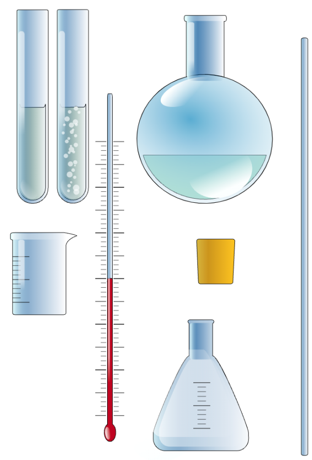
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational B • 2024



GENERAL DIRECTIONS:

- **DO NOT OPEN EXAM UNTIL TOLD TO DO SO.**
- Contestants may take up to two hours to complete the contest. If you are in the process of actually writing an answer when the signal to stop is given, you may finish writing that answer.
- Papers may not be turned in until 30 minutes have elapsed. If you finish the test in less than 30 minutes, remain at your seat and retain your paper until told to do otherwise. You may use this time to check your answers.
- All answers must be written on the answer sheet provided. Indicate your answers in the appropriate blanks provided on the answer sheet. Write clearly and legibly!
- You may place as many notations as you desire anywhere on the test paper but not on the answer sheet, which is reserved for answers only.
- You may use additional scratch paper provided by the contest director.
- All questions have ONE and only ONE correct (BEST) answer. There is a penalty for all incorrect answers.
- If a question is omitted, no points are given or subtracted.
- The back two pages of this test include a copy of the periodic table of the elements, as well as listings of other scientific relationships. You may use this information during the contest and may detach the back page from the test if you wish.
- A simple scientific calculator is sufficient for the high school Science contest. **The UIL provides a list of approved calculators that meet the criteria for use in the Science contest. No other calculators are permitted during the contest.** The Science Contest Approved Calculator List is available in the current Science Contest Handbook and on the UIL website. Contest directors will perform a brief visual inspection to confirm that all contestants are using only approved calculators. Each contestant may use up to two approved calculators during the contest.

B01. Which of the following statements is not true about biological membranes?
A) The hydrogenation of fatty acids influences the fluidity.
B) The hydrophilic heads of phospholipids are always on the outside of the membrane with the fatty acid tails pointing inward.
C) Cholesterol embedded within the membranes helps control fluidity.
D) Having only single covalent bonds between the carbons of the fatty acid tails makes the membrane more fluid.
E) Plasma membrane, nuclear membrane, and mitochondrial membranes are all examples of biological membranes.

B02. A single base change that results in a conversion of the amino acid from phenylalanine to histidine is called a
A) nonsense mutation.
B) silent mutation.
C) coding mutation.
D) frameshift mutation.
E) missense mutation.

B03. Signaling through the use of hormones occurs via the ________ system.
A) integumentary
B) nervous
C) endocrine
D) digestive
E) respiratory

B04. During chemiosmosis of aerobic respiration, which molecule is moving across the membrane, thus releasing energy to generate ATP?
A) oxygen
B) ATP
C) potassium
D) hydrogen ions
E) carbon dioxide

B05. Which of the following is mismatched with its transport mechanism?
A) Channel proteins moving substances from high to low concentration = facilitated diffusion
B) Movement of lipid-soluble molecules from high to low concentration directly through the membrane = active transport.
C) ATP hydrolysis while moving a sugar from low to high concentration through a transport protein = active transport.
D) Movement of substances across the membrane from high to low without a transporter = simple diffusion
E) Osmosis of water = passive transport

B06. Assuming Hardy-Weinberg equilibrium, a population has 43% who are homozygous dominant. What is the frequency of the recessive allele?
A) 0.119
B) 0.344
C) 0.451
D) 0.570
E) 0.656

B07. The enzyme that replicates a majority of the nucleic acid during DNA replication is
A) DNA polymerase I
B) Helicase
C) DNA polymerase III
D) Primase
E) RNA polymerase III

B08. Which of the following would be the best technique, relative to the other choices, to precisely edit the base of a known DNA sequence?
A) CRISPR/Cas9
B) Western blot
C) Northern blot
D) Southern blot
E) Transduction

B09. The mechanism of evolution that states organisms that are more adapted to their environment are more likely to be successful and pass on the genes to their offspring is called
A) natural selection.
B) speciation.
C) gene flow.
D) adaptation.
E) Lamarckism.

B10. An excess of calcium in the blood is called
A) hyperproteinemia.
B) hyperkalemia.
C) hypercalcemia.
D) hypernatremia.
E) metabolic alkalosis.

B11. Which of the following is not an example of microevolution?
A) Bacteria developing antibiotic resistance.
B) Mosquitos developing resistance to a pesticide, such as DDT.
C) Viruses becoming resistance to antiviral medications.
D) The emergence of two different species after geographic isolation.
E) None of the above are examples of microevolution.

B12. Yeast are single-celled organisms that belong to Domain
A) Prokarya.
B) Archaea.
C) Bacteria.
D) Fungi.
E) Eukarya.

B13. Mammals all belong to the same
A) class.
B) order.
C) family.
D) genus.
E) species.

B14. In November 2023, the Centers for Disease Control and Prevention issued alerts for several food items due to possible contamination with *Salmonella*. Which of the following was not part of the alerts?
A) fresh diced onions
B) dry dog food
C) cantaloupe
D) peaches
E) oysters

B15. All of the following are *Enterobacteriaceae* except
A) *Klebsiella pneumoniae*.
B) *Pseudomonas aeruginosa*.
C) *Shigella dysenteriae*.
D) *Escherichia coli*.
E) *Salmonella enterica*.

B16. Which of the following blood types is not a possibility from the following genetic cross?

