Coulomb constant	k	$8.99 \times 10^{9}\ Nm^2/C^2$
Speed of light in a vacuum	c	$3.00 \times 10^{8}\ m/s$
Fundamental charge	e	$1.602 \times 10^{-19}\ C$
Planck's constant	h	$6.626 \times 10^{-34}\ Js$
Electron mass	m_e	$9.11 \times 10^{-31}\ kg$
Proton mass	m_p	$1.67265 \times 10^{-27}\ kg$ $1.007276 amu$
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
2019 STATE

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

CHEMISTRY SOLUTIONS – UIL STATE 2019 – MAY THE 4TH BE WITH YOU!

C01. (A)

C02. (B) The difference in mass between the metal carbonate and the metal oxide is the mass of CO_2 gas given off, and is equal to 59.41 g. 59.41 g / 44.01 g/mol = 1.350 moles of CO_2. All of the answer choices lose one mole of CO_2 per mole of compound, so we start with 1.350 moles of metal carbonate and end up with 1.350 moles of metal oxide. The molar mass of the metal oxide is therefore 127.17 g / 1.350 mol = 94.21 g/mol. This corresponds to K_2O (94.20 g/mol).

C03. (B) The equation for the reaction is $A_2B_3 + 2\ CD_2, \rightarrow C_2B_3 + 2\ AD_2$
Moles of CD_2 = (2.75 M)(0.250 L) = 0.6875 mol. Moles of A_2B_3 = ½(moles of CD_2) = 0.34375 mol
Moles of A = 2 × 0.34375 = 0.6875 mol. Grams of A = 0.6875 mol × 56.5 g/mol = 38.844 g A
Grams of B = 100 g – 38.844 g = 61.156 g. Moles of B = (3/2) × moles of A = 1.0313 mol
Molar mass of B = (61.156 g)/(1.0313 mol) = 59.3 g/mol

C04. (A) The energy required to remove the electron is given by the Rydberg equation. (There are many different forms of this equation, so if you use a different form, just adapt the solution accordingly)

$$E = \mathcal{R}_\mathrm{H}\left(\frac{1}{{n_1}^2} - \frac{1}{{n_2}^2}\right)$$

In this case we're talking about removing the electron completely from $n_1 = 5$, so $n_2 = \infty$ and $1/n_2 = 0$. The equation simplifies to $E = \mathcal{R}_\mathrm{H}/25 = (2.178 \times 10^{-18}\ \mathrm{J})/25 = 8.71 \times 10^{-20}$ J. Using $E = h\nu$ and $\lambda\nu = c$, $\lambda = 2.28 \times 10^{-6}$ m.

C05. (E) The half-cell reactions (both written as reduction potentials) are
$Zn^{2+} + 2e^- \rightleftharpoons Zn(s)$ $E^\circ = -0.762$ V (anode)
and $Cu^{2+} + 2e^- \rightleftharpoons Cu(s)$ $E^\circ = +0.337$ V (cathode)

$$E^\mathrm{o}_\mathrm{cell} = E^\mathrm{o}(\mathrm{cathode}) - E^\mathrm{o}(\mathrm{anode})$$

$$E^\mathrm{o}_\mathrm{cell} = 0.337\ V - (-0.762)\ V = 1.099\ V$$

$$E_\mathrm{cell} = E^\mathrm{o}_\mathrm{cell} - \frac{0.0592\ \mathrm{V}}{n}\log Q$$

$$E_\mathrm{cell} = 1.099\ \mathrm{V} - \frac{0.0592\ \mathrm{V}}{2}\log\frac{[\mathrm{Zn}^{2+}]}{[\mathrm{Cu}^{2+}]}$$

$$E_\mathrm{cell} = 1.099\ \mathrm{V} - \frac{0.0592\ \mathrm{V}}{2}\log\frac{[0.15]}{[0.75]}$$

$$E_\mathrm{cell} = 1.099\ \mathrm{V} - (-0.0207\ \mathrm{V}) = 1.120\ \mathrm{V}$$

C06. (B) The balanced equation for the reaction is $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(\ell)$
H_2O is written as a liquid because the problem says the reaction is cooled to 25°C before calculating the final volume. This problem can be done by working in moles or just working with volumes. Volumes is simpler, so we'll do it that way first.

