UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational B • 2022

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. The nucleus of a eukaryotic cell is surrounded by a double membrane called the
A) rough endoplasmic reticulum.
B) Golgi apparatus.
C) nuclear envelope.
D) nuclear pores.
E) cytoplasmic membrane.

B02. In Mendelian classical genetics, what percent of the offspring from the following genetic cross would phenotypically express both dominant traits?

AAbb x AaBb

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

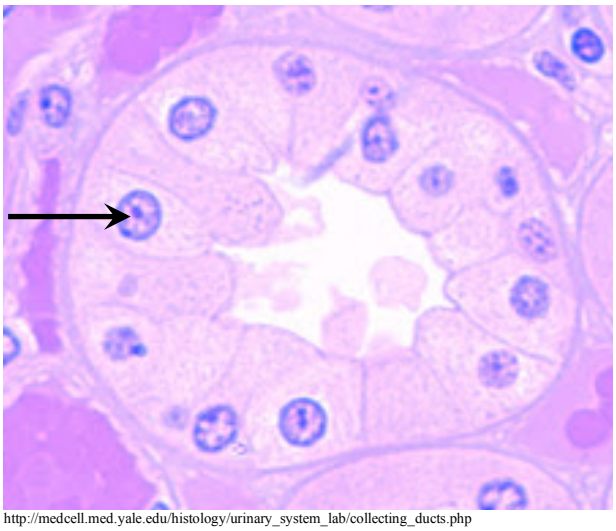
B03. Which of the following statements about DNA replication is incorrect?
A) The replication of DNA produces RNA transcripts.
B) DNA polymerases replicate DNA.
C) Replication is bidirectional.
D) DNA replication must occur prior to cell division.
E) DNA replication occurs within the nucleus of eukaryotic cells and the nucleoid region of prokaryotic cells.

B04. The joining together of DNA pieces from different sources is called
A) Polymerase Chain Reaction.
B) recombinant DNA technology.
C) DNA fingerprinting.
D) whole organism cloning.
E) Northern blotting.

B05. Astrocytes, ependymal, microglia, oligodendrocytes, and Schwann cells are all accessory cells within
A) epithelial tissue.
B) connective tissue.
C) muscle tissue.
D) nervous tissue.

B06. In the Fluid Mosaic Model of biological membranes, the two leaflets of the membrane are asymmetrical in both structure and function. Knowing that membranes are asymmetrical, what could you hypothesize about them?
A) Phospholipids can congregate on one side of the membrane and distort the structure.
B) Glycoproteins, such as those found on red blood cells, are likely embedded within the outer leaflet of the membrane.
C) Enzymes are responsible for moving phospholipids from one leaflet to another, rather than the movement occurring spontaneously.
D) Membrane asymmetry sequesters membrane-involved physiological responses and cellular activities to specific locations on the membrane.
E) All of the above are potential hypotheses regarding asymmetrical membranes.

B07. Examine the microscopic image of the epithelial tissue lining a kidney tubule. This image is a cross-section of a collecting duct. The structure identified by the arrow is the



http://medcell.med.yale.edu/histology/urinary_system_lab/collecting_ducts.php

A) cell wall.
B) connective tissue.
C) basement membrane.
D) plasma membrane.
E) nucleus.

B08. In a chemical reaction catalyzed by an enzyme, the _____ binds to the _____ site.
A) product; substrate
B) substrate; active
C) product; allosteric
D) product; active
E) substrate; allosteric

B09. In a population at Hardy-Weinberg equilibrium, 300 out of 1000 individuals in the population have a recessive phenotype. Which Hardy-Weinberg variable can be solved for first?
A) p^2
B) p
C) q^2
D) q
E) 2pq

B10. The ribosomes on the rough endoplasmic reticulum in eukaryotic cells
A) synthesize cytosolic proteins.
B) generate enzymes only.
C) make lipids.
D) make proteins designated for secretion or export.
E) are permanently attached to the organelle.

B11. Regulation of the cell cycle involves the expression of cyclins that bind to cyclin-dependent kinases to effect an outcome. In which cell cycle phase do you think M cyclins are expressed at their highest level?
A) Mitosis
B) G1/S phase
C) G1 phase
D) S phase
E) G0 phase

B12. What would likely happen if a mutation occurred in the 3'-untranslated region of a gene?
A) Regulation of gene expression would be affected.
B) The stop codon would not be read correctly.
C) Nothing, as this area is downstream of the gene and not translated into protein.
D) An amino acid substitution would occur.
E) The start codon would not be identified, and the protein would not be made.

B13. Which of the following eukaryotic pathogens is vector-borne?
A) *Ancylostoma duodenale*
B) *Plasmodium falciparum*
C) *Naegleria fowleri*
D) *Entamoeba histolytica*
E) *Aspergillus niger*

B14. Examine the following answer choices. Which biological organization level would represent the broadest category relative to the other answer choices?
A) atoms
B) ecosystem
C) community
D) organs
E) molecules

B15. Which of the following is not responsible in the formation of acid rain?
A) deforestation
B) burning of fossil fuels
C) nitrogen oxides and sulfur dioxides
D) volcanic activity
E) manufacturing facilities

B16. A gene in a population that confers a selective advantage would
A) only affect the individual in the population and not the population as a whole in terms of evolution.
B) likely decrease the reproductive success.
C) create a bottleneck effect.
D) increase in frequency over time.
E) none of the above would occur.

B17. All of the following are examples of convergent evolution except
A) the body structure of sharks and dolphins.
B) the presence of wings on insects and bats.
C) the eyes of vertebrates and cephalopods.
D) analogous structures.
E) mammalian forearm structure.

