UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

District • 2021

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 would increase biodiversity?
A) Restoration of an ecosystem by the re-introduction of missing apex predators.
B) Increasing the range of habitats.
C) Planting of native trees and plants within a disturbed area.
D) Removal of non-native predators.
E) All of the above would increase biodiversity.

B02. Which of the following would increase genetic diversity in a population?
A) mutation
B) gene migration
C) recombination
D) sexual reproduction
E) All of the above.

B03. The percent of individuals in a population that actually express a trait given a specific genotype is called
A) expressivity.
B) penetrance.
C) dominance.
D) recessive.
E) phenotype.

B04. Hematopoiesis generates (through both myeloid and lymphoid stem cells)
A) all blood cells.
B) leukocytes only.
C) erythrocytes only.
D) platelets only.
E) plasma.

B05. Oxygenic photosynthesis
A) likely evolved before anoxygenic photosynthesis.
B) uses oxygen as an alternative electron acceptor.
C) produces elemental sulfur as a by-product.
D) requires water.
E) is performed by fungi.

B06. In November and December 2020, the World Health Organization (WHO) reported 67 suspected cases of _______ in Lomé, Togo.
A) *Salmonella*
B) Ebola
C) cholera
D) giardiasis
E) *E. coli*

B07. All of the following increase the reproductive success of organisms except
A) parental investment.
B) mate choice.
C) sexual selection.
D) maladaptive hybridization.
E) nutrition.

B08. Which plant phylum is characterized by no vascularization, no true leaves, no roots, no stems, and includes the mosses and liverworts?
A) Bryophyta
B) Coniferophyta
C) Cycadophyta
D) Ginkgophyta
E) Anthophyta

B09. Peptidyltransferase activity occurs in the _____ subunit of eukaryotic ribosomes.
A) 5S
B) 30S
C) 40S
D) 50S
E) 60S

B10. The spines of a cactus plant are
A) water-storage structures.
B) modified leaves.
C) tendrils.
D) reproductive structures.
E) spores.

B11. Which of the following is not a feature of mitochondria?
A) Likely evolved from a heterotrophic bacterium.
B) Surrounded by two membranes.
C) Contains DNA and ribosomes.
D) Divides in sync with the cell.
E) Contains the enzymes necessary for glycolysis in the eukaryotic cell.

B12. Which of the following describes a primary consumer in a community?
A) herbivore
B) predator
C) carnivore
D) omnivore
E) autotrophs

B13. Red (R) is dominant to white (r) and heterozygotes are pink. A cross between a pink-flowered plant and a red-flowered plant would results in _________ of offspring having red flowers.
A) 0%
B) 25%
C) 50%
D) 75%
E) 100%

B14. The smooth endoplasmic reticulum of muscle fibers is involved in which process?
A) energy storage
B) ATP production
C) muscle contraction
D) glucose storage
E) protein modification

B15. The *trp* operon of *Escherichia coli* is an example of a ______ operon.
A) positive inducible
B) positive repressible
C) negative inducible
D) negative repressible

B16. In a mitotically dividing human somatic cell, how many different types of chromosomes are present in anaphase?
A) 12
B) 23
C) 36
D) 46
E) None of the answers are correct.

B17. Examine the following wild type (WT) and mutated (MU) DNA coding sequences. Predict the type of mutation based on the information given. A genetic code table is provided for reference.

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WT: 5'-CCATGATCTCCTAACG-3'
MU: 5'-CCATGTTCTCCTAACG-3'
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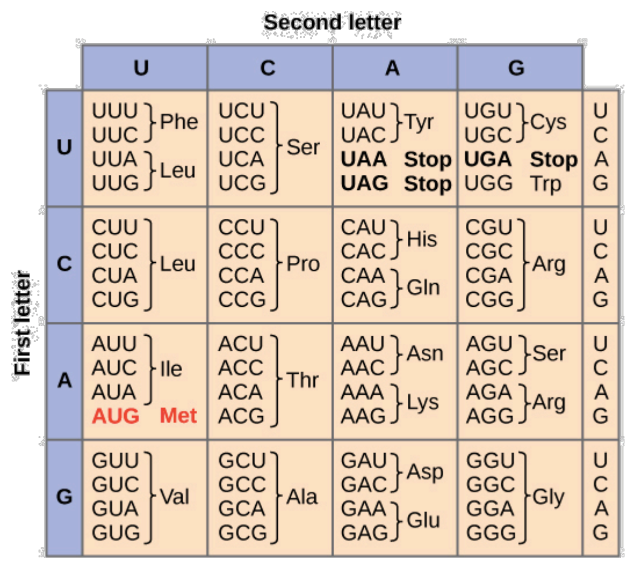


Image credit: "The Genetic Code" by OpenStax College, Biology (CC BY 3.0).

A) silent
B) frameshift
C) nonsense
D) missense
E) deletion

B18. In a hypothetical multicellular, sexually-reproducing organism, a somatic cell has 32 <u>total</u> chromosomes. How many total chromosomes are in a gamete of this same organism?
A) 8
B) 16
C) 32
D) 64
E) None of the answers are correct.

B19. The life cycle of *Plasmodium*, the protist that causes malaria, involves both mosquitoes (*Culex* and *Anopheles*) and humans. The mosquitoes specifically serve as a(an)
A) vector.
B) fomite.
C) reservoir.
D) contaminant.
E) antagonist.

B20. In the first step of glycolysis in *Escherichia coli*, glucose is transported into the cell and modified to glucose-6~phosphate. The energy source for this transport is a small molecule called phosphoenolpyruvate (PEP) and relies on a transport system called the PEP-dependent phosphotransferase system. Based on this information, predict which statement is incorrect.
A) This is a form of active transport.
B) The concentration of PEP could regulate the PTS system.
C) Glucose is being transported down its concentration gradient.
D) The type of transport is group translocation.
E) A transmembrane protein transports the glucose across the plasma membrane.

C01. Modern pennies are made of 97.5% zinc and 2.5% copper by weight, and have a mass of about 2.50 grams. If the government replaced all the zinc atoms in a penny with lead atoms instead, how much would a penny weigh?

A) 2.44 g
B) 7.48 g
C) 7.72 g
D) 7.79 g
E) 7.92 g

C02. If 65.0 g of carbon disulfide, CS_2, is completely combusted, how many liters of SO_2 (g) would be formed at STP?

A) 1.70 L
B) 19.1 L
C) 22.4 L
D) 38.2 L
E) 76.2 L

C03. How many electrons are in *p* orbitals in a ground state Pb atom?

A) 2
B) 6
C) 26
D) 56
E) 82

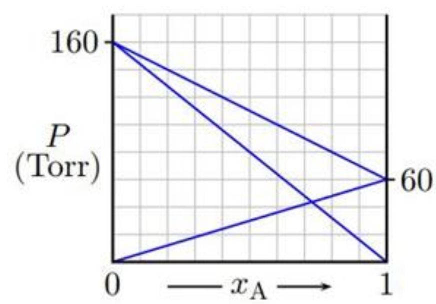
C04. Of the five polyatomic ions listed below, which one has the most single bonds in its Lewis structure? (Consider only one Lewis structure for those with resonance structures.)

A) CN^-
B) NH_4^+
C) CO_3^{2-}
D) SO_4^{2-}
E) PO_4^{3-}

C05. If you have a 10.0 g sample of neon gas in a thick-walled container at STP and you add 10.0 g of argon, what will the new pressure be?