The balanced reaction says 1 mol of C_3H_8 will react with 5 mol of O_2, which also means that at any given temperature and pressure,1 L of C_3H_8 will react with 5 L of O_2. The problem says we have 2 L of C_3H_8 and 5 L of O_2, so O_2 is limiting and if we reacted away all the O_2 we would still have 1 L of C_3H_8 left over. Reacting 5 L of O_2 produces 3 L of CO_2 (plus liquid water which we will ignore). 1.0 L C_3H_8 + 3.0 L CO_2 = 4.0 L total.

The problem can also be done by working in moles. First determine the limiting reactant:

moles of C_3H_8 = (2.0 L)(1.0 atm)/(298 K)(0.08206) = 0.08179 moles
moles O_2 = (5.0 L)(1.0 atm)/(298 K)(0.08206) = 0.2045 moles
The C_3H_8:O_2 mole ratio in the mixture is 2:5, but in the balanced equation they react 1:5, so we have excess C_3H_8 (double the amount required to react all the O_2) and O_2 is the limiting reactant.

0.2045 mol $O_2 \times (3\ CO_2/5\ O_2)$ = 0.1227 mol $CO_2(g)$ produced
Leftover C_3H_8 = 0.08179 mol/2 = 0.04090 mol $C_3H_8(g)$
Total gas moles = 0.1227 + 0.04090 = 0.1636 mol
V = (0.1636 mol)(298 K)(0.08206)/1 atm = 4.0 L
(The $H_2O(\ell)$ produced in the reaction takes up a negligible volume of 2.95 mL.)

C07. (C) The standard state of Cl_2 is gas, not liquid, so there is no need to evaporate $Cl_2(\ell)$.

C08. (C) $\Delta U = q + w$

$q = mc\Delta T$ = (4.00 g)(5.30 J/gK)(100 K) = 2120 J
$w = -P\Delta V$
V_{initial} = 22.4 L for one mole at STP

$$V_{\text{final}} = \frac{nRT}{P} = \frac{(1\ \text{mol})(0.08206\ \text{L}\cdot\text{atm/mol}\cdot\text{K})(373\ \text{K})}{1\ \text{atm}} = 30.6\ \text{L}$$

ΔV = (30.6 L – 22.4 L) = 8.2 L
$P\Delta V$ = (1 atm)(8.2 L)(101.325 J/L·atm) = 831 J
$\Delta U = q + w = q - P\Delta V$ = 2120 J – 831 J = 1289 J = 1290 J

C9. (D) At the equivalence point moles H^+ = moles OH^-
moles of acid × # of H in the acid formula = moles of base × # of OH in the base formula
$M_{acid}V_{acid}$ × # of H in the acid formula = g_{base}/MW_{base} × # of OH in the base formula
$MW_{base} = g_{base}$ × # of OH in the base formula / ($M_{acid}V_{acid}$ × # of H in the acid formula)
MW_{base} = (2.500 g × 5)/(1.50 M × 0.01270 L × 3) = 218.7 g/mol

The problem can also be solved using the balanced equation as a conversion factor. The balanced equation is $5H_3{}_3 + 3{}_2(OH)_5 \rightarrow 3{}_2{}_5 + 15H_2O$. Moles of base = (3/5)×moles of acid.
Moles of base = (3/5)(1.50 M × 0.01270 L) = 0.1143 moles. 2.500 g/0.01143 mol = 218.7 g/mol

C10. (C) First set up a RICE table for the equilibrium. The initial concentration of A is 0.50 M, and the initial concentration of B is 1.50 M.

R	A(aq)	+	2B(aq)	⇌	C(aq)	+	D(aq)
I	0.50		1.50		0		0
C	$-x$		$-2x$		$+x$		$+x$
E	$0.50 - x$		1.25		x		x

The equilibrium concentration of B is given as 1.25 M, so the change in [B] is 1.5 – 1.25 = 0.25 M. According to the RICE table, 0.25 M = $2x$. The change in [D] is $+x$, or +0.125 M, so [D] = 0.125 M.

C11. (E) Calculate $[S^{2-}]$ from the pH, then use this value in the K_{sp} expression.

$$K_{a_1} = \frac{[H^+][HS^-]}{[H_2S]} \qquad K_{a_2} = \frac{[H^+][S^{2-}]}{[HS^-]} \qquad K_{a_1}K_{a_2} = \frac{[H^+]^2[S^{2-}]}{[H_2S]}$$

$$[S^{2-}] = \frac{[H_2S]K_{a_1}K_{a_2}}{[H^+]^2} = \frac{[1.0](8.9\times10^{-8})(1.0\times10^{-19})}{[10^{-4.5}]^2} = 8.9\times10^{-18}\text{ M}$$

$$K_{sp} = [Co^{2+}][S^{2-}]$$

$$[Co^{2+}] = K_{sp}/[S^{2-}] = 4.0\times10^{-21}/8.9\times10^{-18} = 4.5\times10^{-4}\text{ M}$$

The molar solubility is equal to the Co^{2+} concentration. The additional S^{2-} in solution resulting from the CoS dissolving will be immediately protonated to H_2S, and is negligible compared to the initial H_2S concentration.