B18. In temperate climates, the age of a tree can be determined by counting its annual growth rings. Which structure is actually being counted?
A) bark
B) phloem
C) epidermis
D) xylem
E) apical meristem

B19. The Centers for Disease Control and Prevention has identified organic baby spinach as the source of an *E. coli* outbreak in nine states. Which of the following is not associated with this particular outbreak or strain?
A) *E. coli* O157:H7
B) hemolytic uremic syndrome
C) bloody diarrhea
D) Shiga-toxin producing *E. coli*
E) ESBL-*E. coli*

B20. The reactions occurring within the _____ produce a majority of the carbon dioxide in eukaryotic cellular respiration.
A) mitochondria.
B) chloroplast.
C) nucleus.
D) cytosol.
E) plasma membrane.

C01. Which of these elements can be found in the 4*d* section of the periodic table?

A) Ag
B) Cr
C) K
D) La
E) Te

C02. What is the mass of half a mole of sodium bromite ($NaBrO_2$)?

A) 59.45 g
B) 67.45 g
C) 118.89 g
D) 134.89 g
E) 269.78 g

C03. How many grams of solid PbI_2 would be produced by adding excess KI to 88 mL of a 0.052 M $Pb(NO_3)_2$ solution?

A) 0.95 g
B) 1.5 g
C) 2.1 g
D) 2.5 g
E) 3.7 g

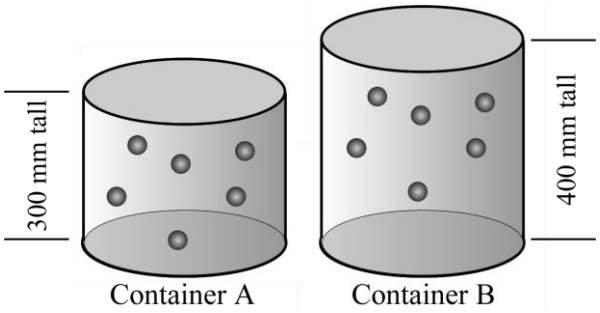
C04. An atom of Element A has an emission spectrum that includes a red line at 695 nm. The emission spectrum of an atom of Element B also has a red line, but at 632 nm. What can you say about the red photons coming off these two atoms?

A) The red photon from Element A is traveling faster than the red photon from Element B.
B) The red photon from Element A is larger than the red photon from Element B.
C) The red photon from Element A is higher energy than the red photon from Element B.
D) The red photon from Element A is lower energy than the red photon from Element B.
E) The two photons are equal in energy because they are both in the red region of the visible spectrum.

C05. What is the shape of a phosphorus trichloride molecule?

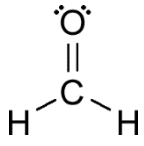
A) trigonal pyramidal
B) trigonal planar
C) linear
D) tetrahedral
E) square planar

C06. Containers A and B have the same diameter and are at the same temperature. If the pressure in container A is 1.50 atm, what is the pressure in container B?



A) 1.500 atm
B) 1.375 atm
C) 1.250 atm
D) 1.125 atm
E) 1.000 atm

C07. What are the strongest intermolecular forces present in liquid formaldehyde, shown here?

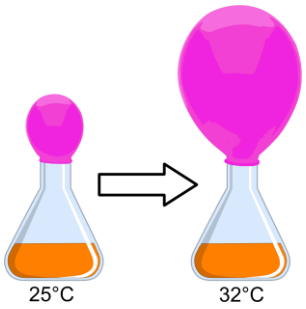


A) Hydrogen bonding
B) Covalent bonds
C) Dipole-dipole forces
D) Dispersion forces
E) Liquid bonds

C08. In which one of these compounds is the metal in a +3 oxidation state?

A) K_2O
B) CaO
C) SnO_2
D) V_2O_5
E) Al_2O_3

C09. A chemical reaction between two compounds dissolved in water is carried out in a flask covered with a balloon and the following changes are observed. Is this reaction endothermic or exothermic, and how do you know?



A) Exothermic because the volume increased.
B) Exothermic because the solution temperature increased.
C) Endothermic because the volume increased.
D) Endothermic because the solution temperature increased.
E) Two of the above answers are correct.

C10. How much energy would it take to melt a pound of ice (454 grams) at 0°C and heat the water to 25°C?

A) 199 kJ
B) 152 kJ
C) 47.5 kJ
D) 1030 kJ
E) 1070 kJ

C11. Which of these is the correct equilibrium expression for the reaction

$AB_2(aq) + C_2D\ (aq) \rightleftharpoons 2CB(s) + AD(g)$

A) $K_{eq} = \frac{[AB_2][C_2D]}{[CB]^2[AD]}$

B) $K_{eq} = \frac{[AB_2][C_2D]}{[AD]}$

C) $K_{eq} = \frac{[2CB][AD]}{[AB_2][C_2D]}$

D) $K_{eq} = \frac{[CB]^2[AD]}{[AB_2][C_2D]}$

E) $K_{eq} = \frac{[AD]}{[AB_2][C_2D]}$

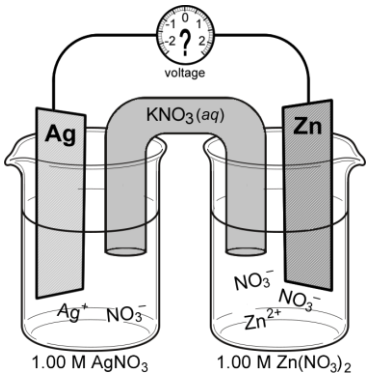
C12. Which of these compounds would result in a solution with the highest pH if 0.03 mole of the compound was dissolved in 1.0 kg of water?