A) 0.51 atm
B) 0.76 atm
C) 1.51 atm
D) 1.76 atm
E) 2.00 atm

C06. Substances A and B are volatile liquids. Using the vapor pressure diagram below, determine the mole fraction of B in the mixture when the vapor pressure of the mixture is 100 torr.

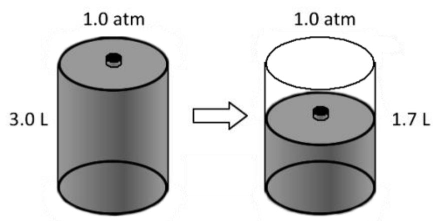


A) 0.0
B) 0.2
C) 0.4
D) 0.6
E) 0.8

C07. A saboteur has spiked your 0.015 M $Ba(OH)_2$ solution with an unknown amount of solid NaOH. If it takes 19.98 mL of 0.50 M HCl to neutralize 125 mL of the spiked $Ba(OH)_2$ solution, how many grams of NaOH were in the titrated sample?

A) 0.400 g
B) 0.150 g
C) 0.600 g
D) 0.500 g
E) 0.250 g

C08. If the process shown below releases 2.155 kJ of heat, what is the change in internal energy for the system?
1 liter atmosphere = 101.325 joules



A) –2.023 kJ
B) 2.287 kJ
C) –2.154 kJ
D) 3.455 kJ
E) 3.587 kJ

C09. For which of these processes at 1 atm pressure is the change of entropy of the universe equal to zero?

A) Water evaporating at 80ºC
B) Ice melting at 25ºC
C) Water vapor condensing to liquid at 100ºC
D) Water freezing to ice at –10ºC
E) None of these has $\Delta S_{universe} = 0$

C10. What is the effective nuclear charge felt by the outermost electrons in a neutral sulfur atom?

A) 0
B) 4
C) 6
D) 10
E) 16

C11. Based on the activity series on the data page, which of these species will react spontaneously with iron metal?

A) Al(*s*)
B) Zn^{2+}(*aq*)
C) Ag(*s*)
D) Pb(*s*)
E) Ni^{2+}(*aq*)

C12. Compound AB_2 is only slightly soluble in water and dissolves according to the equation below.

$$AB_2(s) \rightleftharpoons A^{2+}(aq) + 2B^{-}(aq)$$

You add some solid AB_2 to water and allow it to reach equilibrium. Then you add some solid NaB to the solution and stir, and again allow the system to reach equilibrium. How do the concentrations of A^{2+}(*aq*) and B^{-}(*aq*) after the second equilibrium compare to the concentrations of the ions after the first equilibrium?

A) $[A^{2+}]$ is lower and $[B^{-}]$ is higher after the second equilibrium.
B) $[A^{2+}]$ is higher and $[B^{-}]$ is lower after the second equilibrium.
C) $[A^{2+}]$ and $[B^{-}]$ are both higher after the second equilibrium.
D) $[A^{2+}]$ and $[B^{-}]$ are both lower after the second equilibrium.
E) Both concentrations are unchanged by the addition of NaB to the solution.

C13. The K_{sp} for the metal sulfide MS is 4.4×10^{-5}. How many grams of Na_2S must be added to 1.00 L of a 0.0010 M solution of $M(NO_3)_2$ to begin precipitating out MS? Ignore any acid-base chemistry and any change in volume due to adding solid Na_2S.

A) 1.2 g
B) 2.3 g
C) 3.4 g
D) 4.5 g
E) 5.6 g

C14. A 0.32 M solution of a weak acid HA has a pH of 1.703. What is the percent ionization of the weak acid?

A) 6.2%
B) 5.1%
C) 4.0%
D) 2.9%
E) 1.8%

C15. In the electrochemical cell represented by this shorthand notation, what product is being produced at the cathode?

$$Pt \mid MnO_2 \mid Mn^{2+}, H^+ \parallel Cr_2O_7^{2-}, Cr^{3+} \mid Pt$$

A) MnO_2
B) Cr^{3+}
C) Pt
D) $Cr_2O_7^{2-}$
E) Mn^{2+}

C16. Determine the overall order of the reaction $2\ AB(g) + 2\ C_2(g) \rightarrow A_2(g) + 2\ C_2B(g)$, given the reaction data below.

Experiment	[AB] (M)	$[C_2]$ (M)	Initial rate (M/s)
1	0.250	0.250	1.267×10^{-4}
2	0.500	0.250	5.068×10^{-4}
3	0.500	0.500	1.014×10^{-3}

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

C17. Rubbing alcohol, C_3H_8O, has a normal boiling point of 82.6 ºC, and is commonly sold as either a 91% aqueous solution or a 70% aqueous solution by weight. What is the boiling point of a 91% rubbing alcohol solution? K_b for rubbing alcohol = 1.58 ºC/*m*

A) 91.3 ºC
B) 87.6 ºC
C) 84.5 ºC
D) 81.2 ºC
E) 78.9 ºC

C18. Which answer choice below lists all of the elements whose ground state electron configuration ends with an electron in an $n = 5$ subshell and whose element name begins with the letter P?

A) Pt, Pd
B) Pt, Pa, Pu
C) Pt, Pr, Pm
D) Pt, Pb, Po
E) Pu, P, Py

C19. A student drops a piece of copper wire with a mass of 1.00 grams into a bottle containing 500 mL of 0.100 M $AgNO_3$. When the reaction comes to completion, how much solid silver will be on the bottom of the bottle?

A) 5.39 g
B) 2.89 g
C) 1.70 g
D) 4.70 g
E) 3.39 g

C20. A bored scientist takes a 5.0 mL aliquot from a 100 mL bottle of 1.0 M reagent *R* and dilutes it to 100 mL. Then he takes 25.0 mL of that solution and dilutes it to 98 mL, and then adds 2 mL of the original solution to bring the final volume up to 100.0 mL. What is the concentration of reagent *R* in the final solution?

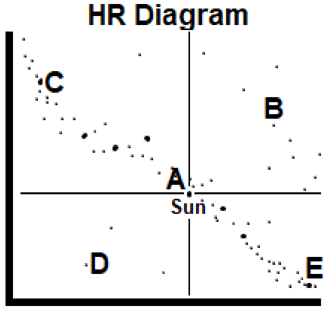
A) 0.0325
B) 0.0555
C) 0.0625
D) 0.0725
E) 0.0775

P01. According to Rovelli, in the universe there are how many planets such as the Earth?
A) Thousands
B) Millions
C) Thousands of millions
D) Billions of billions
E) Thousands of billions of billions of billions

P02. According to Rovelli, a simple and elegant theory was developed in the 1970s but failed because it predicted that a proton could disintegrate (decay) – and despite decades of experiments, proton decay has never been observed. What was the name of this theory?
A) The Standard Model
B) Supersymmetry
C) SU5
D) QCD
E) Dark field theory

P03. According to Rovelli, the equations of the Standard Model lead to nonsensical predictions. Specifically, the equations _________________.
A) Produce calculated quantities that are infinite.
B) Predict that protons will decay.
C) Predict that particles will appear and disappear in empty space.
D) Predict that neutrinos have mass.
E) Predict a new class of particles that have never been observed.