$I^Ai \times I^AI^B$

A) A
B) B
C) AB
D) O
E) All of the above are possibilities.

B17. Examine the chromosome structures below. Which event occurred in the mutation? Note: the "*" represents the centromere.

Normal: ABCD*EFGHI
Mutant: ADCB*EFGHI

A) inversion
B) translocation
C) deletion
D) duplication
E) reciprocal translocation

B18. In the sulfur cycle, sulfates (SO_4^{2-}) are reduced to hydrogen sulfide through
A) aerobic respiration.
B) microbial anaerobic respiration.
C) assimilation.
D) fermentation.
E) microbial oxidation reactions.

B19. Rubisco
A) is an enzyme involved in DNA replication.
B) converts a DNA sequence into RNA.
C) releases carbon dioxide during the Krebs cycle.
D) is a component of reaction centers in the light-harvesting reactions of photosynthesis.
E) catalyzes carbon dioxide fixation in photosynthesis.

B20. Proteins that hold sister chromatids together until the right moment of separation during mitosis are called
A) shugoshin.
B) histones.
C) cohesins.
D) kinetochores.
E) adhesins.

C01. If 4.00×10^{23} atoms of helium are added to a latex balloon, what is the mass of the helium inside the balloon?

A) 0.266 grams
B) 0.900 grams
C) 1.13 grams
D) 2.66 grams
E) 4.22 grams

C02. For the reaction

$$Mg(s) + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

which of the following statements is true at STP?

A) 2 moles of HCl produce 1 L of H_2 gas
B) 1 gram of Mg produces 1 gram of H_2 gas
C) 2 L of HCl produces 1 mole of H_2 gas
D) 24.31 grams of Mg produces 1 gram of H_2 gas
E) 24.31 grams of Mg produces 22.4 L of H_2 gas

C03. When barium forms the ionic compound $BaCl_2$, how many electrons are in the barium ion?

A) 34 B) 54 C) 56 D) 58 E) 137

C04. Which pair of elements below is most likely to form a covalent bond?

A) magnesium and fluorine
B) carbon and hydrogen
C) copper and iron
D) aluminum and chlorine
E) None of these combinations would form a covalent bond

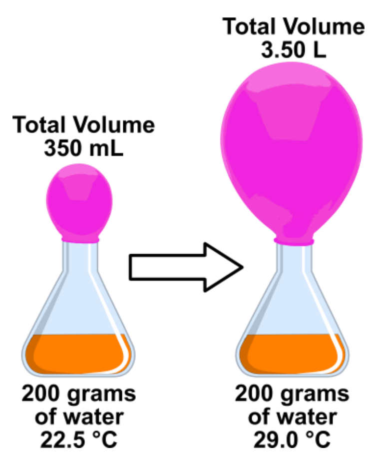
C05. A sample of gas in a rigid container has a pressure of 2.0 atm and is heated from 50°C to 100°C. Which of these describes the new pressure?

A) The new pressure would be 4.0 atm.
B) The new pressure would be 1.0 atm.
C) The new pressure would be more than 2.0 atm but less than 4.0 atm.
D) The new pressure would be less than 2.0 atm but more than 1.0 atm.
E) The pressure would be unchanged.

C06. Which of these liquids would have the highest boiling point?

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

C07. A chemical reaction was carried out in an aqueous solution at 1 atm pressure in a balloon-covered flask and the following changes were observed.



How much heat was given off (–) or absorbed (+) by this reaction?

A) –5439 J
B) +5439 J
C) –1300 J
D) +1300 J
E) +4184 J

C08. What would the boiling point of the solution be if you dissolved 20.0 grams of NaCl in 250 grams of water?

A) 100.7 °C
B) 101.4 °C
C) 102.2 °C
D) 104.5 °C
E) 105.1 °C

C09. Zn^{2+} reacts with aqueous ammonia to form the tetraamminezinc(II) ion, $Zn(NH_3)_4^{2+}$ What is the equilibrium expression for the formation of this complex ion?

A) $K_f = \frac{[Zn^{2+}][NH_3]^4}{[Zn(NH_3)_4{}^{2+}]}$

B) $K_f = \frac{[Zn(NH_3)_4{}^{2+}]}{[Zn^{2+}][NH_3]^4}$

C) $K_f = \frac{[Zn(NH_3)_4{}^{2+}]}{[Zn^{2+}]}$

D) $K_f = \frac{[Zn(NH_3)_4{}^{2+}]}{[Zn^{2+}]4[NH_3]}$

E) $K_f = \frac{[Zn^{2+}]4[NH_3]}{[Zn(NH_3)_4{}^{2+}]}$

C10. What is the pH of an 8.95×10^{-6} M solution of NaOH?

A) 5.05
B) 6.33
C) 7.09
D) 8.21
E) 8.95

C11. The K_{sp} for $Ni(OH)_2$ is 2.8×10^{-16}. What is the concentration of OH^- ions in a saturated solution of $Ni(OH)_2$?

A) 4.1×10^{-6} M
B) 2.4×10^{-8} M
C) 3.2×10^{-5} M
D) 1.3×10^{-5} M
E) 8.2×10^{-6} M

C12. In which of these chemical reactions is hydrogen being reduced?

A) $H_2(g) + 2O_2(g) \rightarrow 2H_2O(g)$
B) $2HCl(aq) + Zn(s) \rightarrow H_2(g) + ZnCl_2(aq)$
C) $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(\ell)$
D) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(\ell)$
E) $2H_2(g) + C(s, graphite) \rightarrow CH_4(g)$

C13. The rate law for an aqueous reaction that is first order in A and B and second order overall is rate = k[A][B]. What are the units on the rate law constant k?

