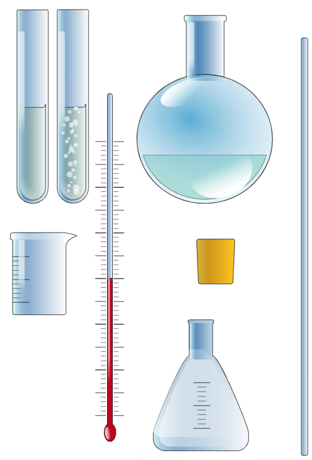
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational A • 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. Where are proteins designated for export synthesized?
A) smooth endoplasmic reticulum
B) rough endoplasmic reticulum
C) peroxisome
D) cytosolic ribosomes
E) lysosome

B02. If P is purple and p is white, what percentage of the second filial generation would be white after crossing PP x pp?
A) 0%
B) 25%
C) 50%
D) 75%
E) 100%

B03. Bacterial genomes are typically arranged as
A) multiple circular chromosomes.
B) one linear chromosome.
C) a mix of both linear and circular chromosomes within the same cell.
D) multiple linear chromosomes.
E) a single, circular chromosome.

B04. *Enterobacteriaceae* are differentiated from non-*Enterobacteriaceae* by
A) the presence of a thin layer of peptidoglycan in only the *Enterobacteriaceae*.
B) the presence of two membranes in the non-*Enterobacteriaceae*, the cytoplasmic membrane and the outer membrane.
C) *Enterobacteriaceae* typically lack an electron transport chain enzyme called cytochrome c oxidase.
D) the presence of lipopolysaccharide (LPS) in *Enterobacteriaceae* only.
E) *Enterobacteriaceae* are disease-causing in humans but the non-*Enterobacteriaceae* are not.

B05. Carbon dioxide is first produced in ______ of aerobic respiration.
A) glycolysis
B) the citric acid cycle
C) chemiosmosis.
D) pyruvate oxidation
E) electron transport chain

B06. In October 2023, the Centers for Disease Control and Prevention issued a food safety warning for diced onions linked to
A) *Salmonella*.
B) Hepatitis virus.
C) *Listeria*.
D) *Escherichia coli*.
E) Shiga-toxin producing *Escherichia coli*.

B07. Epithelial cells are found in all of the following places except
A) skin.
B) esophagus.
C) inside of the bladder wall.
D) the middle or distal end of a hair strand.
E) kidney tubules.

B08. All of the following processes regulate gene expression except
A) attenuation.
B) repressors binding to operators.
C) specific sigma factors binding to RNA polymerase in bacteria.
D) activators binding upstream of a promoter.
E) RNA polymerase binding to a start codon.

B09. R is red and r is white but R exhibits incomplete dominance. Which of the following crosses would not yield any pink flowers?
A) RR x rr
B) Rr x Rr
C) RR x Rr
D) RR x RR
E) All of the above crosses yield pink flowers.

B10. Signaling through the use of acetylcholine occurs via the _______ system.
A) nervous
B) endocrine
C) reproductive
D) digestive
E) respiratory

B11. Organisms that are _______ are only found in one location, such as Puerto Rico or Galapagos.
A) epidemic
B) introduced
C) pandemic
D) migratory
E) endemic

B12. Transcription for almost all genes in the eukaryotic genome occurs
A) in the cytosol.
B) in the nucleus.
C) within mitochondria.
D) on the rough endoplasmic reticulum.
E) on ribosomes.

B13. Which of the following organic molecules functions in long-term energy storage?
A) triglycerides
B) phospholipids
C) amino acids
D) nucleotides
E) monosaccharides

B14. The type of fermentation that produces a mixture of ethanol, carbon dioxide, lactate, formate, succinate, hydrogen gas, and acetate is called
A) alcohol fermentation.
B) homolactic acid fermentation.
C) heterolactic acid fermentation.
D) mixed acid fermentation.
E) 2,3-butanediol fermentation.

B15. Which of the following is an acellular replication process?
A) mitosis
B) meiosis
C) lysogeny
D) binary fission
E) All of the above are acellular processes.

B16. If the frequency of the recessive allele is 0.931, what percent of the population is heterozygous?
A) 0.48%
B) 6.9%
C) 12.8%
D) 86.7%
E) 96.5%

B17. ________ isolation is to time as ________ is to location.
A) Temporal; behavioral
B) Mechanical; ecological
C) Geographic; temporal
D) Behavioral; ecological
E) Temporal; geographic

B18. Pine trees belong to Division (plant phylum) ____.
A) Magnoliophyta
B) Ginkgophyta
C) Coniferophyta
D) Gnetophyta
E) Bryophyta

B19. Plants turning or moving towards a light source is called
A) phototropism.
B) gravitropism.
C) photomorphogenesis.
D) nutation.
E) twining.