C12. (B) The alchemist's temperature scale goes from 0 °A = 327.5 °C (lead freezing/melting) to 333 °A = 2970 °C (gold boiling). A range of 333 °A covers a range of 2642.5 °C, so the °C to °A degree ratio is 2642.5 to 333. The zero offset is 327.5 °C. The conversion factors are therefore

$$°C = \frac{2642.5}{333}°A + 327.5 \qquad \text{and} \qquad °A = (°C - 327.5)\frac{333}{2642.5}$$

Plugging in –273.15 for °C gives absolute zero on the alchemist's scale:

$$°A = (-273.15 - 327.5)\frac{333}{2642.5} = -75.7°A$$

C13. (D) Use the Clausius-Clapeyron equation to relate the boiling point at one pressure to the boiling point at another pressure.

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

P_1 = 1 atm, T_1 = 373.15 K. 600 Pascals = 0.00592 atm. P_2 = 0.00592 atm, T_2 = ?
ΔH_{vap} = 2260 J/g. Convert ΔH_{vap} to J/mol so the units cancel with R:
(2260 J/g)(18.02 g/mol) = 40,725 J/mol

$$\ln\left(\frac{0.00592\text{ atm}}{1\text{ atm}}\right) = \frac{40{,}725\text{ J/mol}}{8.314\text{ J/mol}\cdot\text{K}}\left(\frac{1}{373.15} - \frac{1}{T_2}\right)$$

T_2 = 268.31 K

268.31 – 273.15 = –5 °C ("About 600 pascals" limits the final answer to one significant digit.)

C14. (D). This meaningless equation is a distortion of the integrated rate law for a second order reaction.

C15. (D) First determine the empirical formula from the combustion data, then use the gas density data to determine the chemical formula. 287.0 g / 44.01 g/mol = 6.521 mol C.
6.521 mol C × 12.01 g/mol = 78.32 g C in the hydrocarbon. The hydrocarbon sample has a mass of 100.0 mL × 0.882 g/mL = 88.2 g, so the hydrogen in the sample has a mass of
88.2 g – 78.32 g = 9.88 g.

Moles of C in the sample = 6.521. Moles of H in the sample = 9.782. Divide both moles by the lowest number to get a preliminary empirical formula of $CH_{1.5}$, then double the subscripts to get integer subscripts. The empirical formula is C_2H_3, with an empirical mass of 27.05 g/mol.

Now use the ideal gas law to determine the molar mass (MM) of the sample: $PV = nRT$, so
$PV = (\text{g/MM})RT$. MM = (g/V)RT/P. T = 298 °C = 571.15 K. P = 725 torr = 725/760 = 0.95395 atm.
MM = (2.20 g/L)(0.08206 L·atm/mol·K)(571.15 K)/0.95395 atm = 108.089 g/mol.
(108.089 g/mol) / (27.05 g/mol) = 4.0, so the chemical formula is 4 × C_2H_3 = C_8H_{12}. (The compound is cyclooctadiene.)

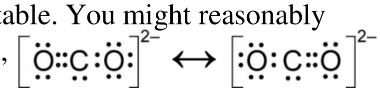
C16. (B) 500 g Cu / 63.55 g/mol = 7.868 moles Cu needed to electroplate.
7.868 moles Cu × 2 mol e^-/mol Cu = 15.74 mol e^-.
15.74 mol e^- × 96,485 C/mol e^- = 1.518×10^6 C.
1.518×10^6 C × 1 sec/5.0 C = 3.036×10^5 seconds required to electroplate the copper.
3.036×10^5 sec × (1 min/60 sec) × (1 hr/60 min) × (1 day/24 hrs) = 3.5 days.

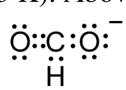
C17. (E) Regardless of the percent yield, the reaction always produces Y and Z in a 3:1 ratio, so if 12 moles of Y are produced, 4 moles of Z are also produced.

C18. (D) The formula is $C_{33}H_{35}FN_2O_5$.