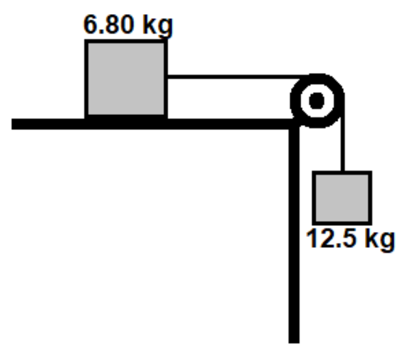
P04. You discover a star that has an absolute luminosity that is about twice that of the Sun, but a temperature that is about half that of the Sun. Where on an HR-diagram would this star be located?



P05. A steel bar that has dimensions 14.0in by 20.0in by 5.00in is stretched into a wire. The wire has a circular cross section with a diameter of 3.30mm. What is the length of the wire that can be made from this bar of steel?
A) 671 m
B) 2680 m
C) 4160 m
D) 5300 m
E) 10600 m

P06. An arrow is fired at an angle of 32.5° above the horizontal. The arrow strikes a target located 230.0m downrange from where it was fired. The range is level, so the arrow strikes the target at the same height from which it was fired. What was the initial speed of the arrow? Ignore air resistance.
A) 24.9 m/s
B) 35.3 m/s
C) 49.9 m/s
D) 62.5 m/s
E) 70.5 m/s

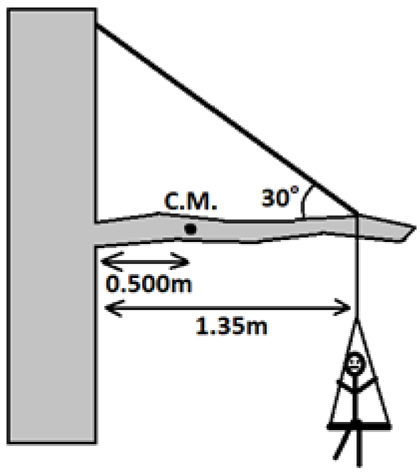
P07. A mass of 12.5kg hangs from a wire that goes up and over a massless/frictionless pulley and attaches to a 6.80kg box sitting on a table (as shown). The coefficient of friction between the 6.80kg box and the table is 0.250. What is the acceleration of the box?
A) 8.47 m/s^2
B) 7.21 m/s^2
C) 6.35 m/s^2
D) 5.48 m/s^2
E) 2.92 m/s^2



P08. A 5.50g acorn falls from a tree branch located 13.8m above the ground. As the acorn falls, air resistance exerts a constant upward force of 12.0×10^{-3} N on it. What is the speed of the acorn when it reaches the ground?
A) 7.76 m/s
B) 10.3 m/s
C) 11.6 m/s
D) 12.9 m/s
E) 14.5 m/s

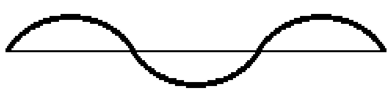
P09. A tree branch has a swing attached to it and there is a 60.0kg child sitting at rest on the swing. The tree branch is horizontal, and the swing is attached at a point 1.35m from the trunk of the tree. A second rope, tied at the same point on the branch, goes up at an angle of 30° and attaches to the trunk. The branch has a mass of 25.0kg and its center of mass is located 0.500m from the trunk. What is the vertical force exerted on the trunk by the branch?

A) 155 N
B) 343 N
C) 525 N
D) 679 N
E) 833 N



P10. You set up a standing wave by oscillating a rope at a frequency of 2.50Hz. The wave you set up is shown below. The tension in the rope is 18.0N and the length of the rope is 4.00m. What is the total mass of the rope?

A) 1.62 kg
B) 2.40 kg
C) 3.40 kg
D) 6.48 kg
E) 10.8 kg

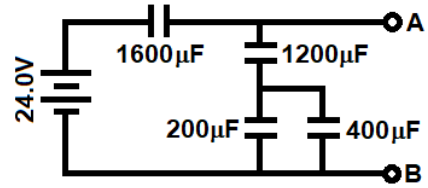


P11. A dark world orbits the remnants of a dead star. The average temperature of the dark world is -160.0°C. The dark world is a sphere with a radius of 2.5×10^5m and a surface emissivity of 0.45. How much energy is radiated into space each day from this cooling world?

A) 1.1×10^{12} J/day
B) 3.3×10^{12} J/day
C) 7.1×10^{16} J/day
D) 2.8×10^{17} J/day
E) 6.3×10^{17} J/day

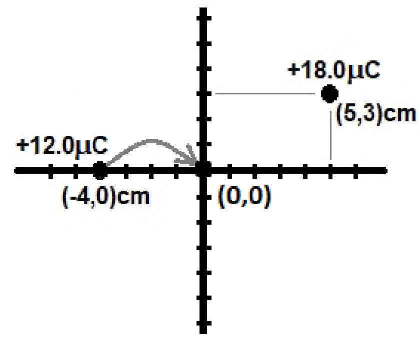
P12. For this capacitor circuit, what is the voltage difference between points A and B?

A) 4.80 V
B) 6.40 V
C) 12.8 V
D) 17.6 V
E) 19.2 V



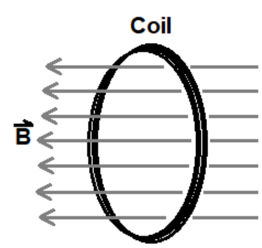
P13. Determine the work needed to move a +12.0μC charge from the point (-4.0, 0)cm to the origin (0, 0), as indicated. There is a fixed charge of +18.0μC located at the point (5.0, 3.0)cm.

A) 12.8 J
B) 20.5 J
C) 33.3 J
D) 46.1 J
E) 53.8 J



P14. A coil containing 200 turns of wire is placed in a magnetic field such that the field is perpendicular to the face of the coil (as shown). The radius of the coil is 12.0cm and the magnetic field strength is 6000Gauss. If the magnetic field strength decreases to 2500Gauss in a time of 150.0ms, what is the voltage induced in the coil?

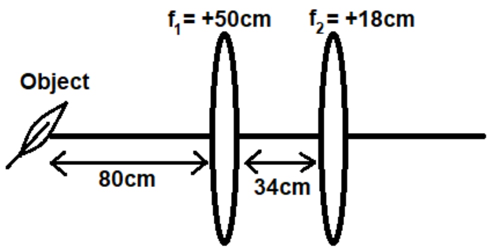
A) 15.1 V
B) 21.1 V
C) 31.7 V
D) 36.2 V
E) 51.3 V



P15. The beam from a 200W flashlight is directed onto a wall, producing a circular spot of light with a diameter of 32.0cm. What is the magnitude of the electric field at the wall due to the light's electromagnetic wave?

A) 470 N/C
B) 680 N/C
C) 970 N/C
D) 1370 N/C
E) 1870 N/C

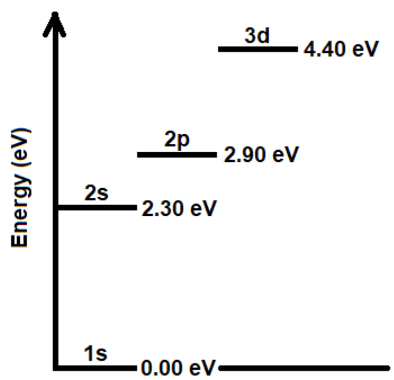
P16. A feather is placed 80.0cm in front of a double-lens telescope (as shown). The first lens has a focal length of +50.0cm and the second lens has a focal length of +18.0cm. The lenses are separated by 34.0cm. Where is the final image of the feather located?