A) M/s
B) M·s
C) s/M
D) $M^{-1} \cdot s^{-1}$
E) s/M^2

C14. A 100 gram sample of KBr contains

A) equal masses of potassium and bromine
B) 39.1 grams of potassium and 79.9 grams of bromine
C) more than twice as many grams of bromine as potassium
D) more than twice as many grams of potassium as bromine
E) More than one of the above answer choices is correct

C15. Which of these forms of electromagnetic radiation has the longest wavelength?

A) Microwaves
B) Infrared
C) Visible light
D) Gamma radiation
E) Ultraviolet light

C16. What is the mass density of a sample of fluorine gas at STP?

A) 1.70 g/L
B) 0.85 g/L
C) 0.045 g/L
D) 1.00 g/L
E) 1.35 g/L

C17. The homework assignment said to write a valid set of quantum numbers for the outermost electron in a nitrogen atom. Your friend turned in his answer and got zero credit, but he doesn't know why. What is wrong with his answer, shown here:

Possible quantum numbers
for the outermost electron
in a nitrogen atom:
$n = 2,\ \ell = 2,\ m_\ell = 0,\ m_s = -½$

A) Nitrogen has three electrons in the outermost subshell, so $n = 3$.
B) m_ℓ can be positive or negative but cannot be 0
C) m_s has to have the same sign as m_ℓ, and since his $m_\ell = 0$, m_s must also be 0.
D) Since $\ell = 2$, n must be at least 3 because $\ell = 0, 1, 2, \ldots, n - 1$
E) $n = 2$ and $\ell = 2$ would be the 2*d* subshell and there is no 2*d* subshell

C18. Which of these properties of a gas molecule contributes most to the gas behaving non-ideally?

A) The number of different elements that make up the gas molecule
B) The number of hydrogen atoms that are found in the gas molecule
C) The molar mass of the gas molecule
D) The polarity of the gas molecule
E) The geometrical shape of the gas molecule

C19. A student dissolves 7.50 grams of NaCl in a beaker containing 100 mL of water and dissolves 30.0 grams of $AgNO_3$ in a different beaker containing 300 mL of water, and then combines the two solutions. The following precipitation reaction occurs:

$$NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

The student then isolates and dries the solid product. If the yield is 100%, what is the mass of the solid product?

A) 7.50
B) 15.0
C) 18.4
D) 12.7
E) 10.9

C20. How is the actual yield in a chemical reaction calculated?

A) From the moles of the limiting reactant in the reaction.
B) From the moles of the excess reactant in the reaction.
C) From the moles of the excess reactant remaining after the reaction is over.
D) From the total number of moles of reactants used in the reaction.
E) Actual yield is measured experimentally and cannot be calculated from the moles of reactants used.

Chemistry

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

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

<u>Water Data</u>

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

<u>Constants</u>

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

<u>Conversion factors</u>

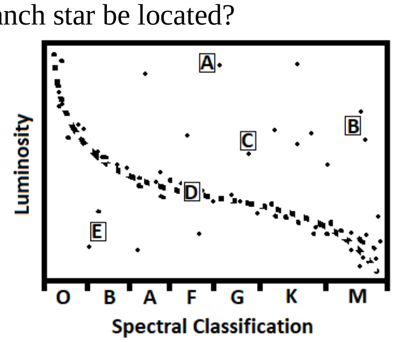
1 L·atm = 101.325 J

P01. According to Guillen, Jakob and Johann Bernoulli struggled with a paper in which Leibniz described the mathematics of calculus. Jakob eventually understood the paper, which hinged on a new idea called…
A) the derivative
B) the Riemann sum
C) the limit
D) the differential
E) the infinitesimal

P02. According to Guillen, Johann Bernoulli began working on an idea regarding a substance possessed by objects that were to some degree animated. He called this substance *vis viva*. Today we know it as …
A) force
B) velocity
C) momentum
D) energy
E) heat

P03. According to Guillen, Nikolai Zhukovsky utilized Daniel Bernoulli's fluid-flow equation to explain how …
A) windmills pump water.
B) airplanes fly.
C) ocean current flow.
D) storm cells form.
E) buoyancy works.

P04. Consider a star similar in mass to our Sun. Towards the end of its life, as the star evolves beyond its red giant phase, it will move across the Hertzsprung-Russell diagram along what is called the 'horizontal branch.' It is along the horizontal branch that many variable stars, such as RR Lyrae stars, exist. Approximately where on the Hertzsprung-Russell diagram would a horizontal branch star be located?
A) point A
B) point B
C) point C
D) point D
E) point E



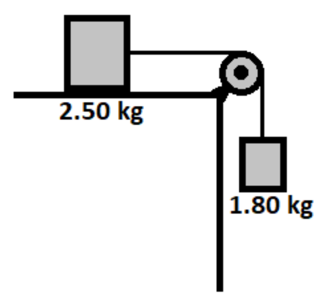
P05. Which result for the following calculation has the correct number of significant figures?

$$x = \frac{13.3 - 9.55}{56.1}$$

A) 0.1
B) 0.07
C) 0.067
D) 0.0668
E) 0.06684

P06. A dog toy is thrown straight up with an initial velocity of 9.65m/s. The toy hits the ceiling, which is located 3.35m above where the toy was thrown. How fast is the toy moving when it hits the ceiling?
A) 5.24 m/s
B) 6.30 m/s
C) 7.76 m/s
D) 8.53 m/s
E) 9.29 m/s

P07. A 1.80kg box is attached to a rope that passes over a pulley and connects to a 2.50kg crate (as shown). The crate is sitting on a frictionless horizontal tabletop, and the pulley is also massless and frictionless. Once released, the box and crate are free to move. What, then, is the acceleration of the two objects?
A) 2.74 m/s^2
B) 3.81 m/s^2
C) 4.10 m/s^2
D) 5.70 m/s^2
E) 7.06 m/s^2