B20. Which statement is incorrect?
A) The basic unit of life is the cell.
B) Viruses are made of cells.
C) All organisms have ribosomes.
D) All organisms are made of cells.
E) All cells come from pre-existing cells.

Chemistry

1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8	8B 9	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
$\mathscr{F}$ = 96,485 C/mol e$^-$
1 amp = 1 C/sec
1 mol e$^-$ = 96,485 C

Conversion factors

1 L·atm = 101.325 J

C01. If 1/8 of a mole of helium is added to a latex balloon at 25°C and 1.1 atm pressure, how many helium atoms are in the balloon?

A) 0.125 atoms
B) 6.02×10^{23} atoms
C) 7.53×10^{24} atoms
D) 4.82×10^{24} atoms
E) 7.53×10^{22} atoms

C02. For the gas phase reaction between H_2 and O_2, which of the statements below is *not* true?

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

A) Two molecules of hydrogen react with one molecule of oxygen to form two molecules of water.
B) Two moles of hydrogen react with one mole of oxygen to form two moles of water.
C) Two grams of hydrogen react with one gram of oxygen to form two grams of water.
D) Two liters of hydrogen react with one liter of oxygen to form two liters of water vapor.
E) Two hydrogen atoms combine with one oxygen atom to form each water molecule.

C03. How many electrons are there in a Se^{2-} ion?

A) 2 B) 36 C) 34 D) 33 E) 32

C04. Which pair of elements below is most likely to form an ionic compound?

A) magnesium and fluorine
B) nitrogen and sulfur
C) oxygen and chlorine
D) sodium and aluminum
E) None of these would form an ionic compound

C05. A SCUBA diver takes a 1.0 L balloon from the surface of the ocean to 33 feet underwater, where the pressure is 2.0 atm. What would the volume of the balloon be at 33 feet of depth?

A) 2.0 L
B) 1.0 L
C) 0.5 L
D) 3.33 L
E) 0.33 L

C06. What type(s) of intermolecular forces would you expect to find in a sample of liquid chloroform, $CHCl_3$?

A) dispersion forces only
B) dipole-dipole and dispersion forces
C) hydrogen bonding and dispersion forces
D) hydrogen bonding, dipole-dipole, and dispersion forces
E) dipole-dipole forces only

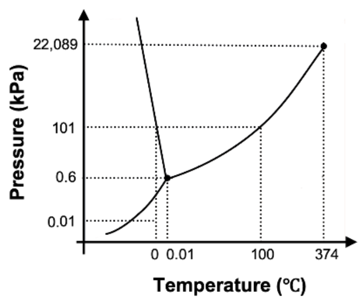
C07. Changes in the internal energy of a system are evident in the form of which two types of energy?

A) heat and work
B) heat and entropy
C) work and entropy
D) heat and enthalpy
E) enthalpy and entropy

C08. A 100 gram sample of NaCl contains

A) equal masses of sodium and chlorine
B) 23 grams of sodium and 35.5 grams of chlorine
C) about twice as many grams of chlorine as sodium
D) about twice as many grams of sodium as chlorine
E) None of the above answer choices is correct

C09. This is a phase diagram for an unknown compound. What phase change(s) would the compound undergo if you took a sample at 0.01 kPa and 0°C and pressurized it to 22,089 kPa while keeping the temperature constant?



A) The solid sample would melt to a liquid and then vaporize to a gas.
B) The liquid sample would freeze to a solid.
C) The solid sample would melt to a liquid.
D) The gaseous sample would condense to a liquid then freeze to a solid.
E) The gaseous sample would deposit as a solid and then melt to a liquid.

C10. The following gas phase reaction has an equilibrium constant K_P of 16.0

$$A_2(g) + B_2(g) \leftrightharpoons 2\ AB(g)$$

In a system at equilibrium the partial pressures of A_2 and B_2 are 0.50 atm. What is the partial pressure of the AB gas?

A) 1.0 atm
B) 2.0 atm
C) 0.50 atm
D) 4.0 atm
E) 0.25 atm

C11. What is the pH of a 3.46×10^{-4} M solution of HCl?

A) 3.46
B) 3.25
C) 3.75
D) 3.60
E) 3.33

C12. The K_{sp} for $Ni(OH)_2$ is 2.8×10^{-16}. What is the concentration of Ni^{2+} in a saturated solution of $Ni(OH)_2$?