A) 15.2 cm right of the second lens
B) 22.0 cm right of the second lens
C) 30.8 cm right of the second lens
D) 33.3 cm right of the second lens
E) 99.3 cm right of the second lens

P17. A certain atomic species has an energy level diagram as shown below. Knowing that allowed atomic transitions require $\Delta\ell = \pm 1$, which of the following photon wavelengths would you not expect to see emitted from a group of these atoms?

A) 428 nm
B) 590 nm
C) 827 nm
D) 2070 nm
E) all of these would be expected.



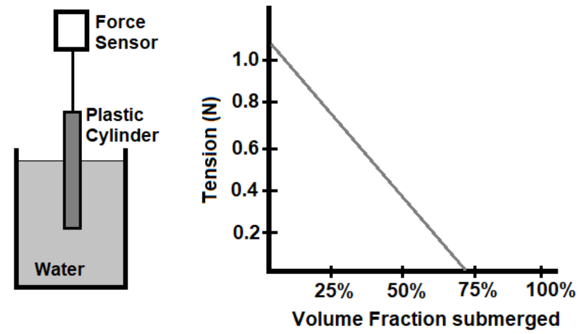
P18. The following nuclear reaction results in the forced emission of an alpha particle:

$$ {}^{1}_{0}n + {}^{209}_{83}Bi \rightarrow {}^{206}_{81}Tl + {}^{4}_{2}\alpha $$

What is the energy released by this reaction? The masses of the isotopes are: ${}^{209}_{83}Bi$ – 208.980399amu, ${}^{206}_{81}Tl$ – 205.976103amu, and ${}^{4}_{2}\alpha$ – 4.0026033amu.

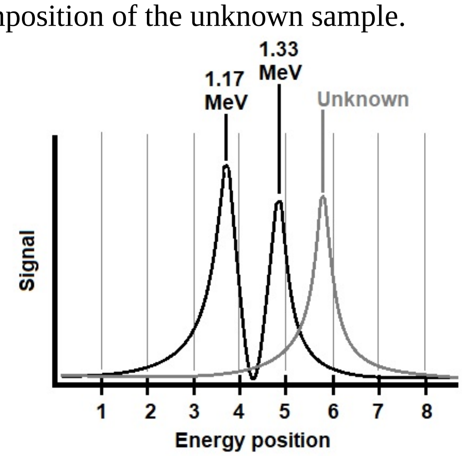
A) 7.0 MeV
B) 8.3 MeV
C) 9.6 MeV
D) 10.9 MeV
E) 12.2 MeV

P19. Using the setup shown, you measure the tension in a string attached to a plastic cylinder as you lower the cylinder into a beaker of pure water. You plot the tension in the string as a function of the percent volume of the cylinder that is submerged in the water. From this plot, determine the density of the plastic cylinder.



A) 290 kg/m^3
B) 500 kg/m^3
C) 710 kg/m^3
D) 920 kg/m^3
E) 1400 kg/m^3

P20. You collect the gamma ray spectrum from an unknown radioactive sample. You use Coblat-60, which produces peaks at 1.17MeV and 1.33MeV, for calibration. Based on this data and the table of known gamma ray energies below, determine the composition of the unknown sample.



${}^{22}Na$	– 1.27 MeV	${}^{40}K$	– 1.46 MeV
${}^{50}V$	– 1.55 MeV	${}^{207}Bi$	– 1.77 MeV
${}^{26}Al$	– 1.81 MeV	${}^{208}Bi$	– 2.61 MeV

A) ${}^{22}Na$
B) ${}^{40}K$
C) ${}^{50}V$
D) ${}^{207}Bi$
E) ${}^{26}Al$

Chemistry

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

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

Water Data

T_{mp} = 0°C

T_{bp} = 100°C

c_{ice} = 2.09 J/g·K

c_{water} = 4.184 J/g·K

c_{steam} = 2.03 J/g·K

ΔH_{fus} = 334 J/g

ΔH_{vap} = 2260 J/g

K_f = 1.86 °C/*m*

K_b = 0.512 °C/*m*

Constants

R = 0.08206 L·atm/mol·K

R = 8.314 J/mol·K

R = 62.36 L·torr/mol·K

$e = 1.602 \times 10^{-19}$ C

$N_A = 6.022 \times 10^{23}$ mol^{-1}

$k = 1.38 \times 10^{-23}$ J/K

$h = 6.626 \times 10^{-34}$ J·s

$c = 3.00 \times 10^{8}$ m/s

$R_H = 2.178 \times 10^{-18}$ J

$m_e = 9.11 \times 10^{-31}$ kg

Activity Series of Metals in Aqueous Solution

Metal	Oxidation Reaction
Lithium	$Li(s) \rightarrow Li^{+}(aq) + e^{-}$
Potassium	$K(s) \rightarrow K^{+}(aq) + e^{-}$
Barium	$Ba(s) \rightarrow Ba^{2+}(aq) + 2e^{-}$
Calcium	$Ca(s) \rightarrow Ca^{2+}(aq) + 2e^{-}$
Sodium	$Na(s) \rightarrow Na^{+}(aq) + e^{-}$
Magnesium	$Mg(s) \rightarrow Mg^{2+}(aq) + 2e^{-}$
Aluminum	$Al(s) \rightarrow Al^{3+}(aq) + 3e^{-}$
Manganese	$Mn(s) \rightarrow Mn^{2+}(aq) + 2e^{-}$
Zinc	$Zn(s) \rightarrow Zn^{2+}(aq) + e^{-}$
Chromium	$Cr(s) \rightarrow Cr^{3+}(aq) + 3e^{-}$
Iron	$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^{-}$
Cobalt	$Co(s) \rightarrow Co^{2+}(aq) + 2e^{-}$
Nickel	$Ni(s) \rightarrow Ni^{2+}(aq) + 2e^{-}$
Tin	$Sn(s) \rightarrow Sn^{2+}(aq) + 2e^{-}$
Lead	$Pb(s) \rightarrow Pb^{2+}(aq) + 2e^{-}$
Hydrogen	$H_2(g) \rightarrow 2\ H^{+}(aq) + 2e^{-}$
Copper	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^{-}$
Silver	$Ag(s) \rightarrow Ag^{+}(aq) + e^{-}$
Mercury	$Hg(l) \rightarrow Hg^{2+}(aq) + 2e^{-}$
Platinum	$Pt(s) \rightarrow Pt^{2+}(aq) + 2e^{-}$
Gold	$Au(s) \rightarrow Au^{3+}(aq) + 3e^{-}$

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
2021 DISTRICT

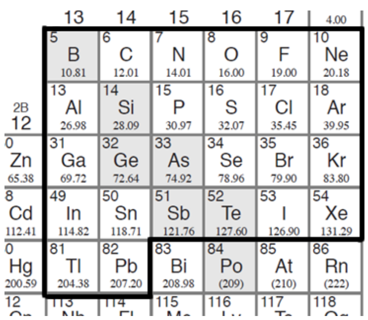
Biology		Chemistry		Physics	
B01.	E	C01.	D	P01.	E
B02.	E	C02.	D	P02.	C
B03.	B	C03.	C	P03.	A
B04.	A	C04.	B	P04.	B
B05.	D	C05.	C	P05.	B
B06.	C	C06.	C	P06.	C
B07.	D	C07.	E	P07.	D
B08.	A	C08.	A	P08.	E
B09.	E	C09.	C	P09.	A
B10.	B	C10.	C	P10.	A
B11.	E	C11.	E	P11.	D
B12.	A	C12.	A	P12.	E
B13.	C	C13.	C	P13.	A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