C19. (A) Delocalized electrons are electrons that are free to move about a region of the molecule and are not associated with any particular atom. Each of the three aromatic ring structures in the molecule has six delocalized π electrons, for a total of 18.

C20. (C) The Lewis dot structure for the carbonite ion (CO_2^{2-}) looks like this: 

The carbon atom has only six electrons in its valence shell and is not stable. You might reasonably expect carbonite to be resonance stabilized with octets on all the atoms, 

but that structure requires the carbon atom to have a –1 formal charge while one of the oxygen atoms is 0, and that can't happen because oxygen is more electronegative than carbon, so the resonance structure is bot a valid Lewis dot structure. The carbonite ion exists only at very low temperatures (below about 10-15 K). Above that temperature carbonite picks up a proton and isomerizes into the formate ion, 

PHYSICS SOLUTIONS – UIL STATE 2019

P01. (A) page 108: "…an even larger number of virtual image copies of the background galaxy might appear. For instance, in the Hubble Space Telescope image of a very massive cluster, CL0024+16, which acts as a lens, the same background galaxy appears five times over! We know that these are images of the same object and not just astronomical doppelgangers because we can measure their spectra, their unique chemical fingerprint. The spectra of these five images are all identical."

P02. (C) page 152: "They [Schmidt and Riess] had both arrived at the same result – they were staring at the evidence for Einstein's infamous cosmological constant, lambda… Given the momentous implications of this finding of a nonzero cosmological constant, several team members urged caution…"

P03. (C) page 183: "Because fusion requires a very high temperature and density… once the universe cooled below a certain temperature, this process stopped, choking the formation of any further heavy elements. Nothing heavier than lithium… could form in the primordial universe."

P04. (E) Solving this requires a simple application of Kepler's Third Law, which for a circular orbit reduces to this: the radius of the orbit cubed divided by the period of the orbit squared is a constant. In other words, when comparing two planets: $\frac{R_1^3}{T_1^2} = \frac{R_2^3}{T_2^2}$. Because this is a ratio, we don't even need to change units. Using the Earth to compare to Planet Z, we get $\frac{(1\ AU)^3}{(1\ year)^2} = 1 = \frac{(52\ AU)^3}{T^2}$ which gives $T = 375$ years.

P05. (A) Z is the product of four terms, so let's start by converting the formula into a units equation: $Z = c\epsilon_0 EB = \left[\frac{m}{s}\right]\left[\frac{C^2}{Nm^2}\right]\left[\frac{V}{m}\right][T] = \left[\frac{C^2VT}{Nm^2s}\right]$. Now we must play with the units a little. First, note that a Volt is a Joule per Coulomb. Also recall that a Tesla is a (Newton*second) per (Coulomb*meter). Putting that into our unit equation: $\left[\frac{C^2VT}{Nm^2s}\right] = \left[\frac{C^2JNs}{CNm^2sCm}\right] = \left[\frac{J}{m^3}\right] = \left[\frac{Nm}{m^3}\right] = \left[\frac{N}{m^2}\right] = [Pa]$. Here we have also used the fact that a Joule is a Newton*meter and a Pascal is a Newton per square meter.

P06. (D) We know both the horizontal and vertical distances, so let's begin by using these values in the kinematic equation: $x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2$. For the horizontal, there is no acceleration, and the horizontal component of velocity is $v_{0x} = v_0 cos\theta$. So, $37.0 = 0 + v_0 \cos(28.4)\, t + 0 = 0.8796v_0t$. This gives a useful relationship: $v_0t = 42.062$.

Now, considering the vertical direction, we note that there is a downward acceleration due to gravity, and that the vertical component of velocity is given by $v_{0y} = v_0 sin\theta$.
This gives: $y = y_0 + v_{0y}t + \frac{1}{2}a_yt^2 = 8.50 = 0 + v_0 \sin(28.4)\, t + \frac{1}{2}(-9.8)t^2$.
Using the relation from before gives: $8.50 = 0.4756v_0t - 4.9t^2 = 0.4756(42.062) - 4.9t^2$, which leads to $8.50 - 20.00 = -4.9t^2 = -11.5$, or $t = \sqrt{\frac{11.5}{4.9}} = 1.53$s. From this we can go back to that relation we found earlier to get the velocity: $v_0t = v_0(1.53) = 42.062 \rightarrow v_0 = 27.4$ m/s.