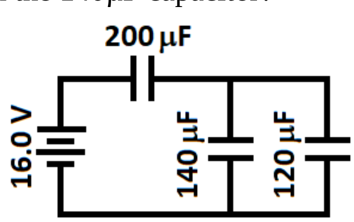
P08. A nail with a mass of 32.0g passes clean through a block of wood. The nail is initially moving at 80.0m/s. After passing through the block of wood, the nail has slowed to 43.0m/s. The block of wood is initially at rest and has a mass of 215g. What is the speed of the block of wood immediately after the nail passes through it?
A) 18.3 m/s
B) 11.9 m/s
C) 6.40 m/s
D) 5.51 m/s
E) 1.16 m/s

P09. A horizontal merry-go-round has a moment of inertia of 8.60kgm^2 and an initial angular velocity of 36.0rad/s. A tree root that is pressed up against the merry-go-round, exerts a torque on the merry-go-round that causes it to slow to a stop after 4.00 complete revolutions. What is the magnitude of the torque exerted by the tree root?
A) 151 Nm
B) 222 Nm
C) 310 Nm
D) 443 Nm
E) 887 Nm

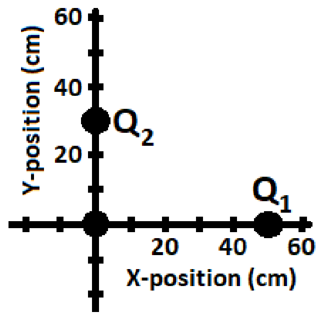
P10. A steel cable is used to hold up a suspension bridge. The cable has a diameter of 18.0cm and is 450.0m in length. During a windstorm, the cable is subjected to an additional pulling force of 8600.0N. By how much does the cable stretch due to the force of the windstorm? Young's modulus for steel is 2.0×10^{11} Pa.
A) 2.3 mm
B) 0.76 mm
C) 0.60 mm
D) 0.38 mm
E) 0.19 mm

P11. A diatomic ideal gas starts at a pressure of 125kPa and a volume of 0.355 liters. The gas expands adiabatically to a volume of 0.610 liters. What is the pressure of the gas after the expansion? Note: The heat capacity ratio for a diatomic ideal gas is 1.40.
A) 102 kPa
B) 84.9 kPa
C) 72.7 kPa
D) 58.6 kPa
E) 44.4 kPa

P12. For the capacitor circuit shown, determine the charge stored on the 140μF capacitor?
A) 2790 μC
B) 2240 μC
C) 1810 μC
D) 1270 μC
E) 974 μC



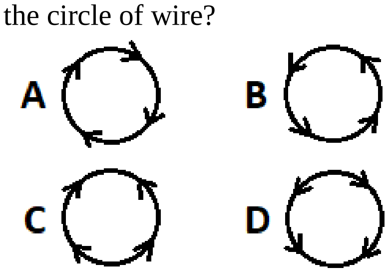
P13. Two charges are placed on a coordinate grid as shown. The first charge, $Q_1 = +25.0\mu C$, is located at (50.0cm, 0.0) and the second charge, $Q_2 = -12.0\mu C$, is located at (0.0, 30.0cm). What is the total electric potential, V, at the origin (0.0, 0.0) due to the two charges?



A) 89.9 kV
B) 576 kV
C) 809 kV
D) 1.50 MV
E) 2.10 MV

P14. A charged particle with a velocity of 2.40×10^5m/s enters an area in which there is a magnetic field. The magnetic field has a strength of 3.60mT and is oriented perpendicular to the velocity of the particle. The particle has the same charge as a proton, and in the field region it traces out a circular path with a diameter of 246.0cm. What is the mass of the particle as compared to the mass of a proton?
A) 1.77 m_p
B) 2.96 m_p
C) 4.43 m_p
D) 5.91 m_p
E) 7.09 m_p

P15. A circle of wire is placed horizontally on a table. A bar magnet is held vertically above the circle, with the North pole of the magnet pointed downward. The magnet is quickly pulled directly upwards, away from the circle of wire. In which direction, as seen from above, does the induced current flow in the circle of wire?



E) There is no current induced in the wire.

P16. A quarter lies at the bottom of a pond, 45.0cm below the water's surface. How far under the surface does the quarter *appear* to be located (in other words: where is the image of the quarter located)? The water's surface is flat and smooth; the index of refraction of water is 1.33.

A) 19.1cm below the surface
B) 25.4cm below the surface
C) 33.8cm below the surface
D) 45.0cm below the surface
E) 59.9cm below the surface

P17. An electron has a velocity of 6.25×10^6 m/s. What is the de Broglie wavelength of this electron?

A) 0.0185 nm
B) 0.0370 nm
C) 0.0720 nm
D) 0.106 nm
E) 0.116 nm

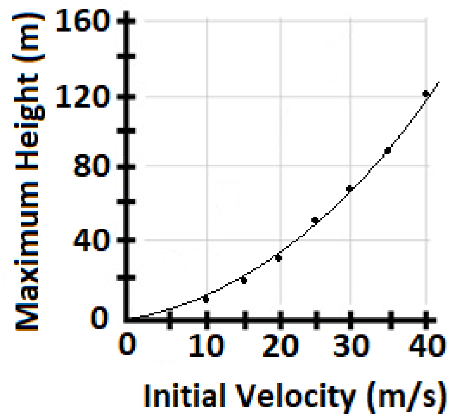
P18. An atom of ${}^{266}_{102}No$ undergoes the following radioactive decays:

$$\alpha\ ,\ \beta^-,\ \alpha\ ,\ \alpha\ ,\ \beta^-,\ \alpha\ ,\ \alpha,\ \gamma.$$

What is the daughter isotope resulting from this series of radioactive emissions?