CHEMISTRY SOLUTIONS – UIL DISTRICT 2021

C01. (D) Mass of zinc = 2.50 g × 0.975 = 2.4375 g. 2.4375 g × (1 mole / 65.38 g) = 0.03728 mol Zn. 0.03728 mol Pb × 207.2 g/mol = 7.7248 g Pb. Mass of Cu in a penny = 2.50 – 2.4375 = 0.0625 g. Total mass of Pb and Cu = 7.7248 + 0.0625 = 7.787 g = 7.79 grams

C02. (D) 2 moles of SO_2 will be formed for every mole of CS_2 combusted. Molar mass of CS_2 = 76.15 g/mol. 65.0 g / 76.15 g/mol = 0.85358 mol CS_2, so 1.7072 mol SO_2 is formed. Molar volume of any gas at STP = 22.4 L. 1.7072 mol × 22.4 L / 1 mol = 38.24 L.

C03. (C) You can write the electron configuration and count the *p* electrons, or just count the squares on the periodic table: $1s^2\ 2s^2\ \mathbf{2p^6}\ 3s^2\ \mathbf{3p^6}\ 4s^2\ 3d^{10}\ \mathbf{4p^6}\ 5s^2\ 4d^{10}\ \mathbf{5p^6}\ 6s^2\ 4f^{14}\ 5d^{10}\ \mathbf{6p^2}$



C04. (B) NH_4^+ has four single bonds. $CN^–$ has no single bonds, $CO_3^{2–}$ has two, $SO_4^{2–}$ has two, and $PO_4^{3–}$ has three.

C05. (C) The mental math shortcut to solving this is to say that we have about ½ mole of gas at 1 atm pressure and we add ¼ moles of gas to that. The number of moles of gas is increasing by about 50% at constant *V* and *T*, so the pressure will increase by about 50%, and will therefore end up at about 1.5 atm.

Here's the full mathematical solution. First calculate the volume of the container:
moles of neon gas = 10.0 g / 20.18 g/mol = 0.4955 moles
V = nRT/P = (0.4955 mol)(0.08206 L·atm/mol·K)(273 K)/(1 atm) = 11.10 L
Adding 10.0 g of argon is adding (10.0 g / 39.95 g/mol) = 0.2503 moles of gas
Total moles of gas = 0.4955 + 0.2503 = 0.7458 moles. Calculate new pressure:
P = nRT/V = (0.7458 mol)(0.08206 L·atm/mol·K)(273 K)/(11.10 L) = 1.51 atm

C06. (C) The mole fraction of substance A (χ_A) increases moving to the right on the *x*-axis, so the mole fraction of B decreases moving to the right on the x-axis. $\chi_A + \chi_B = 1$. Where the vapor pressure of the mixture (the top line in the diagram) is equal to 100 torr, $\chi_A = 0.6$ and $\chi_B = 0.4$.

C07. (E) At the equivalence point moles [H^+] = moles [$OH^–$].
Moles [H^+] = 0.01998 L × 0.50 M = 0.00999 moles H^+ = 0.00999 moles $OH^–$.
The moles of $OH^–$ from the $Ba(OH)_2$ = 0.125 L × 0.015 M × 2 = 0.00375 moles
Added moles of $OH^–$ = 0.00999 – 0.00375 = 0.00624 moles
0.00624 mol NaOH × 40.0 g/mol = 0.250 grams NaOH in the titrated sample

C08. (A) ΔU = heat + work = q + w. q is given as –2155 J. w can be calculated by $w = -P\Delta V$
w = –(1 atm)(–1.3 L) = +1.3 L·atm. 1.3 L·atm × 101.325 J/ L·atm = 131.72 J.
ΔU = –2155 + 131.72 = –2023 J

C09. (C) $\Delta S_{universe} = 0$ when $\Delta G = 0$, and that is when a system is at equilibrium. The only time a phase change is at equilibrium is when it occurs at its phase change temperature (for example ice melting at 0ºC or water vaporizing at 100 ºC). The only phase change listed among the choices that occurs at its equilibrium temperature is vapor condensing to liquid at 100 ºC.

C10. (C) The effective nuclear charge Z_{eff} is calculated as the nuclear charge minus the inner electrons (the shielding electrons). Since the outer electrons in a sulfur atom are in $n = 3$, all the electrons in $n = 1$ and $n = 2$ are shielding electrons. $n = 1$ contains 2 electrons and $n = 2$ contains 8 electrons, so $Z_{eff} = +16 - 10 = +6$ (for main group elements Z_{eff} is the same as the Roman numeral group number).

C11. (E) Iron metal is being oxidized in the activity series table, so the correct answer will be something that is being reduced, which is to say an ion on the right side of the arrows. This leaves only Zn^{2+}(*aq*) and Ni^{2+}(*aq*) as possible answers. Metals that are lower on the table are more stable. Ni is lower in the table than Fe, so Ni^{2+}(*aq*) will oxidize Fe metal and become reduced to Ni metal in the process. The products of the reaction would be Fe^{2+}(aq) and Ni(s).

C12. (A) LeChatelier's Principle says that when you add more B^- to a system at equilibrium, the reverse reaction will occur. This will use up some A^{2+} from solution along with some of the added B^- (but not all of the added B^-), so $[A^{2+}]$ will be lower than it was after the first equilibrium and $[B^-]$ will be higher.

C13. (C) $K_{sp} = [M^{2+}][S^{2-}]$. $[S^{2-}] = K_{sp}/[M^{2+}] = 4.4 \times 10^{-5}/0.0010 = 4.4 \times 10^{-2}$ M
For the 1 L solution this means you need 4.4×10^{-5} moles of Na_2S to start the precipitation.
4.4×10^{-2} moles × 78.05 g/mol = 3.4 g

C14. (A) $[H^+] = 10^{-pH} = 10^{-1.703}$ = 0.01982 M. (0.01982 M / 0.32 M) × 100% = 6.2% ionized

C15. (B) In the electrochemical shorthand notation the anode is on the left of the salt bridge (‖) and the cathode is on the right. Reduction always occurs at the cathode. In this cell $Cr_2O_7^{2-}$ is being reduced to Cr^{3+}.

C16. (D) Looking at experiments 1 and 2, doubling [AB] while keeping $[C_2]$ constant results in a 4× increase in the rate, so the reaction is second order in [AB]. Looking at experiments 2 and 3, doubling $[C_2]$ while keeping [AB] constant doubles the rate of the reaction, so the reaction is first order in $[C_2]$. Second order in [AB] and first order in $[C_2]$ is third order overall.

C17. (A) $\Delta T = imK_b$
Assume 100 g of solution, that's 91 grams of rubbing alcohol and 9 grams of water. The molality of the water in the rubbing alcohol is 9 g / 18 g/mol = 0.5 mol in 0.091 kg of solvent.
molality = 0.5 mol /0.091 kg = 5.4945 molal
$\Delta T = imK_b$ = (1)(5.4945)(1.58) = 8.68 ºC
The new boiling point is 82.6 + 8.68 = 91.3 ºC

C18. (B) In the main group (the *s*- and *p*- blocks) there are no elements in $n = 5$ that begin with P. In the *d*-block $n = 5$ appears in row 6, and there we find Pt. In the *f*-block $n = 5$ appears in row 7 (the actinides), and there we find Pa and Pu.