P07. (B) Since this is a statics problem, we know all the forces will sum to zero in both the horizontal and vertical. The challenging part is that we don't know the angle of the rightmost rope. That said, we can still write the force equations. Starting with the horizontal, we get: $\sum F_x = T\cos\theta - 160\cos(60) = 0$. In other words, $T\cos\theta = 80$.

For the vertical direction, the forces are: $\sum F_y = T\sin\theta + 160\sin(60) - mg = 0$, which leads to $T\sin\theta + 138.56 - (20)(9.8) = 0$, or $T\sin\theta - 57.44 = 0$. In other words, $T\sin\theta = 57.44$.

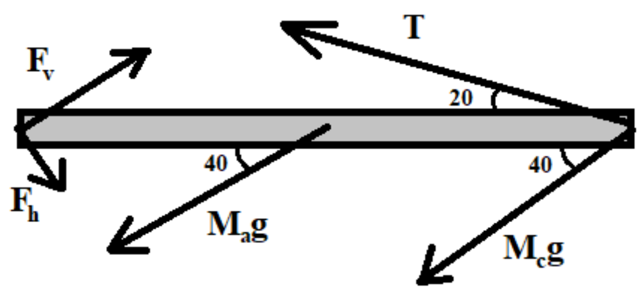
Now we can do some quick math by dividing the resulting equations: $\frac{T\sin\theta}{T\cos\theta} = \frac{57.44}{80} = \tan\theta = 0.7179$. This gives the angle of the rightmost rope: $\theta = 35.68°$. Then we can get the tension in the rightmost rope: $T\cos(35.68) = 80 \rightarrow T = 98.5$ N.

P08. (D) Since the collision is perfectly elastic, kinetic energy is conserved. Momentum is, of course, also conserved. Putting these into equations: $KE_i = KE_f$ and $p_i = p_f$. We have both initial velocities, so we get: $KE_i = \frac{1}{2}m_{1i}v_{1i}^2 + \frac{1}{2}m_{2i}v_{2i}^2 = (0.5)(0.06)(1.25)^2 + 0 = 0.04688$ J. Also, the initial momentum is: $p_i = m_{1i}v_{1i} + m_{2i}v_{2i} = (0.06)(1.25) + 0 = 0.075$ kgm/s. Now we can set up our conservation equations: $KE_i = 0.04688 = KE_f = \frac{1}{2}m_{1f}v_{1f}^2 + \frac{1}{2}m_{2f}v_{2f}^2$, and for momentum: $p_i = 0.075 = p_f = m_{1f}v_{1f} + m_{2f}v_{2f}$. Plugging in the values we know for after the collision, we get these two equations: $0.03v_{1f}^2 + 0.02v_{2f}^2 = 0.04688$, and $0.06v_{1f} + 0.04v_{2f} = 0.075$.

These are mildly challenging to solve. I begin by using the momentum equation to solve for v_{1f}, and then square the equation to plug it into the energy equation: $v_{1f} = 1.25 - 0.667v_{2f}$, which leads to $v_{1f}^2 = 1.5625 - 1.667v_{2f} + 0.444v_{2f}^2$. Plugging this into the energy equation and simplifying gives: $3(1.5625 - 1.667v_{2f} + 0.444v_{2f}^2) + 2v_{2f}^2 = 4.688$. This reduces to a factorable equation: $3.33v_{2f}^2 - 5v_{2f} = 0 = v_{2f}(3.33v_{2f} - 5) = 0$. The solutions are then $v_{2f} = 0$ or $v_{2f} = 1.50$. The first answer is the initial condition, but cannot be the final condition, so the velocity of the second ball after the collision must be $v_{2f} = 1.50$ m/s.

P09. (C) This is another statics problem, this time involving torques as well as forces. First, let's list the forces and where they are acting. The crane arm has a weight ($M_a g$) pointed downward and acting at a point halfway up the arm. There is the weight of the car ($M_c g$) pointed downward and acting at the end of the crane arm. There are horizontal (F_h) and vertical (F_v) forces acting at the base of the crane arm, and there is the tension (T), acting at an angle on the end of the crane arm. Let's start with the torque equation, keeping in mind that the magnitude of a torque is $\tau = Fr\sin\theta$. Tilting the coordinate system so that the crane arm is horizontal helps visualize the torque angles and locations.

If we choose the torque axis to be at the base of the crane arm, then we don't have to worry about F_h and F_v since their torque arms would be zero. The other angles can all be found through some simple geometry.