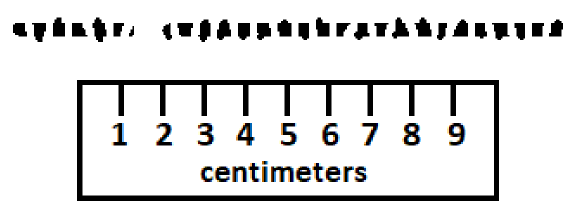
A) ${}^{245}_{93}Np$
B) ${}^{246}_{93}Np$
C) ${}^{245}_{94}Pu$
D) ${}^{246}_{94}Pu$
E) ${}^{246}_{95}Am$

P19. You are on an alien planet doing a physics experiment. In the experiment, a ball is launched directly upward, and the maximum height reached by the ball is measured as a function of the launch velocity. The data are plotted below. What is the acceleration due to gravity on the alien planet?



A) 3.2 m/s^2
B) 6.6 m/s^2
C) 9.8 m/s^2
D) 13 m/s^2
E) 17 m/s^2

P20. You direct a Helium-Neon laser with a wavelength of 633nm onto a double slit apparatus, producing an interference pattern on a screen that is located 2.40m from the double slit. The pattern that you observe is shown below, along with a ruler for scale. Based on the results, what is the separation distance of the two slits in the double slit apparatus?



A) 3.19 mm
B) 1.28 mm
C) 0.64 mm
D) 0.32 mm
E) 0.16 mm

Physics

Useful Constants

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

DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!

UIL HIGH SCHOOL SCIENCE CONTEST
ANSWER KEY
2024 INVITATIONAL B

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL B 2024

C01. (D) 4.00×10^{23} atoms / 6.02×10^{23} atoms/mol = 0.66445 mol × 4.00 g/mol = 2.66 grams

C02. (E) One mole of Mg produces one mole of H_2 gas. One mole of Mg is 24.31 grams, and 1 mole of any gas at STP takes up 22.4 L.

C03. (B) The barium in $BaCl_2$ is Ba^{2+}, so it is missing two electrons from its neutral count of 56, leaving it with 54 electrons.

C04. (B) Covalent bonds are typically formed between two nonmetals.

C05. (C) Doubling the temperature in Kelvins would double the pressure, but the temperature change in this case is not doubled in Kelvins, it goes from 323 K to 373 K, an increase of 15.5%. The pressure would therefore increase by 15.5%, from 2.0 atm to 2.31 atm. $P_2/P_1 = T_2/T_1$

C06. (E) CH_4 is non-polar and has only dispersion forces, compounds B-D all have dipole-dipole forces in addition to dispersion forces, and methanol (CH_3OH) has hydrogen bonding as well.

C07. (A) The heat absorbed by the water = $q = mc\Delta T$ = (200)(4.184)(6.5) = 5439 J, so that much heat was given off by the reaction.

C08. (B) 20.0 g / 58.44 g/mol = 0.3422 mol. 0.3422 mol/0.25 kg H_2O = 1.369 molal.
$\Delta T = ik_bm = 2 \times 0.512 \times 1.369 = 1.40$°C. $T_{bp} = 100 + 1.40 = 101.4$°C

C09. (B) The chemical reaction is $\mathrm{Zn^{2+}}(aq) + 4\ \mathrm{NH_3}(aq) \rightarrow \mathrm{Zn(NH_3)_4}^{2+}(aq)$, so the equilibrium constant is products over reactants, each raised to their stoichiometric coefficients.

C10. (E) pOH = –log[OH^-] = –log (8.95×10^{-6}) = 5.05. pH = 14 – pOH = 14 – 5.05 = 8.95

C11. (E) $K_{sp} = [Ni^{2+}][OH^-]^2 = [x][2x]^2 = 4x^3$. $x = (2.8 \times 10^{-16}/4)^{1/3} = 4.13 \times 10^{-6}$ $[OH^-] = 2x = 8.3 \times 10^{-6}$.

C12. (B) Hydrogen is being oxidized in A and E, is neither oxidized nor reduced in C and D, and is reduced in B.

C13. (D) Reaction rate is in M/s, so if M/s = $k \times M^2$, the units on k must be $M^{-1}\cdot s^{-1}$

C14. (C) The percent composition of KBr is: Potassium (39.10/(39.10 + 79.90) × 100 = 32.9% potassium and 67.1% bromine, so in a 100 gram sample there would be about 33 grams of K and 67 grams of Br, or just over twice as many grams of bromine as potassium.

C15. (A) The mnemonic *Raging Martians Invaded Venus Using X-Ray Guns* lists the regions of the electromagnetic spectrum from lowest energy (longest wavelength) to highest energy (shortest wavelength): radio, microwave. Infrared, visible, ultraviolet, x-ray, gamma. Of the answer choices, microwaves are the lowest energy and therefore the longest wavelength.

C16. (A) $PV = nRT$ so $PV = (g/MM)RT$. Therefore mass density = g/L = $P\times MM/RT$ = 1 × 38.00/22.4 = 1.70 g/L. Alternatively you could assume one mole of gas at STP, in which case you would have 38 grams in 22.4 liters, which is the same math and comes out to 1.70 g/L.

C17. (E)

C18. (D) Ideal gases have no intermolecular attractions between the molecules and a more polar molecule will have stronger IMF's, which increases the van der Waals *a* constant and leads to non-ideal behavior.