C19. (E) This is a redox reaction between Ag^+ and Cu(s): $2Ag^+(aq) + Cu(s) \rightarrow 2Ag(s) + Cu^{2+}(aq)$.
Moles of Cu = 1.00 g × (1 mol/63.55 g) = 0.01574 moles.
Moles of Ag = 0.500 L × 0.100 M = 0.0500 moles.
Since the reaction stoichiometry is 2 Ag^+ to 1 Cu, 0.01574 moles of Cu will react with 0.03148 moles of Ag^+. Ag^+ is in excess and Cu is the limiting reagent, and 0.03148 moles of Ag(s) will form. 0.03148 mol Ag × 107.87 g/mol = 3.39 g Ag.

C20. (A) First dilution: $M_1V_1 = M_2V_2$ (1.0 M)(5.0 mL) = (M_2)(100 mL). M_2 = 0.050 M
The second "dilution" is actually a combination of two different solutions rather than just a dilution, so calculate total moles and total volume to calculate the final concentration.
25 mL from the diluted solution: M×V = moles. (0.05 M)(25.0 mL) = 1.25 millimoles of *R*
2 mL from the original solution: M×V = moles. (1.0 M)(2 mL) = 2 millimoles of *R*
Final concentration = total moles / total volume = 3.25 millimoles / 100.0 mL = 0.0325 M.

PHYSICS SOLUTIONS – UIL DISTRICT 2021

P01. (E) page 26: "Through the Hubble telescope a dusting of vastly distant dots appears. Each black dot in the image is a galaxy containing a hundred billion suns similar to ours. In the past few years, it has been observed that the majority of these suns are orbited by planets. There are therefore in the universe thousands of billions of billions of billions of planets such as Earth."

P02. (C) page 34: "A fine theory proposed in the 1970s, and given the technical name SU5, for example, replaced the disordered equations of the Standard Model with a much simpler and more elegant structure. The theory predicted that a proton could disintegrate, with a certain probability, transforming into electrons and quarks…. But, alas, no proton was ever seen disintegrating."

P03. (A) page 32: "The very way in which the equations of the Standard Model make predictions about the world is also absurdly convoluted. Used directly, these equations lead to nonsensical predictions where each calculated quantity turns out to be infinitely large."

P04. (B) On an HR diagram, higher luminosity is towards the top of the diagram, so a more luminous star than the Sun, would be located above the Sun on the diagram. Temperature, however, decreases as you go to the right on the diagram, so a cooler star than the Sun would be to the right of the Sun's location on the HR diagram. Thus, the newly discovered star would be located up and to the right of the sun, or at location B. This is, by the way, the location of red giant stars.

P05. (B) First, we convert the dimensions of the steel bar into metric units. Specifically, we convert those dimensions into centimeters: $L = 14.0in * \frac{2.54cm}{in} = 35.56cm$, $W = 20.0in * \frac{2.54cm}{in} = 50.8cm$, and $H = 5.00in * \frac{2.54cm}{in} = 12.7cm$. This gives a steel bar volume of $V = LWH = 22942cm^3$. This same volume will be converted into a very long cylinder (a length of wire). The volume of a cylinder is $V = \pi r^2 l = 22942cm^3$. Calculating the radius of the wire and converting that into centimeters: $r = \frac{3.30mm}{2} = 1.65mm = 0.165cm$. Putting it all together: $\pi(0.165)^2 l = 22942$, which gives a length of $l = 268233cm = 2682.33m \approx 2680m$.

P06. (C) First, let's consider the horizontal direction. The component of the initial velocity that is horizontal is $v_{ix} = v_i \cos(32.5) = 0.8434v_i$. Putting this into a kinematic equation and including the horizontal distance to the target: $x_f = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = 230.0 = 0 + 0.8434v_i t + 0 = 0.8434v_i t$.
Rearranging gives the useful relation: $v_i t = 272.7$.
Turning to the vertical direction, note that the initial and final heights are the same: $y_f = y_i$. The vertical component of the initial velocity is: $v_{iy} = v_i \sin(32.5) = 0.5373v_i$. Putting the vertical into a kinematic equation: $y_f = y_i + v_{iy}t + \frac{1}{2}a_y t^2 = 0 = 0.5373v_i t - \frac{1}{2}(9.8)t^2 = 0.5373v_i t - 4.9t^2$.
Plugging in the relation from the horizontal equation: $0 = 0.5373(272.7) - 4.9t^2$, which leads to $0 = 146.5 - 4.9t^2 \;\rightarrow\; 4.9t^2 = 146.5 \;\rightarrow\; t = 5.47s$. From this we can get the initial velocity: $v_i t = 272.7 \;\rightarrow\; v_i(5.47) = 272.7 \;\rightarrow\; v_i = 49.9$m/s.

P07. (D) Let's consider the force diagram for the two masses. For the hanging mass, we have two forces: gravity, directed downward; and tension, directed upward. There is also a downward acceleration. Taking upward to be positive and putting this into Newton's acceleration law gives:
$\sum F = T - mg = m(-a) \;\; \rightarrow \;\; T - (12.5)(9.8) = -12.5a \;\; \rightarrow \;\; T - 122.5 = -12.5a.$
Now, for the other mass, there are four forces: gravity, directed downward; the normal force, directed upward; tension, directed to the right; and friction, directed to the left. In the vertical, there is no acceleration, so Newton's acceleration law gives:
$\sum F_y = F_N - Mg = 0 \;\; \rightarrow \;\; F_N = Mg = (6.80)(9.8) = 66.64\text{N}.$
For the horizontal, there is acceleration to the right, which is the direction we take to be positive. From Newton's acceleration law, we get: $\sum F_x = T - F_f = Ma = 6.80a.$
To get the force of friction, we use the coefficient of friction. Specifically: $F_f = \mu F_N$, so the force of friction is $F_f = (0.250)(66.64) = 16.66\text{N}$. Putting this in the previous equation gives:
$T - 16.66 = 6.80a$. Solving for tension gives: $T = 6.80a + 16.66.$
Finally, we plug this into the equation we found for the hanging mass:
$T - 122.5 = -12.5a \;\; \rightarrow \;\; 6.80a + 16.66 - 122.5 = -12.5a \;\; \rightarrow \;\; -105.84 = -19.3a$. Thus, the acceleration of the box is $a = \frac{105.84}{19.3} = 5.48\text{m/s}^2$.