A) 1.7×10^{-8} M
B) 1.2×10^{-8} M
C) 1.6×10^{-6} M
D) 4.2×10^{-6} M
E) 6.3×10^{-6} M

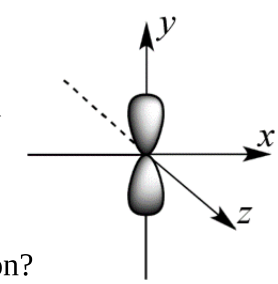
C13. Which of the equations below represents an oxidation half-reaction?

A) $H_2(g) + 2O_2(g) \rightarrow 2H_2O(g)$
B) $2H^+(aq) + 2e^- \rightarrow H_2(g)$
C) $O_3(aq) + 2H^+(aq) + 2e^- \rightleftharpoons O_2(g) + H_2O(\ell)$
D) $2H_2O(g) \rightarrow H_2(g) + 2O_2(g)$
E) $H_2(g) \rightarrow 2H^+(aq) + 2e^-$

C14. If a reaction rate is second order with respect to reactant A and you triple the concentration of A, how much faster will the reaction go?

A) Twice as fast
B) Four times faster
C) Six times faster
D) Nine times faster
E) Eighteen times faster

C15. An electron is in an orbital with this shape. Which set of quantum numbers below could be a valid set for this electron?



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

C16. What is the energy of a photon of visible light that has a wavelength of 610 nm?

A) 3.04×10^{-22} J
B) 3.26×10^{-19} J
C) 4.51×10^{-20} J
D) 9.92×10^{-18} J
E) 7.58×10^{-19} J

C17. How many fluorine atoms are in a 10.0 L sample of fluorine gas at STP?

A) 2.69×10^{23} F atoms
B) 3.47×10^{23} F atoms
C) 4.91×10^{23} F atoms
D) 5.38×10^{23} F atoms
E) 6.73×10^{23} F atoms

C18. The compressibility factor Z for one mole of gas is calculated as

$$Z = \frac{PV}{RT}$$

Which of the following statements about compressibility factor is true?

A) As you decrease the pressure of an ideal gas, Z increases
B) As you increase the pressure of an ideal gas, Z increases
C) As you increase the temperature of an ideal gas, Z increases
D) As you decrease the volume of an ideal gas, Z increases
E) Z for an ideal gas is always equal to 1

C19. What is the limiting reactant in a chemical reaction?

A) The reactant that slows down the reaction rate.
B) The reactant that is the most expensive or the most difficult to obtain.
C) The reactant that runs out first, causing the reaction to stop.
D) A reactant that is in the solid or liquid phase.
E) The reactant that you have the most of, which limits how small of a reaction vessel you can use for the reaction.

C20. What is the percent yield of nickel(II) sulfide if the actual yield is 345.7 grams and the theoretical yield is 360.5 grams?

A) 95.89%
B) 96.33%
C) 97.95%
D) 94.42%
E) 91.11%

P01. According to Guillen, Isaac Newton did not publish his ideas concerning light until after one his rivals had died in 1704. Who was this rival?
A) Nicolaus Copernicus
B) Michael Faraday
C) Robert Hooke
D) Wilhelm Leibniz
E) Thomas Young

P02. According to Guillen, Isaac Newton was cheered on by Edmund Halley. Halley was overjoyed about Newton's equation of gravity because it helped make sense of…
A) The retrograde motion of planets
B) The orbits of the moons of Jupiter
C) The behavior of comets
D) The motion of the Moon
E) The motions within star clusters

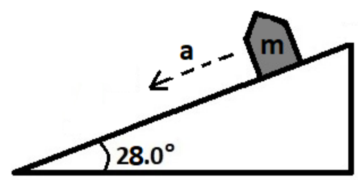
P03. According to Guillen, one particular application of Newton's Laws is impossible to compute exactly. The best one can do is approximate an answer. What is this complicated problem?
A) The centrifugal force problem
B) The light spectrum problem
C) The retrograde motion problem
D) The escape velocity problem
E) The three-body problem

P04. Only one moon in our solar system has a thick atmosphere. It is also the only nitrogen-rich dense atmosphere found anywhere in the solar system. Which moon does this describe?
A) Titan
B) Io
C) Triton
D) Earth's Moon
E) Europa

P05. A domestic cat is chased across a yard by a domestic dog. You observe that the cat crosses the entire 18.0m length of the yard in a time of 4.50 seconds. How fast was the cat running in miles per hour?
A) 1.79 mph
B) 4.00 mph
C) 6.40 mph
D) 8.95 mph
E) 14.4 mph