A) KOH
B) KCl
C) H_2SO_4
D) $BaCl_2$
E) $Ba(OH)_2$

C13. If insoluble salt XY has a K_{sp} of 6.2×10^{-5}, how many moles of XY will dissolve in 1 L of solution?

A) 6.2×10^{-5}
B) 7.9×10^{-3}
C) 2.0×10^{-3}
D) 2.5×10^{-4}
E) 3.8×10^{-9}

C14. What is the potential of the electrolytic cell shown below?



A) +1.56 V
B) –1.56 V
C) +0.04 V
D) –0.04 V
E) +0.80 V

C15. Based on periodic trends, which of these ions would be expected to have the largest radius?

A) Cl^-
B) Ga^{3+}
C) K^+
D) Ca^{2+}
E) F^-

C16. The overall reaction $A + B_2 + C \rightarrow AB + CB$ has the following reaction mechanism:

Step 1: $A + B_2 \rightarrow AB_2$
Step 2: $AB_2 \rightarrow AB + B$
Step 3: $B + C \rightarrow CB$

Which compound in the mechanism is an intermediate?

A) A
B) B
C) AB_2
D) B_2
E) There is no intermediate.

C17. A tank of compressed helium gas holds 12.8 moles of helium gas. How many balloons can you fill from one tank of compressed helium gas if at 1.00 atm pressure and 25.0°C, each balloon has a volume of 6.25 L?

A) 40
B) 50
C) 60
D) 65
E) 75

C18. What is the mass of 8.50×10^{25} atoms of iron?

A) 7.89 kg
B) 141 kg
C) 39.6 kg
D) 2.21 kg
E) 2.53 kg

C19. When salt is dissolved in water, what happens to the freezing point and boiling point of the solution compared to those of pure water?

A) They both increase.
B) They both decrease.
C) The boiling point goes up and the freezing point goes down.
D) The boiling point goes down and the freezing point goes up.
E) They do not change.

C20. If you dissolve 100. grams of solid $CaCl_2$ in water and then dilute it to 500. mL, what will the concentration of chloride ions be in the final solution?

A) 1.80 M
B) 3.60 M
C) 5.30 M
D) 0.90 M
E) 2.65 M

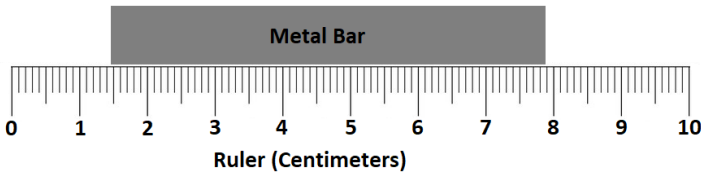
P01. According to Kaku, the concept of a field is one of the most important concepts in all of physics. Who invented the concept of a field?
A) Galileo
B) Newton
C) Faraday
D) Maxwell
E) Hertz

P02. According to Kaku, the first experimental test of Einstein's theory of General Relativity was ____.
A) the bending of light around the Sun.
B) the erratic orbit of Mercury.
C) the conversion of mass into energy.
D) the discovery of Neptune.
E) the speeding up of time when in orbit.

P03. According to Kaku, electrons are both particles and waves. What is it about an electron that is a wave, described by a wave function?
A) the magnetic moment of the electron
B) the momentum of the electron
C) the electric charge of the electron
D) the probability of finding the electron
E) the trajectory of the electron

P04. Long period comets are thought to originate from a spherical shell of icy objects orbiting thousands of Astronomical Units from the Sun. What is this spherical shell of objects called?
A) The Kuiper Belt
B) The Hill Cloud
C) The Asteroid Belt
D) The Scattered Disk
E) The Oort Cloud

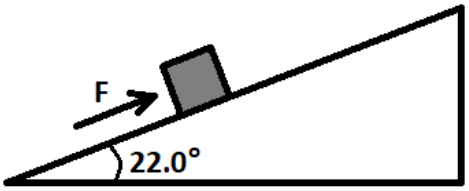
P05. Which answer gives the best measurement of the length of the metal bar shown, using the ruler shown with the bar.



A) 1.45 cm
B) 6.43 cm
C) 6.43126 cm
D) 6.5 cm
E) 7.88 cm

P06. A small car is moving at 30.0 mph when it gets on the entrance ramp for a highway. The car accelerates at a rate of 9500 mi/hr^2 for the entire 0.15-mile length of the ramp. What is the speed of the car as it enters the highway?
A) 36 mph
B) 48 mph
C) 53 mph
D) 61 mph
E) 73 mph

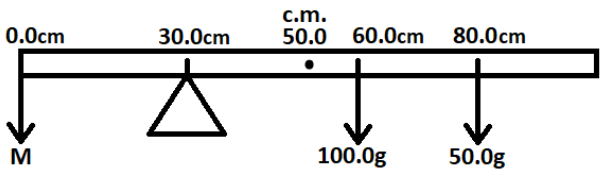
P07. You are pushing a 50.0kg crate of zucchini up a frictionless inclined plane. The plane is angled at 22.0° with respect to the horizontal, and the 200.0N force you apply to the crate is parallel to the plane (as shown). What is the velocity of the crate after 2.50 seconds?