P08. (E) The acorn starts with only gravitational potential energy and ends with only kinetic energy. During the acorn's fall, some work is done by the air resistance, so that energy is converted to heat and lost. Mathematically we have: $GPE_i - W = KE_f$. We can calculate these individually:
$GPE_i = mgh = (5.50 \times 10^{-3}kg)(9.8m/s^2)(13.8m) = 0.74382\,J$. Since the distance that the acorn travelled while experiencing the force of air resistance equals the height, then the work done by air resistance is $W = fd = fh = (12.0 \times 10^{-3}N)(13.8m) = 0.1656\,J$.
Finally, the kinetic energy is: $KE_f = \frac{1}{2}mv^2 = (0.5)(5.50 \times 10^{-3}kg)v^2$. Putting it all together gives: $0.74382 - 0.1656 = 0.57822 = (2.75 \times 10^{-3})v^2 \;\; \rightarrow \;\; v^2 = 210.3 \;\; \rightarrow \;\; v = 14.5m/s.$

P09. (A) This is a static equilibrium problem, so our basic premise here is that all forces sum to zero and all torques sum to zero. We begin with a force diagram, which has five forces on it: a vertical upward force where the branch meets the trunk (F_v), a horizontal force (to the right) where the branch meets the trunk (F_h), the downward weight of the branch located at the center of mass ($m_b g$), the downward weight of the swing located where the ropes attached to the branch ($m_s g$), and the tension in the second rope (angled up and left) located where the ropes attach to the branch (T). Only the tension is at an angle, so we should break it up into components: for the horizontal component (to the left) we get $T_h = Tcos(30) = 0.866T$, and for the vertical component (upward) we get $T_v = Tsin(30) = 0.500T$.

It is best to begin with torque. Torque is defined as a cross-product of a force and a distance from an axis. We can choose our axis, so I choose the location where the branch meets the trunk; that is where $d = 0$. There are several ways to interpret a cross product, but one way to regard it is to say that only forces perpendicular to the torque-arm (the branch in this case) contribute to the torque. Since the branch is horizontal, this simply means that only vertical forces can contribute to the torque on the branch. One other thing to remember: torques that would cause clockwise rotation are negative, and those that would cause counterclockwise rotation are positive. Now we can sum up our torques: $\sum \tau = F_v d_0 + (-)m_b g d_b + (-)m_s g d_s + (+)T_v d_s = 0$. Here the signs are put in based on the direction of the torque, and the distances d are measured from the axis, which is where the branch and trunk meet. Only vertical forces are included. Putting in the given and known values, we get: $F_v(0) - (25.0)(9.8)(0.500) - (60.0)(9.8)(1.35) + (0.500T)(1.35) = 0$. This leads to $-122.5 - 793.8 + 0.675T = 0$, or $0.675T = 916.3 \;\; \rightarrow \;\; T = 1357N$.

Now things get a lot simpler: Summing up the forces in the horizontal gives: $\sum F_x = F_h - T_h = 0$. In other words, $F_h = T_h = 0.866T = (0.866)(1357) = 1176N$. Not that we care about F_h anyway. Summing up the forces in the vertical gives: $\sum F_y = F_v - m_b g - m_s g + T_v = 0$. Putting in our known values: $F_v - (25.0)(9.8) - (60.0)(9.8) + 0.500T = 0 = F_v - 245 - 588 + (0.500)(1357)$. This simplifies to $F_v - 833 + 678.5 = 0 \;\; \rightarrow \;\; F_v = 154.5N \approx 155N$.

P10. (A) From the image we can see that this standing wave is in the $n = 3$ harmonic (there are three anti-nodes). This, along with the length of the rope, gives us the wavelength of the standing wave: $\lambda = \frac{2L}{n} = \frac{2(4.00)}{3} = 2.67$m.

Since we also know the frequency, we can determine the velocity of the travelling waves that compose the standing wave: $v = f\lambda = (2.5Hz)(2.67m) = 6.67$m/s. This velocity, in turn, is related to the mechanical properties of the rope by: $v = \sqrt{\frac{T}{\mu}}$ where T is the tension and μ is the mass per unit length of the rope. Putting things together, we get: $6.67 = \sqrt{\frac{18.0}{\mu}} \quad \rightarrow \quad \mu = \frac{18.0}{(6.67)^2} = 0.405\frac{kg}{m} = \frac{M}{L}$. Finally, we can get the total mass of the rope: $M = \mu L = (0.405)(4.00) = 1.62$kg.

P11. (D) The energy radiated into space is based on the Stephan-Boltzmann law: $P = \sigma A e T^4$. In order to use this law, we need the temperature to be in Kelvin: $T = -160 + 273 = 113$K. Also, since this temperature of the planet is much greater than the temperature of empty space (which is around 2.7K), we can ignore any energy from space that might be reabsorbed by the dark world.

Now we need the surface area of the planet. Since it is a sphere, the surface area is $A = 4\pi r^2$, which for this planet gives an area of $A = 4\pi(2.5 \times 10^5)^2 = 7.854 \times 10^{11}$m^2.

So, the power radiated by the dark world is: $P = (5.67 \times 10^{-8})(7.854 \times 10^{11})(0.45)(113)^4$, which gives a power of $P = 3.267 \times 10^{12}$J/s. This is the energy radiated per second. To calculate how much is radiated in a day, we convert seconds to days:

$P = (3.267 \times 10^{12} J/s)(\frac{60s}{min})(\frac{60min}{hr})(\frac{24hr}{day}) = 2.82 \times 10^{17} J/day \approx 2.8 \times 10^{17} J/day.$

P12. (E) To begin, we must reduce this circuit to a single equivalent capacitance. Starting with the two small ones in parallel, the equivalent parallel capacitance is $C_p = 200 + 400 = 600\mu F$. This equivalent capacitance is in series with the other two capacitors, so we can combine all three into a single equivalent capacitance. Capacitors in series add in reciprocal, so $\frac{1}{C_s} = \frac{1}{1600} + \frac{1}{1200} + \frac{1}{600} = 0.003125 \quad \rightarrow \quad C_s = 320\mu F$. Now that we have reduced the circuit to a single equivalent capacitance, we can find the charge stored on this equivalent capacitance: $Q_s = C_s V$

$Q_s = (320)(24) = 7680\mu C$. This same charge is stored on each of the individual capacitances in series, so $Q_{1600} = Q_{1200} = Q_p = 7680\mu C$. So, the voltage across each of the capacitances that are in series is $V_{1600} = \frac{Q_{1600}}{C_{1600}} = \frac{7680}{1600} = 4.80V$; and $V_{1200} = \frac{Q_{1200}}{C_{1200}} = \frac{7680}{1200} = 6.40V$; and $V_p = \frac{Q_p}{C_p} = \frac{7680}{600} = 12.8V$. Between points A and B are two of these capacitances, C_{1200} and C_p; therefore, the total voltage between the points A and B is $V_{AB} = V_{1200} + V_p = 6.40 + 12.8 = 19.2V$.

P13. (A) The easiest way to find the work needed to move the charge is to calculate the difference in electric potential energy between the two locations. This, in turn, reduces to just calculating the difference in electric potential between the two locations due to the fixed charge. Mathematically, $W = \Delta U = q\Delta V = q(V_2 - V_1)$. To calculate the electric potential, we use $V = \frac{kQ}{r}$. Thankfully, this is not a vector, so we don't have to worry about direction. The distances, r_1 and r_2, are measured from the fixed charge to the two locations where we put the moving charge. So, the distances are: $r_1 = \sqrt{(5+4)^2 + (3)^2} = \sqrt{90} = 9.487$cm, and $r_2 = \sqrt{(5)^2 + (3)^2} = \sqrt{34} = 5.831$cm. This gives electric potentials due to the fixed charge of: $V_1 = \frac{(8.99 \times 10^9)(18.0 \times 10^{-6})}{(0.09487)} = 1.706 \times 10^6$ V, and $V_2 = \frac{(8.99 \times 10^9)(18.0 \times 10^{-6})}{(0.05831)} = 2.775 \times 10^6$ V. Now we can calculate the work needed to move the smaller charge: $W = q(V_2 - V_1) = (12.0 \times 10^{-6})(2.775 \times 10^6 - 1.706 \times 10^6) = 12.8$ J.