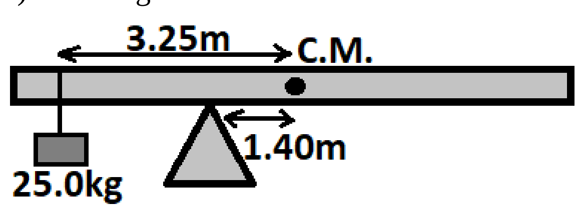
P06. A domestic cat, starting from rest, accelerates at $3.50 m/s^2$. The cat reaches its final speed after travelling a distance of 2.60m. What is the final speed of the cat?
A) 4.27 m/s
B) 4.86 m/s
C) 9.10 m/s
D) 11.8 m/s
E) 18.2 m/s

P07. A bag of cat food slides without friction down an inclined plane (as shown). The angle of the incline is 28.0° and the mass of the bag of food is 3.30kg. What is the acceleration of the bag of cat food down the incline?
A) $8.65 m/s^2$
B) $4.60 m/s^2$
C) $2.97 m/s^2$
D) $2.62 m/s^2$
E) $1.39 m/s^2$



P08. A cat toy with a mass of 220g slides across a horizontal floor. The coefficient of friction between the cat toy and the floor is 0.320. The toy slides a distance of 4.50m before coming to rest. How much work was done on the toy by the force of friction?
A) 9.70 J
B) 5.31 J
C) 3.10 J
D) 2.16 J
E) 0.690 J

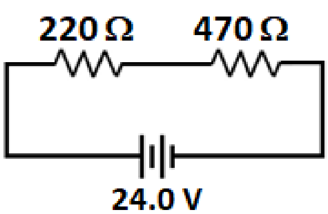
P09. A metal beam is arranged horizontally with a fulcrum (pivot point) located 1.40m to the left of the center of mass of the beam. A 25.0kg mass is attached to the beam at a location that is 3.25m to the left of the center of mass (as shown). The system is perfectly balanced. What is the mass of the metal beam?
A) 10.8 kg
B) 14.2 kg
C) 33.0 kg
D) 43.9 kg
E) 58.0 kg



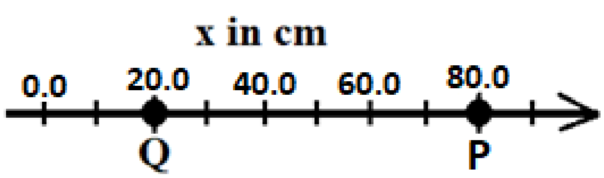
P10. You create a pendulum by tying a 150.0g mass to a long string. You attach the string to a branch on a tree and start the pendulum swinging. You observe that ten complete oscillations of the pendulum take 28.0seconds. What is the length of the pendulum?
A) 6.54 m
B) 5.29 m
C) 4.11 m
D) 2.38 m
E) 1.95 m

P11. A cube of steel, 8.00cm on a side, is heated to 750.0°C. At this temperature, the steel glows a bright red color. If the emissivity of the steel is 0.750, then how much power is emitted by the heated cube as electromagnetic radiation?
A) 296 W
B) 517 W
C) 1080 W
D) 1780 W
E) 2380 W

P12. For the circuit shown, determine the voltage drop across the 470Ω resistor.
A) 24.0 V
B) 16.3 V
C) 11.2 V
D) 7.65 V
E) 3.48 V

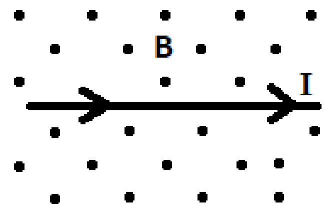


P13. A charge, Q, with a magnitude of $250.0 nC$, is located on a line at the 20.0cm mark, as shown. What is the magnitude of the electric field at the point P, located on the line at the 80.0cm mark, due to the presence of the charge Q?



A) 2250 N/C
B) 2810 N/C
C) 3510 N/C
D) 3750 N/C
E) 6240 N/C

P14. A 24.0cm length of wire carries a current of 14.0A in the positive x-direction (to the right, as shown). A magnetic field with a strength of 650mT is directed in the positive z-direction (out of the page). What is the magnitude and direction of the force acting on the current-carrying wire due to the magnetic field?



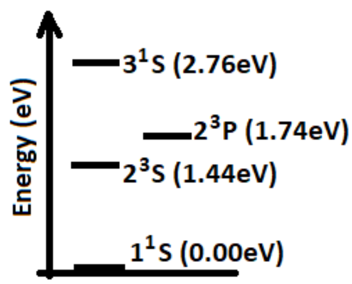
A) 2.18 N up (positive y-direction)
B) 2.18 N down (negative y-direction)
C) 5.76 N down (negative y-direction)
D) 9.10 N up (positive y-direction)
E) 9.10 N down (negative y-direction)

P15. A laser beam, which is naturally vertically polarized, has an intensity of 500W/m^2. The beam is sent through a polarizer whose axis is oriented at 32.0° with respect to vertical. What is the intensity of the laser beam after passing through the polarizer?
A) 500 W/m^2
B) 420 W/m^2
C) 360 W/m^2
D) 260 W/m^2
E) 140 W/m^2

P16. A butterfly sits 29.0cm to the left of a diverging lens. The lens has a focal length of −18.0cm. What is the magnification of the image of the butterfly formed by the lens?
A) 2.64
B) 1.64
C) 0.617
D) 0.383
E) 0.234

P17. The energy level diagram for a newly discovered element is shown below. Atoms of this element produce a strong spectral line at a wavelength of 713nm. Which transition on the energy level diagram is responsible for producing this strong spectral line?