A) 0.822 m/s
B) 4.90 m/s
C) 9.18 m/s
D) 10.0 m/s
E) 14.5 m/s

P08. A small 150.0g cart rolls frictionlessly across a horizontal table at a speed of 1.50 m/s (to the right). The cart collides with a large 220.0g cart that is stationary. After the collision, the small cart bounces directly backwards (to the left) with a speed of 0.250 m/s. What is the speed of the large cart after the collision?
A) 0.852 m/s
B) 1.02 m/s
C) 1.19 m/s
D) 1.83 m/s
E) 2.57 m/s

P09. A 40.0g meter stick with its center-of-mass at the 50.0cm mark is set up with a fulcrum at the 30.0cm mark (as shown). Two known masses are hung from the meter stick: a 100.0g mass at the 60.0cm mark and a 50.0g mass at the 80.0cm mark. An unknown mass is hung from the 0.0cm end, and the entire system is balanced. What is the value of the unknown hanging mass at the 0.0cm end?



A) 400.0g
B) 333.3g
C) 267.7g
D) 210.0g
E) 183.3g

P10. A firecracker explosion releases 13.0W of power as pure sound. The sound pulse expands spherically as it moves away from the source. What is the intensity (in decibels) of the sound at a distance of 4.20m from the explosion?

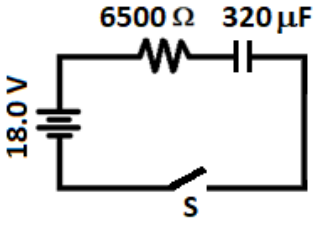
A) 92.8 dB
B) 97.7 dB
C) 108 dB
D) 114 dB
E) 120 dB

P11. A large plastic disk with a volume of $0.157 m^3$ is placed in pure water, and a 12.0kg rock is placed on top of the disk. The disk, with the rock on top, floats on the water, with 50% of the disk showing above the surface. What is the density of the plastic disk?

A) $424\ kg/m^3$
B) $500\ kg/m^3$
C) $576\ kg/m^3$
D) $618\ kg/m^3$
E) $924\ kg/m^3$

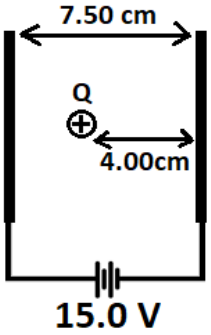
P12. For the RC circuit shown below, the switch S is closed at time = 0, and the capacitor in initially uncharged. What is the charge stored on the capacitor 3.00 seconds after the switch is closed?

A) 5470 µC
B) 4400 µC
C) 2880 µC
D) 1360 µC
E) 720 µC



P13. Two parallel plates, separated by 7.50cm, are connected to a 15.0V power supply, as shown. A charged piece of dust starts at rest between the plates, at a distance of 4.00cm from the negative plate. The charge on the piece of dust is +30.0µC and the mass of the piece of dust is 12.0mg. The piece of dust accelerates to the negative plate – how fast is it moving when it impacts the negative plate? Ignore air resistance.

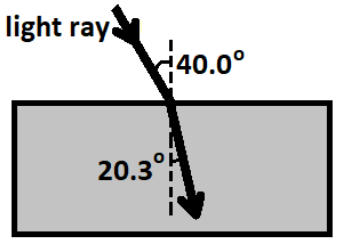
A) 20.0 m/s
B) 17.3 m/s
C) 14.6 m/s
D) 10.5 m/s
E) 6.32 m/s



P14. A square loop of wire is placed in a 70.0 Gauss magnetic field such that the field is perpendicular to the face of the loop. The length of a side of the square loop is 18.0cm, and the resistance of the loop is 1.25Ω. Suddenly, in a time of 9.00milliseconds, the field strength increases to 430.0 Gauss. What is the magnitude of the current induced in the loop by this sudden field increase?

A) 104 mA
B) 124 mA
C) 155 mA
D) 202 mA
E) 576 mA

P15. You observe the following refraction of a light ray as it passes from air into a crystal.



Based on the observed angles, what is the speed of the light in the crystal?

A) 1.32×10^8 m/s
B) 1.62×10^8 m/s
C) 2.45×10^8 m/s
D) 3.00×10^8 m/s
E) 5.56×10^8 m/s

P16. While visiting a modern art exhibit, you notice that a polished metal sphere in one of the sculptures acts as a convex mirror. When you stand 1.80m in front of the sphere, you observe that your image in the sphere is 1/10 of your normal height. What is the magnitude of the radius of curvature of the polished metal sphere?

A) 16.4cm
B) 20.0cm
C) 32.7cm
D) 40.0cm
E) 80.0cm

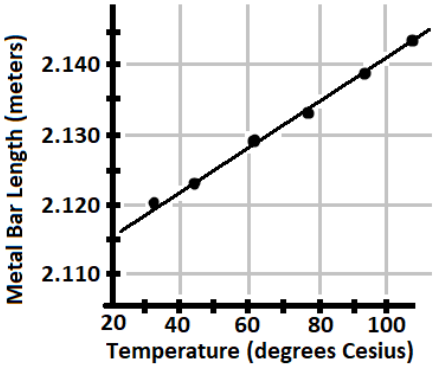
P17. Light with a wavelength of 460nm is directed onto the surface of a photoelectric metal. The workfunction of the metal is 1.60eV. What is the velocity of the photoelectrons emitted from the metal surface?

A) 1.45×10^4 m/s
B) 4.39×10^5 m/s
C) 6.21×10^5 m/s
D) 7.50×10^5 m/s
E) 9.74×10^5 m/s

P18. A particle you are seeking consists of an up quark and an anti-charm quark ($u\bar{c}$). What are the expected properties of this particle?