C19. (C) The volumes of the solutions do not matter here, only the moles of each reactant. Moles of NaOH = 7.5 g/58.44 g/mol = 0.1283 moles. Moles of $AgNO_3$ = 30.0 g/169.88 g/mol = 0.1766 moles. NaOH is limiting, producing 0.1283 moles of AgOH × 143.32 g/mol = 18.4 grams.

C20. (E) Actual yield is measured, not calculated. Theoretical yield is calculated from the moles of the limiting reactant.

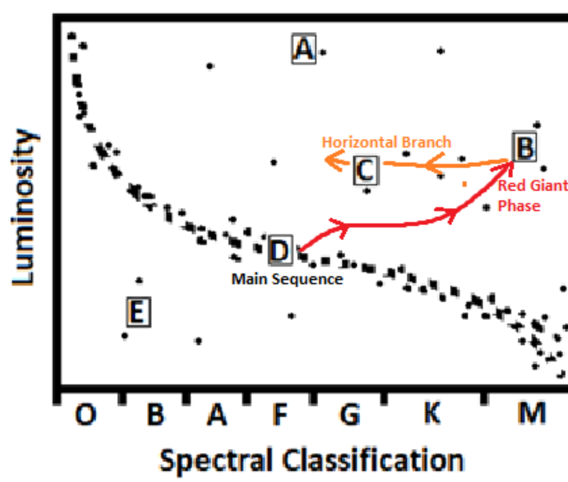
PHYSICS SOLUTIONS – UIL INVITATIONAL B 2024

P01. (E) page 72: "The Bernoulli brothers, too, were unable to make much sense of Leibniz's paper, despite their dogged efforts to do so…. Undiscouraged, they persevered, until one day, as if by some miracle, Jakob suddenly understood everything…. It all hinged on something called the 'infinitesimal,' Jakob explained,"

P02. (D) pages 79-80: "…like his illustrious friend Leibniz, the elder Bernoulli called it *vis viva*… because it appeared to be something possessed by objects that were to some degree animated…. It was as if an object's *vis viva* could never be destroyed… they called it the 'Law of *Vis Viva* Conservation' (Late in the next century, scientists would call it the 'Law of Energy Conservation'"

P03. (B) pages 115-116: "Now, two years after the Wright brothers' stunning achievement, forty-four-year-old Zhukovsky himself was about to fly straight into the history books. Airplanes were able to fly, he announced in 1905, because of Bernoulli's fluid-flow equation."

P04. (C) A star similar in mass to our Sun will become a red giant after running out of hydrogen in its core. The red giant phase is located near the point B on the HR-diagram. When helium fusion initiates, the changes in the star push it along the horizontal branch, so named because the star evolves along a near-horizontal line on the HR-diagram (as shown). Thus, near the point C on the HR diagram is where you would find the horizontal branch stars.



P05. (C) Following proper order of operation, the subtraction in the numerator would be completed first. During addition or subtraction, it is the quantity with the least significant place that determines the significant place of the result. In our case, the quantity 13.3 is significant to the tenths place, while 9.55 is significant to the hundredths place. The least significant place of these two is the tenths place, so the result will only be significant to the tenths place. That is $13.3 - 9.55 = 3.7[5]$ is only significant to the tenths place. Thus, the result has two significant digits.
Now we consider the division. During multiplication or division, it is the quantity with the least number of significant digits that determines the significant digits of the result. In our case, 3.7[5] has two significant digits, and 56.1 has three significant digits. Thus, the result (and the final answer) will only have two significant digits: $\frac{3.7[5]}{56.1} = 0.066[8449198] \approx 0.067$.

P06. (A) This is a free fall situation, even though the toy is travelling upward throughout the problem. We aren't given the time between throwing the toy and hitting the ceiling, so we should use the kinematic equation that doesn't involve time: $v_f^2 = v_i^2 + 2a(y_f - y_i) = (9.65)^2 + 2(-9.80)(3.35 - 0)$. This gives $v_f^2 = 27.46 \;\rightarrow\; v_f = 5.24\text{m/s}$, which is the speed of the toy when it hits the ceiling.

P07. (C) We begin with a free-body force diagram for each box. For the dangling box, there are two forces: gravity ($m_1 g$, pointed downward) and tension (T, pointed upward). For the box on the table, there are three forces: gravity ($m_2 g$, pointed downward), the normal force (F_N, pointed upward), and tension (T, pointed to the right). The magnitude of the acceleration for both boxes will be the same, but for the dangling box the acceleration is downward, and for the box on the table the acceleration is to the right. Now we use Newton's second law for each of the boxes. For the dangling box, we sum up the vertical forces: $\sum F_y = T - m_1 g = m_1(-a) = -m_1 a$. Here the acceleration is negative since the acceleration is directed downward, and we are taking "up" to be positive. For the box on the table, we sum the horizontal forces (of which there is only one). Taking "to the right" to be positive: $\sum F_x = T = m_2 a$. Plugging in the values for the masses and g, we get $T - (1.80)(9.80) = -1.80a$, and $T = 2.50a$. This simplifies to $T - 17.64 = -1.80a = 2.50a - 17.64 \rightarrow 17.64 = 4.30a \rightarrow a = 4.10\text{m/s}^2$.

P08. (D) Since this situation involves a collision, we will use conservation of momentum to solve it. Initially, the block is stationary and only the nail is moving. The initial momentum is $p_i = m_n v_{ni} + m_b v_{bi} \rightarrow$ $p_i = (0.032kg)(80.0m/s) + (0.215kg)(0.0m/s) = 2.56$kgm/s. After the collision, both the nail and the block are moving. Thus, the final momentum is $p_f = m_n v_{nf} + m_b v_{bf} \rightarrow$ $p_f = (0.032kg)(43.0m/s) + (0.215kg)v_{bf} = 1.376 + 0.215v_{bf}$. By conservation of momentum, the initial and final momentum must be the same. That is $p_f = p_i \rightarrow 1.376 + 0.215v_{bf} = 2.56$. This leads to $0.215v_{bf} = 1.184 \rightarrow v_{bf} = 5.51$m/s.