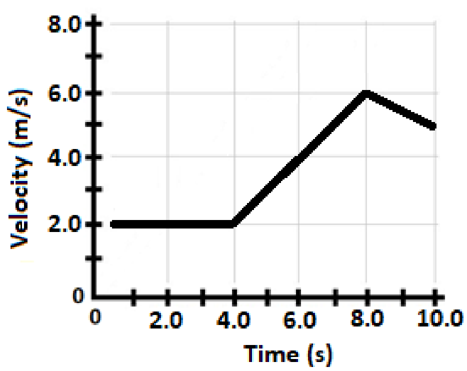
A) $3^1S \rightarrow 2^3S$
B) $3^1S \rightarrow 2^3P$
C) $2^3P \rightarrow 2^3S$
D) $2^3P \rightarrow 1^1S$
E) $2^3S \rightarrow 1^1S$



P18. Positronium is the bound state of an electron and its antiparticle, a positron. It exists for only a brief time, after which the electron and positron annihilate one another, producing a pair of gamma rays. Which of the fundamental forces is responsible for the existence and decay of positronium?

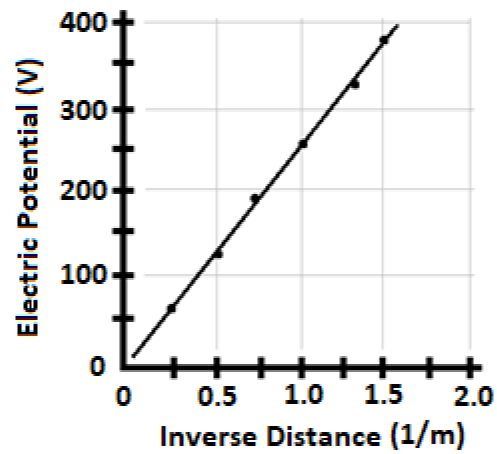
A) The Electromagnetic Force
B) The Gravitational Force
C) The Strong Force
D) The Higgs Force
E) The Weak Force

P19. A large bird flies in a straight line for ten seconds. Shown below is a plot of the velocity of the bird (v) as a function of time (t) for those ten seconds. What is the instantaneous acceleration of the bird at $t = 5.0$seconds?



A) 3.0 m/s^2
B) 1.0 m/s^2
C) 0.75 m/s^2
D) 0.60 m/s^2
E) 0.50 m/s^2

P20. Shown below is a plot of the electric potential (V) produced by a point charge as a function of the inverse of the distance $\left(\frac{1}{r}\right)$ from the point charge. Based on these data, determine the magnitude of the point charge (Q).



A) 28 nC
B) 40 nC
C) 140 nC
D) 250 nC
E) 360 nC

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 A

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL A 2024

C01. (E) 1 mole = 6.022×10^{23} atoms. $(1/8)(6.022 \times 10^{23}) = 7.53 \times 10^{22}$ atoms

C02. (C) A balanced chemical equation works for molecules and for moles, and if all the reactants and products are in the gas phase, it works for liters of gas as well. But it never works for grams – in answer C there are three grams of reactants but only two grams of product.

C03. (B) A selenium atom has atomic number 34 so it has 34 protons and 34 neutrons, so a Se^{2-} ion has two extra electrons, or 36.

C04. (A) Ionic compounds are usually formed when a metal is bonded to a nonmetal.

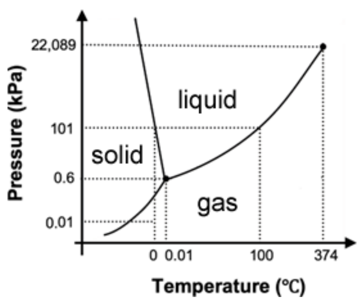
C05. (C) $P_1V_1 = P_2V_2$, so doubling the pressure reduces the volume by half.

C06. (B) $CHCl_3$ is a polar molecule, so it will have dipole-dipole and dispersion forces.

C07. (A) $\Delta U = q + w$. Changes in internal energy are equal to the heat and work associated with the change.