Taking counterclockwise to be positive, the torque equation is then: $\sum\tau = TL\sin(20) - M_c gL\sin(40) - M_a g\frac{1}{2}L\sin(40) = 0$. Plugging in for the length of the crane arm and the known masses gives:
$T(250)\sin(20) - (540)(9.8)(250)\sin(40) - (170)(9.8)\frac{1}{2}(250)\sin(40) = 0$, which simplifies to $85.51T = 850408 + 133861 = 984269 \rightarrow T = 11510 \approx 11500$ N. Notice that we didn't need to write the force equations to answer the question.

P10. (C) In this problem we must consider both doppler shifts – approaching and receding. And we must account for the fact that the observer is also moving along at an unknown speed. At 20°C, the speed of sound is 343m/s.

For the approaching doppler shift (with the observer travelling away from the source and the source coming up from behind at a higher speed) we get: $f = f_0 \frac{v - v_o}{v - v_s} = 767 = (630)\frac{343 - v_o}{343 - v_s}$.

For the second part, after the police car has passed you, we have a receding doppler shift (with the observer travelling towards from the source and the source moving away at a higher speed). For this we get: $f = f_0 \frac{v + v_o}{v + v_s} = 524 = (630)\frac{343 + v_o}{343 + v_s}$. At this point we need to simplify these two equations. A little algebra gives us these equations: $417.6 - 1.217v_s = 343 - v_o$, and $285.3 + 0.8317v_s = 343 + v_o$. Adding these two equations is useful and gives: $702.9 - 0.3853v_s = 686 \rightarrow v_s = 43.8$ m/s.

P11. (D) To find the height of the fluid in the siphon tube, we will use Bernoulli's equation; but before we can do that, we need to know the velocity of the water flowing in the narrow potion of the large pipe. To find the fluid velocity, we will use the continuity equation, which relates the cross-sectional area of a pipe to the fluid velocity in the pipe: $A_1v_1 = A_2v_2$. Since the pipe has a circular cross section, we know $A = \pi r^2$.

Plugging in gives: $\pi r_1^2 v_1 = \pi r_2^2 v_2 \rightarrow \left(\frac{0.16}{2}\right)^2 (1.50) = \left(\frac{0.11}{2}\right)^2 v_2 = (.0064)(1.50) = (0.003025)v_2$. This gives the velocity in the narrow portion of the pipe to be: $v_2 = 3.174$ m/s. Now we can go to Bernoulli's equation.

Bernoulli's equation, $P_A + \rho g h_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g h_B + \frac{1}{2}\rho v_B^2$, relates any two points in a connected fluid. To begin, we will select point A to be at the junction of the siphon tube and the main pipe; and point B will be at the open end of the main pipe, where the water empties into an open pond. Both points A and B are at the same height, and the air pressure at point B is atmospheric pressure. Noting that the density of water is 1000 kg/m^3, we can use Bernoulli's equation to determine pressure of the air in the siphon tube: $P_A + 0 + (0.5)(1000)(3.174)^2 = P_{atm} + 0 + (0.5)(1000)(1.50)^2$, which gives $P_A = P_{atm} - 3912$.

Now we choose a pair of points in the lower fluid: point C at the top of the fluid in the siphon tube and point D at the surface of the water in the open container. For both points C and D, we note that the fluid is not moving – thus $v_C = v_D = 0$, and we can choose the height at point D to be zero as well. Then, using Bernoulli's equation: $P_C + (1000)(9.8)h + 0 = P_D + 0 + 0$. The gas pressure at point D is just atmospheric pressure, but P_C is the pressure of the air in the siphon tube, which is the same as P_A. Putting it all together: $P_C + 9800h = P_A + 9800h = P_{atm} - 3912 + 9800h = P_D = P_{atm}$. Solving this gives us: $9800h = 3912 \rightarrow h = 0.399\text{m} = 39.9\text{cm}$.