A) Meson, +1 charge, −1 charm, 0 strangeness
B) Meson, 0 charge, −1 charm, 0 strangeness
C) Meson, −1 charge, +1 charm, −1 strangeness
D) Baryon, +1 charge, −1 charm, 0 strangeness
E) Baryon, 0 charge, −1 charm, +1 strangeness

P19. You are testing the thermal properties of a new metal alloy. For the first test, you carefully measure the length of a bar of this metal alloy while heating it. A graph of the data is shown below. Based on the data, what is the approximate coefficient of thermal expansion of this metal alloy around 60°C?



A) 1.5×10^{-4} °C^{-1}
B) 2.5×10^{-4} °C^{-1}
C) 3.3×10^{-4} °C^{-1}
D) 4.0×10^{-4} °C^{-1}
E) 6.8×10^{-4} °C^{-1}

P20. You are working with an optometrist and have been asked to help correct a patient's nearsightedness. Here are some data collected regarding this patient's vision:

Far Point	33.0 cm
Near Point	8.00 cm
Pressure	17 mmHg
Astigmatism	None

What power of corrective contact lens is needed to correct this patient's nearsightedness?

A) +5.88 diopter
B) +4.13 diopter
C) -1.25 diopter
D) -2.13 diopter
E) -3.0 diopter

Chemistry

1A 1												3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1 H 1.01	2A 2																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	3B 3	4B 4	5B 5	6B 6	7B 7	8	8B 9	10	1B 11	2B 12	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*

Standard Reduction Potentials

$Ag^+(aq) + e^- \rightarrow Ag(s)$ $\quad E° = +0.80$ V
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ $\quad E° = -0.76$ V

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

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
2022 INVITATIONAL B

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL B 2022

C01. (A) The 4*d* section of the periodic table includes elements 39-48.

C02. (B) $NaBrO_2$ = 22.99 + 79.90 + 16.00×2 = 134.89 g/mol × ½ mol = 67.45 g.

C03. (C) You have 0.088 L × 0.052 mol/L = 0.004576 mol Pb^{2+} so you can form 0.00458 mol PbI_2. 0.00458 mol PbI_2 × 461.0 g/mol = 2.1 g

C04. (D) Wavelength and energy are inversely proportional, so a longer wavelength in a photon means a lower energy.

C05. (A) Phosphorus trichloride has four regions of electron density around the central phosphorus atom, giving it tetrahedral electronic geometry. Since one of those regions of electron density is a lone pair, the molecular shape is trigonal pyramidal.

C06. (D) The containers have the same temperature and the same number of moles, so the change in pressure depends only on the change in volume. $P_AV_A = P_BV_B$, so $P_B = P_A(V_A/V_B)$. Since their diameters are the same, the volume ratio is equal to the height ratio, and V_A/V_B = 300/400. P_B = 1.50(300/400) = 1.125 atm.

C07. (C) Formaldehyde is a polar molecule, so its strongest intermolecular forces are dipole-dipole forces.

C08. (E) The metal oxidation states are A) +1; B) +2, C) +4, D) +5, E) +3

C09. (B) The water that the chemicals are dissolved in is part of the surroundings, and the surroundings gained heat, which means the system gave off heat, making the reaction exothermic.

C10. (A) The heat of fusion for ice is 334 J/g and you have 454 grams, so 334 × 454 = 151,636 J. To heat the water from 0°C to 25°C, q = mcΔT = (454 g)(4.184 J/g°C)(25 °C) = 47,488 J. The total energy required is 199,124 J = 199 kJ.

C11. (E) The equilibrium expression is product concentrations raised to their stoichiometric coefficients divided by reactant concentrations raised to their stoichiometric coefficients, but you leave out the solids and liquids.

C12. (E) KOH and $Ba(OH)_2$ are both strong bases, but on a mole-to-mole basis $Ba(OH)_2$ releases twice as many hydroxide ions as KOH and will have a higher pH (by 0.3 pH units) at the same concentration. $BaCl_2$ and KCl are both neutral salts, and H_2SO_4 is a strong acid and would have the lowest pH below 7. (Barium hydroxide is not as soluble as KOH, but at this concentration all of the $Ba(OH)_2$ dissolves.)

C13. (B) For a 1:1 salt like XY, $K_{sp} = [x][x] = x^2$, where x is the molar solubility of the salt. The molar solubility therefore equals $\sqrt{K_{sp}} = (6.2 \times 10^{-5})^{½} = 7.9 \times 10^{-3}$.

C14. (B) $E°_{cell} = E°_{reduction} - E°_{oxidation}$. We are not told which electrode is the anode and which is the cathode, but we are told that it is an electrolytic cell, which means the cell potential is negative. (In a galvanic cell the half-reaction with the higher standard potential is the cathode; in an electrolytic cell the half-reaction with the *lower* standard potential is the cathode.)
$E°_{red}$ = –0.76 V and $E°_{ox}$ = +0.80 V. $E°_{cell}$ = (–0.76 V) – (+0.80 V) = –1.56 V

C15. (A) Except for F^- these are all isoelectronic (same electron configuration), so the one with the fewest protons in the isoelectronic series would be the largest. The fluoride ion will be smaller than Cl^- so we don't need to know where it falls among the cations in order to answer the question. The actual radii in pm are Cl^- (167) > K^+ (152) > F^- (119) > Ca^{2+} (114) > Ga^{3+} (76) [Wikipedia].

C16. (C) An intermediate is produced as a product early in the mechanism and consumed as a reactant in a later step, so it does not appear in the overall chemical equation for the reaction.

C17. (B) Solve for the total volume of the gas at 1 atm and 25°C, then divide by the volume of one balloon to determine how many balloons can be filled. $PV = nRT$, so $V = nRT/P$. n = 12.8 mol, T = 298 K, R = 0.08206 L·atm/mol·K, and P = 1.00 atm. V = (12.8)(0.08206)(298)/1.00 = 313 L total volume. Each balloon is 6.25 L, so the number of balloons is 313 L ÷ 6.25 L/balloon = 50.08 balloons.