C08. (E). The percent composition of NaCl is: Sodium (22.99/(22.99 + 35.45) × 100 = 39.33% sodium and 60.66% chlorine, so in a 100 gram sample there would be 39.3 g of Na and 60.7 g of Cl.

C09. (E)



C10. (B) $K_P = 16 = P^2_{AB} / (P_{A2})(P_{B2})$ therefore $P^2_{AB} = 16 \times (0.5)(0.5) = 4$, so $P_{AB} = 2$ atm. The partial pressure of a gas in a mixture is the same as the pressure of that gas.

C11. (A) $pH = -\log[H^+] = -\log(3.46 \times 10^{-4}) = 3.46$. (Yes, I chose the numbers like that on purpose.)

C12. (D) $K_{sp} = [Ni^{2+}][OH^-]^2 = [x][2x]^2 = 4x^3$. $x = (2.8 \times 10^{-16}/4)^{1/3} = 4.2 \times 10^{-6} = [Ni^{2+}]$.

C13. (E) In an oxidation half-reaction electrons appear as a product.

C14. (D) If rate = $k[A]^2$ and you triple [A], the reaction will go $[3]^2 = 9$ times faster.

C15. (D) The orbital shown is a *p* orbital, so $\ell = 1$. That leaves D and E as possible answers, but E has $m_\ell = 2$, which is not an allowed value for m_ℓ when $\ell = 1$.

C16. (B) $\nu\lambda = c$ and $E = h\nu$, so $E = hc/\lambda$.
$E = (6.626 \times 10^{-34}\ J\cdot s)(3.00 \times 10^8\ m/sec)/(610 \times 10^{-9}\ m) = 3.26 \times 10^{-19}$ J

C17. (D) $PV = nRT$, so $n = PV/RT$. $P = 1$ atm, $V = 10.0$ L, $T = 273$K, $R = 0.08206$ L·atm/mol·K
$n = (1)(10.0)/(0.08206)(273) = 0.4464$ moles F_2. (Alternatively, $n = 10.0/22.4 = 0.4464$ moles F_2)
0.4464 moles $F_2 \times 6.022 \times 10^{23}$ molecules/mol = 2.688×10^{23} F_2 molecules
2.688×10^{23} F_2 molecules × 2 F atoms/1 F_2 molecule = 5.38×10^{23} F atoms.

C18. (E) For an ideal gas it is always true that $PV=nRT$. Therefore if n=1, it is always true that $PV=RT$, and PV/RT always equals 1, no matter what the pressure, volume, or temperature are.

C19. (C)

C20. (A) % yield = (actual/theoretical)×100%

PHYSICS SOLUTIONS – UIL INVITATIONAL A 2024

P01. (C) page 55: "…had decided to withhold from this magnum opus any mention of his ideas concerning light; he would not publish those until the bully Hooke had died – which would not happen until 1704…"

P02. (C) page 54: "Halley had been overjoyed to hear of Newton's equation of gravity; with it, he finally had been able to make sense of cometary behavior."

P03. (E) page 60: "Theirs was a dreadfully complicated task, because it required applying Newton's equation to three objects simultaneously – earth, moon, and spaceship – not just two. It was what scientists referred to as a three-body problem.", "…predicting the net effect of three objects pulling on one another, was impossible to compute exactly….the best one could hope to do was approximate an answer…"

P04. (A) Most moons in the solar system have little or no atmosphere at all. However, Titan, the largest moon on Saturn, has a thick atmosphere that is 95% nitrogen and 5% methane. The surface of Titan is shrouded by the hazy atmosphere and cannot be seen with visible light. Titan is the only moon in the solar system with a thick atmosphere.

P05. (D) The cat moves 18.0m in a time of 4.50sec. This means that the speed of the cat is $v = \frac{d}{t} = \frac{18.0}{4.50} = 4.00$m/s. Now we need to convert this speed into miles per hour: $4.00\frac{m}{s} * 60\frac{s}{min} * 60\frac{min}{hr} * \frac{1}{1609}\frac{miles}{m} = 8.95$mph.

P06. (A) We don't know how long the cat took to reach its final speed, so we will use the kinematic equation that doesn't involve time: $v_f^2 = v_i^2 + 2a\left(x_f - x_i\right)$. The initial velocity is zero, and we are given the acceleration and the distance, so: $v_f^2 = 0^2 + 2(3.50)(2.60) = 18.2 \;\rightarrow\; v_f = 4.27$m/s.