P09. (B) First, let's consider the magnitude of the angular acceleration of the merry-go-round. The initial angular velocity is given, and the final angular velocity is zero. The angular distance through which the merry-go-round travels while stopping is $\Delta\theta = 4.00rev * 2\pi = 25.13$rad. Now we use the following angular motion kinematic equation: $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta \rightarrow 0 = (36.0)^2 + 2\alpha(25.13)$. This gives an angular acceleration of $\alpha = -25.8$ rad/s^2. The negative sign confirms that it is slowing down, but only the magnitude, $|\alpha| = 25.8$ rad/s^2, is needed in the next calculation. The total torque acting on the merry-go-round is related to the magnitude of the angular acceleration by $\tau = I\alpha$ where I is the moment of inertia. Thus, $|\tau| = I|\alpha| = (8.60)(25.8) = 222$Nm.

P10. (B) The relationship between the force on the cable and the change in length of the cable is given by the equation $\frac{F}{A} = Y\frac{\Delta L}{L_0}$. We know the force ($F = 8600N$), Young's modulus ($Y = 2.0 \times 10^{11}Pa$), and the original length of the cable ($L_0 = 450.0m$). We need the cross-sectional area of the cable. Since the cross section is a circle, we can find the area by $A = \pi r^2$. The diameter is 18.0cm, so the radius of the cable is 9.00cm, giving a cross-sectional area of $A = \pi(0.0900m)^2 = 0.0254$m^2. Putting it all together, we get $\frac{8600.0N}{0.0254m^2} = (2.0 \times 10^{11}Pa)\frac{\Delta L}{450.0m} \rightarrow 338580 = (4.44 \times 10^8)\Delta L$. This gives a change in length (a stretch) of $\Delta L = 7.6 \times 10^{-4}m = 0.76mm$.

P11. (D) For an adiabatic process, we have a modified form of Boyle's Law: $P_1 V_1^\gamma = P_2 V_2^\gamma$ where the exponent γ is the heat capacity ratio, a value which is given in the problem. Conveniently, we don't need to change any of the units, we just insert the given values and calculate the final pressure: $(125kPa)(0.355L)^{1.40} = P_2(0.610L)^{1.40} \rightarrow 29.32 = 0.501P_2 \rightarrow P_2 = 58.6$kPa.

P12. (E) First, we must combine the individual capacitances into a single equivalent capacitance. We begin by combining the two capacitors that are in parallel; recalling that capacitors in parallel add to get the equivalent capacitance we get: $C_p = C_1 + C_2 = 120\mu F + 140\mu F = 260\mu F$. Now, we combine this equivalent capacitance with the third capacitor. These are in series, and capacitances in series add in reciprocal: $\frac{1}{C_T} = \frac{1}{C_p} + \frac{1}{C_3}$. This gives us: $\frac{1}{C_T} = \frac{1}{260\mu F} + \frac{1}{200\mu F} \rightarrow C_T = 113\mu F$. This is the total equivalent capacitance of the circuit. Using this total capacitance, and the voltage provided by the battery, we can find the total charge associated with the circuit: $Q_T = C_T V_T = (113\mu F)(16.0V) = 1808\mu C$. At this point, we work back through the circuit. Capacitances in series will have the same charge as their combined capacitance. In other words, the charge on the series capacitances C_p and C_3 will be $Q_p = Q_3 = Q_T = 1808\mu C$. From this, we can determine the voltage across the parallel group of capacitors: $V_p = \frac{Q_p}{C_p} = \frac{1808\mu C}{260\mu F} = 6.95V$. For capacitors in parallel, they will all have the same voltage. That is, $V_1 = V_2 = V_p = 6.95V$. Finally, we can calculate the charge stored on the $140\mu F$capacitor: $Q_2 = C_2 V_2 = (140\mu F)(6.95V) = 974\mu C$.

P13. (A) In this kind of problem, the electric potential can be calculated using the equation $V = \frac{kQ}{r}$ where Q is the charge, k is the Coulomb constant, and r is the distance from the charge to the point of interest (in this case, the origin). Fortunately, electric potential is a scalar, so we calculate the electric potential due to each charge individually and add them to get the total. The electric potential due to the first charge is $V_1 = \frac{kQ_1}{r_1} = \frac{(8.99\times 10^9 Vm/C)(25.0\times 10^{-6}C)}{(0.50m)} = 449{,}500\ V$. Similarly, the electric potential due to the second charge is $V_2 = \frac{kQ_2}{r_2} = \frac{(8.99\times 10^9 Vm/C)(-12.0\times 10^{-6}C)}{(0.30m)} = -359{,}600\ V$. This potential is negative since the second charge is negative. To get the total electric potential, we add the potentials from each individual charge: $V = (449{,}500) + (-359{,}600) = 89{,}900\ V = 89.9\ kV$.