C18. (A) (8.50×10^{25} atoms) / (6.02×10^{23} atoms/mole) = 141.2 moles of Fe. 141.2 moles × 55.85 g/mol = 7885.8 grams = 7.89 kg Fe

C19. (C) Boiling point elevation and freezing point depression are two colligative properties of solutions.

C20. (B) 100 g $CaCl_2$ / 110.98 g/mol = 0.90106 moles $CaCl_2$ × 2 mol Cl^- / mol $CaCl_2$ = 1.802 mol Cl^-. 1.802 mol Cl^- / 0.500 L = 3.60 M

PHYSICS SOLUTIONS – UIL INVITATIONAL B 2022

P01. (C) page 20: "But because Faraday had no formal education, he did not have the command of the mathematics that would allow him to describe his remarkable discoveries. Instead, he filled up notebooks with strange diagrams showing lines of force that look like the web of lines iron filings make when surrounding a magnet. He also invented the concept of a field, one of the most important concepts in all of physics."

P02. (B) page 45: "Any theory, no matter how beautiful, must eventually confront experimental verification. So, Einstein seized upon several possible experiments. The first was the erratic orbit of Mercury."

P03. (D) pages 65-66: "If the electron had wavelike properties, then what was disturbing the medium in which the wave existed? What was waving?... According to a paper by Max Born in 1926, what was waving was the probability of finding an electron at that point…. In other words, electrons are particles, but the probability of finding the particle at any given location is given by a wave function."

P04. (E) Long period comets have orbital periods greater than 200 years, and their orbits are often highly inclined to the ecliptic. This suggests that these comets originate in the spherical shell of ice bodies known as the Oort Cloud, which extends from 2000 to 200,000 AU from the Sun.

P05. (B) When using any analog measurement tool, like a ruler, you should always estimate the measurement to one decimal place better than the smallest markings on the tool. In this case, the smallest markings are the millimeter scale, so we should estimate the measurement to the nearest tenth of a millimeter.
To complete this specific measurement, we must read the ruler at both ends of the metal bar. One end, to the nearest tenth of a millimeter is at 1.45cm. The other end is at 7.88cm. The length of the bar is the difference between these two readings: $L = 7.88 - 1.45 = 6.43$cm.

P06. (D) The units are odd, but they are compatible, so we don't need to make any unit conversions to solve the problem. We have distance information but are not given any information about the time that the car is on the entrance ramp. Thus, we should use the kinematic equation: $v_f^2 = v_i^2 + 2a(x_f - x_i)$. Plugging in the given values: $v_f^2 = (30.0)^2 + 2(9500)(0.15) = 3750$. So $v_f = \sqrt{3750} = 61$mph.

P07. (A) Since the incline is frictionless, the forces acting on the crate are as follows: gravity, directed downwards; the normal force, directed up and left, perpendicular to the plane; and the applied force, directed up and right, parallel to the plane. As is typical with an inclined plane, we rotate our coordinate system so that the x-axis is parallel to the plane and the y-axis is perpendicular to the plane. Thus, the applied force is in the positive x-direction and the normal force is in the positive y-direction. The gravitational force must be broken into components: in the negative x-direction is the component $mg\sin\theta$ and in the negative y-direction is the component $mg\cos\theta$. There is no motion in the y-direction, so we will ignore it and move on to the x-direction. Adding up the forces in the x-direction gives: $\sum F_x = F - mg\sin\theta = ma = 200.0 - (50.0)(9.8)\sin 22 = (50.0)a$ This gives: $(50.0)a = 200 - 183.6 = 16.4 \quad \rightarrow \quad a = 0.329\text{m/s}^2$. To find the velocity, we will use the kinematic equation: $v_f = v_i + at = 0 + (0.329)(2.50) = 0.822$m/s.

P08. (C) This problem requires us to use conservation of momentum. Taking "to the right" to be positive, the initial momentum is: $p_i = m_1 v_{1i} + m_2 v_{2i} = (0.150)(1.50) + (0.220)(0) = 0.225$ kgm/s. And the final momentum is given by:
$p_f = m_1 v_{1f} + m_2 v_{2f} = (0.150)(-0.250) + (0.220)\left(v_{2f}\right) = -0.0375 + 0.220 v_{2f}$.
By conservation of momentum, the final momentum must equal the initial momentum, thus:
$p_i = p_f \quad \rightarrow \quad 0.225 = -0.0375 + 0.220 v_{2f} \quad \rightarrow \quad 0.220 v_{2f} = 0.2625 \quad \rightarrow \quad v_{2f} = 1.19$m/s.