P07. (B) First, we need to construct a free-body force diagram. There is no friction, so the only forces acting on the bag are gravity (mg, downward) and the normal force (F_N, up and left, perpendicular to the inclined plane). As is usual for problems involving inclined planes, we tilt our coordinate system so that the x-axis is parallel to the plane, and the y-axis is perpendicular to the plane. In the tilted coordinate system, the normal force acts in the positive y-direction, but the gravitational force must be broken into components. The component $mg\sin\theta$ is directed down and left, parallel to the plane, in the positive x-direction; and the component $mg\cos\theta$ is directed down and right, perpendicular to the plane, in the negative y-direction. The motion of the bag of food is entirely in the x-direction, so we need only consider that component. Utilizing Newton's second law, we obtain: $\sum F_x = mg\sin\theta = ma_x$. Thus, the acceleration in the positive x-direction (down the incline) is $a_x = g\sin\theta = (9.80)\sin(28.0) = 4.60$m/s^2.

P08. (C) Work is defined as force multiplied by distance multiplied by the cosine of the angle between the force and the displacement, $W = Fd\cos\theta$. In this problem, to find the work done by friction, we first need the magnitude of the frictional force. This requires us to draw a force diagram. There are three forces acting on the toy: gravity (mg, downward, in the negative y-direction), the normal force (F_N, upward, in the positive y-direction), and the frictional force (F_f, horizontal, opposite of the motion, in the negative x-direction). There is no motion in the y-direction, so the forces in the y-direction (gravity and the normal force) must sum to zero:
$\sum F_y = F_N - mg = 0 \;\rightarrow\; F_N = mg = (0.220)(9.80) = 2.16$N. Now that we have the normal force, we can find the frictional force: $F_f = \mu F_N = (0.320)(2.16) = 0.690$N.
Finally, we can calculate the work done by friction. Because the frictional force and the motion are both horizontal, we'll use $\theta = 0°$. Thus, the work can be calculated:
$W = F_f d\cos\theta = (0.690N)(4.50m)\cos 0° = 3.10$J. Note: Technically, the displacement and frictional force are pointed in opposite directions ($\theta = 180°$), so this work would be negative – which means that the toy loses energy.

P09. (C) In order to solve this problem, we must consider the torques acting on the beam. Torque is defined as $\tau = Fr\sin\theta$, where F is a force acting on the beam, r is the distance from the pivot point to the location of the force, and θ is the angle between the force direction and the beam. For a situation like ours, the pivot point is obvious: it is the fulcrum location. We have two forces to consider – the weight of the metal beam itself, and the weight of the hanging mass. The weight of the metal beam, W, has a torque arm (the distance from the fulcrum to the force) of $r_w = 1.40$m, while the hanging mass has a torque arm of $r_h = 3.25 - 1.40 = 1.85$m. Both forces are directed vertically downward, so the angle between the force and the beam is 90° for both forces. The weight of the beam produces a torque that would cause a clockwise rotation, so it is considered negative. The hanging mass produces a torque that would cause a counterclockwise rotation, so it is considered positive. Finally, because the system is balanced, the torques must sum to zero. Mathematically: $\sum\tau = \tau_h - \tau_w = 0$. Using the formula for torque gives: $F_h r_h \sin\theta_h - W r_w \sin\theta_w = 0 \;\rightarrow\; m_h g(1.85)\sin 90° - m_w g(1.40)\sin 90° = 0$. This leads to $(25.0)(9.80)(1.85)(1) - m_w(9.80)(1.40)(1) = 0 \;\rightarrow\; 453 = 13.72m_w$. So, the mass of the beam is $m_w = \frac{453}{13.72} = 33.0$kg.

P10. (E) First, we find the period, T, of a single oscillation of the pendulum by using the time given for ten oscillations: $T = \frac{t}{10} = \frac{28.0}{10} = 2.80$sec. Now we go to the equation relating the period of oscillation to the length of the pendulum: $T = 2\pi\sqrt{\frac{L}{g}} \;\rightarrow\; 2.80 = 2\pi\sqrt{\frac{L}{9.80}} \;\rightarrow\; \frac{2.80}{2\pi} = 0.4456 = \sqrt{\frac{L}{9.80}}$. Thus, $L = 9.80(0.4456)^2 = 1.95$m.

P11. (D) The power lost as electromagnetic radiation by a hot object is given by $P = \sigma Ae(T^4 - T_0^4)$. Here, σ is the Stephan-Boltzmann constant, A is the surface area of the object, e is the emissivity of the object, T is the temperature of the object in Kelvin, and T_0 is the ambient (room) temperature around the object (also in Kelvin). Our object has a temperature of $T = 750 + 273 = 1023$K, while the room can be assumed to be about $T_0 = 20 + 273 = 293$K. Our object is a cube, so it has six sides, and each side has a surface area of $A_{side} = (8.00cm)^2 = (0.0800m)^2 = 0.00640$m^2. So, the total surface area is $A = 6A_{side} = 6(0.00640) = 0.0384$m^2. Thus, the total power output as electromagnetic radiation from the heated cube is $P = (5.67 \times 10^{-8})(0.0384)(0.750)[(1023)^4 - (293)^4] = 1776W \approx 1780W$. Note: the ambient (room) temperature doesn't make much difference in this problem since the cube is so hot. You will still get the right answer even if you ignore the room temperature contribution.