P12. (A) To answer the question, we need the currents in each branch of this circuit. To solve for the currents, we will need to use Kirchhoff's Laws. Defining the currents, Let I_1 be the leftmost branch current (directed downward), let I_2 be the current in the middle branch (directed downward), and let I_3 be the current in the rightmost branch (directed upward). Using Kirchhoff's node rule at the bottom node, we get: $I_1 + I_2 = I_3$. Now using the loop rule on the left loop, going around the loop counterclockwise: $11.0 - 900I_1 + 2000I_2 - 1200I_1 = 0$. Similarly, going around the right loop, also counterclockwise: $16.0 - 1800I_3 - 2000I_2 = 0$. This gives us three equations and three unknowns. One substitution and a little rearranging gives us two equations:

$2100I_1 - 2000I_2 = 11.0$ and $1800I_1 + 3800I_2 = 16.0$. Multiplying the first equation by 1.9 gives us the useful equation: $3990I_1 - 3800I_2 = 20.9$. If we add this equation to our second loop equation, the I_2 terms cancel out and we are left with $5790I_1 = 36.9 \rightarrow I_1 = 0.006373A = 6.373mA$. Using this value for the first current in one of the loop equations gives $I_2 = 0.001192A = 1.192mA$. Finally, we can get the third current: $I_3 = 0.006373 + 0.001192 = 0.007565A = 7.565mA$.

Finally, to get the voltage between points A and B, we do a partial Kirchhoff loop: Starting at point A and going down towards point B we have: $V_{AB} = 11.0 - 900I_1 = 11.0 - 900(0.006373) = 5.26V$.

P13. (E) This is a Gauss' Law problem. The first thing we will need to establish is the Gaussian surface, which will be a cylinder with radius r and length L, coaxial to the actual charged cylinder. Then Gauss' Law states: $\oint E \cdot dA = EA = \frac{Q_{inside}}{\epsilon_0}$, where we have simplified the surface integral by exploiting the natural symmetry of the problem. The charge contained inside the Gaussian surface, Q_{inside}, can be found from a ratio of volumes – be careful, though, this is only valid because the charge is distributed uniformly. Thus, $Q_{inside} = \frac{V_{Gauss}}{V_{total}}Q = \frac{\pi r^2 L}{\pi R^2 L}Q = \frac{r^2}{R^2}Q$. Also note that the surface area of a cylinder (ignoring the ends) is $A = 2\pi rL$. Plugging this in, Gauss' Law gives: $E(2\pi rL) = \frac{r^2}{\epsilon_0 R^2}Q$. Solving for the magnitude of the electric field gives: $E = \frac{r^2}{2\pi rL\epsilon_0 R^2}Q = \frac{rQ}{2\pi\epsilon_0 R^2 L}$.

P14. (A) This problem requires the use of Faraday's Law, which states that the EMF (Voltage) generated in a loop equals the rate of charge of the magnetic flux through the loop. Mathematically, $\mathcal{E} = -\frac{d\Phi}{dt}$. Since the loop face and the magnetic field are perpendicular, the flux is given by $\Phi = BA = B(t)\pi r^2$, where the radius of the loop is $r = \frac{16}{2} = 8.0cm = 0.08m$. Since the radius is constant, then the EMF equation reduces to $\mathcal{E} = -\frac{d\Phi}{dt} = -\pi r^2\frac{dB}{dt} = -\pi r^2\frac{d}{dt}(0.10t^2 + 0.20t) = -\pi r^2(0.20t + 0.20)$. Thus, at $t = 2.0$s, we have an EMF of $\mathcal{E} = -\pi(0.08)^2(0.20(2) + 0.20) = -0.01206$V. Using the resistance and Ohm's Law gives the current: $I = \frac{|\mathcal{E}|}{R} = \frac{0.01206}{1.5} = 0.00804A = 8.04mA$.

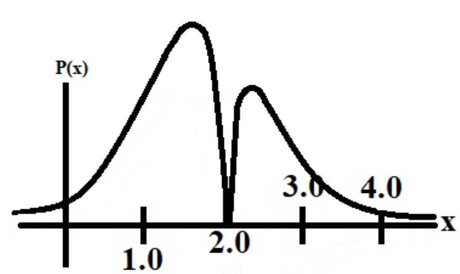
P15. (B) The root-mean-square voltage is given by the formula: $V_{rms} = \sqrt{\frac{1}{T}\int_0^T [V(t)]^2 dt}$. Essentially, this is the square root of the average (over one period) of the square of the waveform. Fortunately, most of these pieces are given, with the observation that we must integrate from $t = -2$ to $t = +2$. We have the period $T = 4.0$s, and the voltage function $V(t) = 10t$. Putting it together:

$V_{rms} = \sqrt{\frac{1}{4}\int_{-2}^{+2}(10t)^2 dt} = \sqrt{\frac{1}{4}\int_{-2}^{+2} 100t^2 dt}$. Integrating gives

$V_{rms} = \sqrt{25\frac{1}{3}t^3 \begin{cases}+2\\-2\end{cases}} = \sqrt{\frac{25}{3}(2^3 - (-2)^3)} = \sqrt{\frac{25}{3}(8+8)} = \sqrt{\frac{25*16}{3}} = \frac{20}{\sqrt{3}} = 11.5\text{V}.$