P09. (D) If the system is balanced, that means that the sum of the forces add up to zero and the sum of the torques also add up to zero. Summing up forces is not helpful since we do not know the magnitude of the upward Normal Force provided by the fulcrum. Instead, we will solve the problem by summing up torques.
First, we must choose a pivot point. For a lever system like this, it makes sense to choose the pivot point to be at the fulcrum. All torque-arm distances will be measured from this pivot point. Torque is defined at the product of the force, the torque-arm distance, and the sine of the angle between the torque-arm and the force. Fortunately for us, the forces in this problem are all perpendicular to the torque-arm (the torque arm is parallel to the meter stick). Thus, the sine of those 90-degee angles is equal to 1 and does not affect the calculations. Therefore, we need the product of the forces and the distances of those forces from the fulcrum. We must do some conversions as well – masses into kilograms, distances into meters, and we have to multiply the hanging masses by g.
For the known masses, we get torques of $\tau_1 = (0.1000kg)(9.8)(0.600m - 0.300m) = 0.294Nm$ and $\tau_2 = (0.0500kg)(9.8)(0.800m - 0.300m) = 0.245Nm$. The meter stick itself has a mass (effectively acting at the center-of-mass), so it also produces a torque:
$\tau_3 = (0.0400kg)(9.8)(0.500m - 0.300m) = 0.0784Nm$.
The Normal Force at the fulcrum provides no torques since its torque-arm length is zero.
All of these torques (so far) are trying to make the meter stick rotate clockwise. Thus, they will all be negative when we sum up the torques. The only torque that is trying to make the meter stick rotate counterclockwise is that produced by the unknown mass. This counterbalancing torque, which will be positive, is $\tau_4 = (M)(9.8)(0.300m - 0.0m) = 2.94M$.
Now we can sum up all the torques and set the sum to zero. Taking into account their signs we get:
$\sum \tau = -0.294 - 0.245 - 0.0784 + 2.94M = 0$.
This gives: $2.94M = 0.6174 \;\rightarrow\; M = 0.2100kg = 210.0g$

P10. (C) Since the sound wave expands spherically, the absolute intensity is the power divided by the surface area of the spherical wavefront, given by $I = \frac{P}{4\pi r^2}$. In this problem that gives the result:
$I = \frac{13.0\,W}{4\pi(4.20m)^2} = 0.0586\,\frac{W}{m^2}$. To convert this into decibels, we use $I(dB) = 10Log\left(\frac{I}{I_0}\right)$,
where $I_0 = 10^{-12}\,\frac{W}{m^2}$. Thus, we get $I(dB) = 10Log\left(\frac{0.0586}{10^{-12}}\right) = 10(10.8) = 108\,dB$.

P11. (A) Since the system is floating, we know that the downward gravitational force is exactly balanced by the upward buoyant force. The total downward gravitational force includes both the weight of the rock and the weight of the disk: $F_g = M_{rock}g + M_{disk}g$. Since we want the density of the disk, we will rewrite its mass in terms of its density: $M_{disk} = \rho_{disk}V_{disk}$. This gives a total gravitational force of $F_g = M_{rock}g + \rho_{disk}V_{disk}g$.

The buoyant force is based on the density of the liquid (pure water) and the volume of the disk submerged under the surface. Since 50% of the disk is above the surface, we know that 50% of the disk must be below the surface. Thus, the buoyant force is $F_B = \rho_{water}V_{under}g = \rho_{water}\frac{1}{2}V_{disk}g$.

Setting the gravitational force equal to the buoyant force and putting in our given and known values (in mks units):

$F_g = M_{rock}g + \rho_{disk}V_{disk}g = F_B = \rho_{water}\frac{1}{2}V_{disk}g$

$(12.0)(9.8) + \rho_{disk}(0.157)(9.8) = (1000)(\frac{1}{2})(0.157)(9.8)$

$117.6 + 1.5386\rho_{disk} = 769.3 \quad\rightarrow\quad 1.5386\rho_{disk} = 651.7 \quad\rightarrow\quad \rho_{disk} = 424\text{kg/m}^3$.

P12. (B) Since the capacitor is initially uncharged, we should use the RC charging equations. The equation for the amount of charge stored on a capacitor during the charging phase is given by $Q = CV(1 - e^{-t/RC})$. All of these quantities, including the time, are given.
Thus, $Q = (320 \times 10^{-6})(18.0)(1 - e^{-(3)/[(6500)(320 \times 10^{-6})]}$.
This simplifies to $Q = (5.76 \times 10^{-3})(1 - e^{-1.442}) = (5760\,\mu C)(0.7635) = 4400\,\mu C$.

P13. (E) First, we need to find the electric field between the plates. For parallel plates, the electric field is uniform and constant, and given by $E = \frac{V}{d}$. Converting the distance into meters, this gives an electric field of $E = \frac{15.0V}{0.0750m} = 200$V/m. From this we can determine the electric force on the particle of dust: $F = qE = (30.0 \times 10^{-6})(200) = 6.00 \times 10^{-3}$N. We also know the mass of the piece of dust, so we can find its acceleration using Newton's second law. Converting the mass into kilograms, we get: $F = ma = 6.00 \times 10^{-3} = (12.0 \times 10^{-6}kg)(a)$. This gives the acceleration:
$a = \frac{6.00 \times 10^{-3}}{12.0 \times 10^{-6}} = 500$ m/s^2. Finally, we can use kinematics to determine the velocity of the piece of dust when it reaches the negative plate:
$v_f^2 = v_i^2 + 2a(x_f - x_i) = 0 + 2(500)(0.0400) = 40 \quad \rightarrow \quad v_f = \sqrt{40} = 6.32$m/s.

P14. (A) This is an application of Faraday's Law, which states that the voltage induced in a conductor by a changing magnetic flux is given by $\mathcal{E} = -\frac{d\Phi}{dt} \approx -\frac{\Delta\Phi}{\Delta t}$. Here the magnetic flux is $\Phi = BA$, the magnetic field strength multiplied by the area of the loop. We don't need to worry about an angle since the field is perpendicular to the face of the loop. The loop is square, so the area of the loop is: $A = \ell^2 = (0.18)^2 = 0.0324$m^2. The area is constant, so $\mathcal{E} = -\frac{\Delta\Phi}{\Delta t} = -\frac{\Delta(BA)}{\Delta t} = -A\frac{\Delta B}{\Delta t} = -A\frac{B_f - B_i}{\Delta t}$.
Converting the magnetic field to Tesla, and bringing it all together:
$\mathcal{E} = -A\frac{B_f - B_i}{\Delta t} = -(0.0324)\frac{0.0430 - 0.0070}{9.00 \times 10^{-3}} = -(0.0324)\frac{0.0360}{0.009} = -0.1296$V. So, $|\mathcal{E}| = 0.1296$V
Lastly, we turn to Ohm's Law to find the current: $I = \frac{\mathcal{E}}{R} = \frac{0.1296}{1.25} = 0.104\text{A} = 104\text{mA}$.