P14. (B) The voltage induced in the coil is given by Faraday's Law: $V = -\frac{\Delta\Phi_B}{\Delta t}$. Since we don't care about directionality, we can ignore the negative sign. Now, Φ_B is the magnetic flux through the coil. Since the magnetic field is perpendicular to the face of the coil, the flux is simply: $\Phi_B = NBA$. Here, N is the number of turns and B is the magnetic field strength. A, the area of the coil, is $A = \pi r^2 = \pi(12.0cm)^2 = 452.39cm^2 = 0.04524m^2$. Thus, we can now calculate both the initial and final magnetic flux through the coil (after converting the magnetic field into Teslas). Initially, $\Phi_{Bi} = (200)(0.6000T)(0.04524) = 5.43$ Wb, and $\Phi_{Bf} = (200)(0.2500T)(0.04524) = 2.26$ Wb. Finally, the induced voltage is: $|V| = \left|\frac{\Phi_{Bf}-\Phi_{Bi}}{\Delta t}\right| = \left|\frac{2.26-5.43}{0.150}\right| = \frac{3.17}{0.150} = 21.1$V.
Note: the unit of magnetic flux is the Weber (Wb).

P15. (D) The magnitude of the electric field in an electromagnetic wave is related to the intensity of the wave by the equation: $I = \frac{1}{2}c\epsilon_0 E^2$. The intensity itself is the power per unit area, so we should begin with the area of the circular spot: $A = \pi r^2 = \pi\left(\frac{32.0}{2}\right)^2 = \pi(16.0)^2 = 804.2cm^2 = 0.08042m^2$. Thus, the intensity of the light spot is $I = \frac{200W}{0.08042m^2} = 2487$ W/m^2. Now, we can find the electric field magnitude: $2487 = \frac{1}{2}(3.00 \times 10^8)(8.854 \times 10^{-12})E^2 \rightarrow E^2 = 1872446 \rightarrow E = 1370$N/C.

P16. (A) In this problem we can treat the two lenses independently, so we start with finding the image produced by the first lens. Here we can work entirely in centimeters. Using the lens image equation, we get: $\frac{1}{p_1} + \frac{1}{q_1} = \frac{1}{f_1} \rightarrow \frac{1}{80.0} + \frac{1}{q_1} = \frac{1}{50.0} \rightarrow q_1 = 133.3$cm. This is where the image would be formed by the first lens. In two-lens problems, the image from the first lens becomes the object for the second lens. To move over to the second lens, we use the equation: $p_2 = D - q_1$ where D is the separation of the two lenses. This gives: $p_2 = 34.0 - 133.3 = -99.3$cm. The fact that this is negative is fine, it just means that the object for the second lens is located to the right of the second lens. Now, we can use the lens image equation to find the image from the second lens, which is the final image of the feather: $\frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f_2} \rightarrow \frac{1}{-99.3} + \frac{1}{q_2} = \frac{1}{18.0} \rightarrow q_2 = 15.2$cm. Since this result is positive, we know that it is located to the right of the second lens.

P17. (B) Based on the requirement that $\Delta\ell = \pm 1$, we are limited to transitions that are $p \leftrightarrow s$ and $d \leftrightarrow p$. Transitions from $d \leftrightarrow s$ are singly forbidden (which means they rarely happen) and transitions from $s \leftrightarrow s$ are doubly forbidden, which makes them near impossible. Only considering allowed transitions, we have $2p \rightarrow 1s$, $2p \rightarrow 2s$, and $3d \rightarrow 2p$. The energies associated with these three transitions are $E_1 = 2.90 - 0.00 = 2.90eV$, $E_2 = 2.90 - 2.30 = 0.60eV$, and $E_3 = 4.40 - 2.90 = 1.50eV$, respectively. The wavelengths associated with these energies are $\lambda_1 = \frac{1240}{2.90} = 428nm$, $\lambda_2 = \frac{1240}{0.60} = 2070nm$, and $\lambda_3 = \frac{1240}{1.50} = 827nm$. There is one wavelength in our list of answer choices that is not one of these allowed wavelengths – the 590nm wavelength. This wavelength corresponds to the forbidden $3d \rightarrow 2s$ transition, so we would not expect to see it emitted from a group of these atoms.

P18. (C) First, let's consider the mass on each side of the reaction equation. On the left we have a neutron and bismuth: $m_L = 1.008665 + 208.980399 = 209.989064amu$ and on the right side we have thallium and an alpha particle: $m_R = 205.976103 + 4.0026033 = 209.9787063amu$. Thus, the mass difference is $\Delta m = m_L - m_R = 209.989064 - 209.9787063 = 0.0103577amu$. As is often the case in these problems, the difference is very small, so it is important to carry a lot of decimal places up to this point. Now we just need to convert this mass difference into energy to find the energy liberated by this reaction: $E = (0.0103577)(931.5) = 9.648 \approx 9.6$ MeV.

P19. (C) The decreasing tension shown on the plot illustrates the effect of the buoyant force on the system. The force diagram would include the buoyant force (upward), weight (downward) and the tension (upward). Since the system is not accelerating, these forces are in equilibrium. This means that they all sum to zero. Taking upward to be positive, we get: $\sum F = T + F_B - W = 0$. Plugging in the equations for Buoyant force and weight: $T + \rho_{liquid} V_{submerged} g - mg = 0$. Some rearrangement gives the equation of the line shown on the plot: $T = mg - p_{liquid} g V_{submerged}$. Letting f be the volume fraction submerged, and V being the total volume of the cylinder, then we can write the equation as: $T = mg - p_{liquid} g V f$.

From here, there are many ways to determine the density of the cylinder, but the quickest is to observe the point at which the tension reaches zero (the x-intercept). That is the point at which the plastic cylinder is free floating in the water. Based on the graph, that point is when $f \sim 70\%$. Going to our equation: $T = 0 = mg - p_{liquid} g V(0.70)$. Plugging in the known value of the density of water and gravitational acceleration: $0 = (9.8)m - (1000)(9.8)(0.7)V \;\; \rightarrow \;\; (9.8)m = (700)(9.8)V$, This gives the density of the cylinder as: $\frac{m}{V} = \rho = 700$ kg/m^3 ≈ 710kg/m^3.

P20. (B) You should notice immediately that the "Energy position" scale is not calibrated to absolute energy. We may assume, however, that the scale is linear. Looking at the calibration peaks, we can estimate their position: 1.17MeV is at about 3.7, and 1.33MeV is at about 4.9. Thus, the scale can be determined: $scale = \frac{1.33-1.17}{4.9-3.7} = \frac{0.16}{1.2} = 0.133$MeV/position.

Now, the unknown peak is at position 5.8. Utilizing the scale equation again, along with one of the known peaks: $0.133 = \frac{X-1.33}{5.8-4.9} = \frac{X-1.33}{0.9} \;\; \rightarrow \;\; X - 1.33 = 0.12 \;\; \rightarrow \;\; X = 1.45$ MeV. Comparing to the table of isotopes, we can see that this is closest to the ^{40}K energy. Thus, we conclude that the unknown sample consists of potassium-40.