P16. (D) We begin by finding the image location of the image formed by the primary mirror. Here we have $p_1 = 1.80m = 180cm$, and $f_1 = 80.0cm$. So, $\frac{1}{p_1} + \frac{1}{q_1} = \frac{1}{f_1} = \frac{1}{180} + \frac{1}{q_1} = \frac{1}{80.0} \rightarrow q_1 = 144cm$. Relative to the secondary mirror, this image is located at $p_2 = D - q_1 = 40.0 - 144 = -104cm$. As you may be able to tell, we use the image from the first mirror as the object for the second mirror. It doesn't matter that the secondary object location is negative – it is just a virtual object, which is perfectly acceptable. So, for the second mirror we have $p_2 = -104cm$, and $f_2 = 25.0cm$. This gives $\frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f_2} = \frac{1}{-104} + \frac{1}{q_2} = \frac{1}{25.0} \rightarrow q_2 = 20.2cm$. This is the location relative to the secondary mirror. Relative to the primary mirror, the distance is $d = D - q_2 = 40 - 20.2 = 19.8cm$.

P17. (A) The wavefunction squared represents the probability of detecting the particle at a particular location. Once squared, the probability distribution looks like the graph shown here. You can see that there is a chance to detect the particle on the right or on the left of $x = 2$, but at that specific point, the probability of finding the particle is zero.



P18. (B) We have $KE = 24.0$MeV. Energy of this magnitude will result in relativistic speeds, so we will have to use the relativistic kinetic energy formula: $KE = (\gamma - 1)mc^2 = 24.0$MeV. Since we know the rest mass of the particle, we know $(\gamma - 1)(106MeV) = 24.0MeV \rightarrow \gamma - 1 = 0.2264$, or $\gamma = 1.2264$.

Now we use the formula for gamma to get the velocity of the particle: $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 1.2264$. This leads to $\sqrt{1 - \frac{v^2}{c^2}} = 0.8154 \rightarrow 1 - \frac{v^2}{c^2} = 0.6649 \rightarrow \frac{v^2}{c^2} = 0.3351$, giving $\frac{v}{c} = 0.579$, or $v = 0.579c$.

P19. (C) The important formulas here are the velocity formula for waves on a string: $v = \sqrt{\frac{T}{\mu}}$, and the frequency formula for a standing wave on a string: $f = \frac{nv}{2L}$. Putting these together shows the relationship between standing-wave frequency and string tension: $f = \frac{n}{2L}\sqrt{\frac{T}{\mu}}$. The data is not linear, so I will just utilize a couple of data points to estimate the value of μ. On the first harmonic curve, I will use the point (200N, 200Hz) and on the second harmonic curve, I'll choose (400N, 550Hz). Plugging in the first point: $200Hz = \frac{1}{2(0.65)}\sqrt{\frac{(200N)}{\mu}} \rightarrow \mu = 0.00296$ kg/m, or $\mu = 2.96$g/m. Using the second data point, we get: $550Hz = \frac{2}{2(0.65)}\sqrt{\frac{(400N)}{\mu}} \rightarrow \mu = 0.00313$ kg/m, or $\mu = 3.13$g/m. Both cases round to the nearest choice of $\mu = 3.0$g/m.

P20. (E) The magnitude of the impedance of the AC circuit can be found from Ohm's Law: $|Z| = \frac{V}{I} = \frac{12.0}{0.110} = 109.1\Omega$. To get the individual components of the impedance, we must consider the phase relationship between voltage and current. Specifically, the resistance is given by $R = |Z|cos\phi = (109.1)\cos(21.5) = 102\Omega$. That helps to narrow it down, but we also need the reactance: $X = |Z|sin\phi = (109.1)\sin(21.5) = 40.0\Omega$.

Now we must decide if the reactance is an inductor or capacitor. When the current leads the voltage, it means that the reactance is negative. This means that it is a capacitor. The reactance of a capacitor is given by $X = \frac{1}{2\pi fC}$. Setting this equal to our calculated reactance: $\frac{1}{2\pi fC} = 40$ gives $C = \frac{1}{2\pi f(40)} = \frac{1}{2\pi(60)(40)} = 6.63 \times 10^{-5}F = 66.3\mu F$. So, the answer is $R = 102\Omega$ and $C = 66.3\mu F$.