P15. (B) In order to determine the speed of light in a substance, you need the index of refraction of that substance. Fortunately, we can use the angles given, and Snell's law, to get the index of refraction. Snell's law states $n_1 \sin\theta_1 = n_2 \sin\theta_2$, and since the light starts in air, we know $n_1 = 1.00$. Plugging this, and the angles, into the equation, we get:
$(1.00)\sin(40.0) = n_2\, sin(20.3) \quad \rightarrow \quad 0.6428 = 0.3469n_2$. So, the index of refraction of the crystal is $n_2 = 1.85$. The speed of light in a substance equals the speed of light in a vacuum divided by the index of refraction. Thus, the speed of light in the crystal is
$v = \frac{c}{n_2} = \frac{3.00 \times 10^8}{1.85} = 1.62 \times 10^8$ m/s.

P16. (D) The information that your image is 1/10 of your normal height gives the magnification of the optical system. This relates to the object (p) and image (q) locations: $M = -\frac{q}{p} = 0.100 = -\frac{q}{1.80}$. Thus, the image location is $q = -0.180$m. That it is negative indicates that it is a virtual image.

To determine the radius of curvature, we utilize the mirror equation to find the focal length:
$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \quad \rightarrow \quad \frac{1}{1.80} + \frac{1}{-0.180} = \frac{1}{f} \quad \rightarrow \quad f = -0.200\text{m} = -20.0\text{cm}$. The radius of curvature of a mirror is twice the focal length of the mirror: $R = 2f = 2(-20.0) = -40.0$cm. Thus, the magnitude of the radius of curvature of the polished metal sphere is: $|R| = |-40.0| = 40.0$cm.

P17. (C) First, we need the energy of the photons shining on the metal surface. Using the equation for the energy of a photon, we get: $E_\gamma = \frac{hc}{\lambda} = \frac{1240\ eVnm}{460nm} = 2.70\text{eV}$. Now we must subtract the workfunction of the metal to find the energy of the emitted electrons: $E_e = E_\gamma - \phi = 2.70 - 1.60 = 1.10\text{eV}$. This is well below relativistic energies, so we can equate this to the classical kinetic energy of the electrons: $\frac{1}{2}mv^2 = 1.10\text{eV}$. Converting the energy units and putting in the mass of an electron gives us $(1.10eV)(1.602 \times 10^{-19}J/eV) = (0.5)(9.11 \times 10^{-31}kg)v^2 \quad \rightarrow \quad v^2 = 3.86 \times 10^{11}$. This gives an emitted electron velocity of $v = 6.21 \times 10^5\ m/s$.

P18. (B) First, we should notice that the particle contains a quark-antiquark pair. This means that the particle is a meson (baryons contain three quarks). Thus, the answer is neither D nor E. Now, notice that there are no strange quarks/antiquarks in the particle, this means that the strangeness must be zero. Thus, C cannot be the correct answer

Finally, we know that an up quark has a charge of $+\frac{2}{3}e$, but a charm antiquark has a charge of $-\frac{2}{3}e$. Combined, these charges cancel – leaving the particle with a net charge of zero. Thus, A is not the correct answer. Only answer choice B correctly describes the properties of this particle. By the way, this particle is cataloged as the $\overline{D}^0$ meson.

P19. (A) Thermal expansion is approximately linear and is described by the equation $\Delta L = \alpha L_0 \Delta T$. The data collected form a straight line; and, based on the equation, the slope of the line would be equal to $slope = \frac{\Delta L}{\Delta T} = \alpha L_0$. For the slope, I used two points that are reasonably far apart: $(20℃, 2.115m)$ and $(100℃, 2.141m)$. From these, I get a slope of: $slope = \frac{2.141-2.115}{100-20} = \frac{0.026m}{80℃} = 3.25 \times 10^{-4}\frac{m}{℃} = \alpha L_0$. For L_0 we use the length at $60℃$ (the temperature of interest) and calculate the coefficient of thermal expansion to be: $3.25 \times 10^{-4}\frac{m}{℃} = \alpha(2.128m) \quad \rightarrow \quad \alpha = 1.53 \times 10^{-4}\ ℃^{-1} \approx 1.5 \times 10^{-4}\ ℃^{-1}$.

P20. (E) The power of a lens is the inverse of the focal length of the lens, with the units of diopters being equal to (meters)$^{-1}$. Nearsightedness means that the far point of the patient's eye is too small. A normal far point should be very large – we usually use a far point of infinity to represent normal vision. Therefore, to correct nearsightedness, we need a lens that takes an object at infinity and produces an image at the patient's far point: negative 33.0cm in this case. The image location must be negative because the image should be out in front of the person's face – on the same side of the corrective lens as the object. Using the lens equation: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = Power$ with $p = \infty$ and $q = -0.33$m, we can get the power of the corrective lens needed: $\frac{1}{\infty} + \frac{1}{-0.33} = Power = 0 - 3.0 = -3.0$ diopter. This is the power of the lens needed to correct this patient's nearsightedness.