P14. (A) The radius of the circle traced out by a charged particle in a magnetic field is given by the equation $r = \frac{mv}{QB}$. The velocity, v, of the particle is given, as is the strength of the magnetic field, B. The charge of the particle is the same as that of a proton: $Q = 1.602\times 10^{-19}C$. And the radius is half of the diameter: $r = \frac{D}{2} = \frac{246}{2} = 123cm = 1.23m$. Putting it all together, we get $(1.23m) = \frac{m(2.40\times 10^5 m/s)}{(1.602\times 10^{-19}C)(3.60\times 10^{-3}T)} \rightarrow$ $1.23 = (4.161\times 10^{26})m \rightarrow m = 2.96\times 10^{-27}kg$. The mass of a proton is $m_p = 1.67\times 10^{-27}kg$, so the mass of the particle as compared to a proton is the ratio $\frac{m}{m_p} = \frac{2.96\times10^{-27}kg}{1.67\times10^{-27}kg} = 1.77 \rightarrow m = 1.77m_p$.

P15. (A) Since the north end of the magnet is pointed downward, the magnetic field passing through the loop is also pointed downward (the magnetic field points away from the North end of a magnet). When the magnet is pulled away, the strength of the field decreases. This will induce a current in the loop. The induced current will oppose the change – in this case it will try to strengthen the field that is decreasing. That is, the induced current will be oriented so as to produce a downward pointed magnetic field. We now use the right-hand rule: Pointing your thumb in the direction of the induced field (downward), the curl of your fingers shows the direction of the induced current. In this case, that curl of the fingers (as seen from above) is clockwise around the loop – thus, the correct answer is A.

P16. (C) The surface of the water functions as a refracting surface, and the equation for an image formed by a refracting surface is $\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$. Since the surface is flat and smooth, it has an effective radius of curvature of infinity, and the object distance is given as $p = 45.0$cm. The object (the quarter) is down in the water, so the first index of refraction is that of the water. The second index of refraction, where the observer is located, is that of the air. Thus, $n_1 = 1.33$ and $n_2 = 1.00$. Putting the values that we know into the equation: $\frac{1.33}{45.0} + \frac{1.00}{q} = \frac{1.00-1.33}{\infty}$. This gives $\frac{1.33}{45.0} + \frac{1}{q} = 0 \rightarrow \frac{1}{q} = -0.02956 \rightarrow q = -33.8$cm. The negative sign tells us that the image is located below the surface. Thus, we conclude that the image of the quarter is located 33.8cm below the surface.

P17. (E) We begin by finding the momentum of the electron. Its velocity is much less than the speed of light, so we can use a classical formula for finding the momentum: $p = mv = (9.11\times 10^{-31}kg)(6.25\times 10^6 m/s) = 5.69\times 10^{-24}kgm/s$. Now we use de Broglie's formula for the wavelength of a particle: $\lambda = \frac{h}{p}$, where h is Planck's constant.

This gives $\lambda = \frac{6.626\times 10^{-34}Js}{5.69\times 10^{-24}kgm/s} = 1.16\times 10^{-10}m = 0.166nm$.

P18. (D) The parent isotope is Nobellium-266; it has $Z = 102$ protons and $N = 266 - 102 = 164$ neutrons. Each alpha decay subtracts two protons and two neutrons from the total. Each negative beta decay changes a neutron into a proton, and each gamma decay carries away energy but doesn't change the isotope. The decay chain includes five alpha decays, two negative beta decays, and one gamma decay. So, the proton number will become $Z = 102 - 5(2)[alpha] + 2(1)[beta] + 0[gamma] = 94$, which is the element Plutonium, Pu.
Likewise, the neutron number will become $N = 164 - 5(2)[alpha] - 2(1)[beta] + 0[gamma] = 152$. Thus, the mass of the daughter isotope will be $A = Z + N = 94 + 152 = 246$. Therefore, the final daughter isotope in this decay chain will be Plutonium-246, ${}^{246}_{94}Pu$.

P19. (B) The maximum height is not a linear function of the initial upward velocity. The relationship between the maximum height and the initial velocity is described by the equation $v^2 = v_i^2 + 2a(y - y_i)$. Here $(y - y_i) = h$ is the height. Also, at the maximum height, the velocity v is zero.
Thus, $(0)^2 = v_i^2 + 2ah \rightarrow 2ah = -v_i^2$. We can use a single point on the curve to solve for the acceleration. I chose the point $(32.5m/s, 80m)$. Using the chosen point, we find the approximate acceleration due to gravity on this planet to be: $2a(80m) = -(32.5m/s)^2 \rightarrow 160a = -1056 \rightarrow a = -6.6m/s^2$. The negative means that the acceleration is directed downward (as expected), but we only need to report the magnitude $|a| = 6.6m/s^2$. Using other points on the curve gives results that range from $6.4 m/s^2$ to $6.8 m/s^2$ – all of which are close enough to the correct choice.

P20. (D) Double slit interference is governed by the equation $d \sin\theta = m\lambda$. The first thing we need to determine is the angle subtended by a single interference fringe. Measuring a single fringe is inaccurate, so we will measure ten fringes, and divide by 10 to get the average spacing for a single fringe. Starting with the fringe above the 4-cm mark on the ruler, and counting ten fringes to the right lands us at about the 8.75-cm location on the ruler. Thus, the ten-fringe distance is $Y = 8.75 - 4 = 4.75cm$. This gives an average single fringe spacing of $y = 4.75cm/10 = 0.475cm = 0.00475m$. Now we can use the distance from the double slit to the screen to find the tangent of the subtended angle:
$\tan\theta = \frac{y}{L} = \frac{0.00475m}{2.40m} = 0.001979$. This gives a subtended angle of $\theta = \tan^{-1}(0.001979) = 0.1134°$.
Since we are using the spacing for a single fringe, we know that $m = 1$; and we are given that the wavelength of the laser is $\lambda = 633nm$. Putting it all together, we get: $d \sin\theta = m\lambda \rightarrow d \sin(0.1134°) = (1)(633nm) \rightarrow d = 320000nm = 0.32mm$, which is the slit separation.