P12. (B) First, we combine the resistors to find a single equivalent resistance. Since the resistors are in series, we combine them by adding them: $R_{total} = R_1 + R_2 = 220 + 470 = 690\Omega$. This is the total circuit resistance. Now we can use Ohm's Law to find the total current produced by the battery: $I_{total} = \frac{V_{total}}{R_{total}} = \frac{24.0}{690} = 0.03478$A. Since everything in this circuit is in series, this same current flows from the battery and through each of the two resistors. Thus, by series rules: $I_1 = I_2 = I_{total} = 0.03478$A. Now we return to Ohm's Law to find the voltage drop across the 470Ω resistor. $V_2 = I_2R_2 = (0.03478)(470) = 16.3$V.

P13. (E) Since there is only a single charge, we can find the magnitude of the electric field simply by using $|E| = \frac{kQ}{r^2}$. The distance from the charge Q to the point P is found from the coordinate system: $r = 80.0 - 20.0 = 60.0cm = 0.600m$. Now, the magnitude of the electric field is $|E| = \frac{(8.99 \times 10^9)(250 \times 10^{-9})}{(0.600)^2} = 6240$N/C.

P14. (B) We find the magnitude of the force on the current-carrying wire by using $|F| = ILB\sin\theta$, where I is the current in the wire, L is the length of the wire in the magnetic field, B is the magnitude of the magnetic field, and θ is the angle between the field direction and the current direction. Fortunately, the field direction and the current direction are perpendicular, so $\theta = 90°$. Putting this all together gives $|F| = (14.0)(0.240)(0.650)\sin 90 = 2.18$N. Using the right-hand rule, we have the current (index finger) pointed in the positive x-direction, and the magnetic field (middle finger) pointed in the positive z-direction. This gives a force (thumb) pointed in the negative y-direction (down). Thus, the correct answer is that $F = 2.18N$ down (negative y-direction).

P15. (C) Since the laser beam is initially vertically polarized, we only need to use Malus' Law once to calculate the intensity of the beam after it passes through the tilted polarizer. Malus' Law is $I = I_0(\cos\theta)^2$ where θ is the angle between the initial polarization of the beam and the polarizer. In this case that is given as $\theta = 32.0°$. So, the final intensity is $I = (500)(\cos 32)^2 = 360\text{W/m}^2$.

P16. (D) First, we need to find the location of the image of the butterfly by using $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$. Putting in the object location $p = 29.0$cm and the focal length $f = -18.0$cm, we get an image location of $\frac{1}{(29.0)} + \frac{1}{q} = \frac{1}{(-18.0)} \rightarrow q = -11.1$cm. From this, we can determine the magnification of the image: $M = -\frac{q}{p} = -\frac{-11.1}{29.0} = 0.383$.

P17. (D) The spectral line wavelength allows us to determine the energy of the photons emitted during the transition: $E = \frac{1240eVnm}{\lambda} = \frac{1240}{713} = 1.74$eV. This energy must be equal to the difference between two of the energy levels of the element. From the energy level diagram, we can see that the $2^3P \rightarrow 1^1S$ difference exactly equals the photon energy we calculated. Thus, the strong spectral line is caused by the $2^3P \rightarrow 1^1S$ transition. Note: the other energy differences are 2.76eV, 1.44eV, 1.32eV, 1.02eV, and 0.30eV; so, none of the other possible transitions give the correct photon energy.

P18. (A) When a particle and its antiparticle interact, it will end with the particles annihilating one another and producing gamma rays. It does not matter if they are hadrons or leptons, massive or light, charged or uncharged: matter-antimatter interactions always end the same way. The products of this interaction, gamma rays, represent pure electromagnetic energy. This result also tells us which force is responsible: The Electromagnetic Force.

P19. (B) We are given a plot of velocity versus time. Acceleration is represented by a slope on this plot. Instantaneous acceleration is represented by the slope of the curve at a particular place on the plot – in our case at a time of five seconds. The point of interest lies in the middle section of the plot, and the line segment in this section has a slope of $slope = a = \frac{6.0m/s - 2.0m/s}{8.0s - 4.0s} = \frac{4.0m/s}{4.0s} = 1.0\text{m/s}^2$. This is the acceleration of the bird at $t = 5.0$seconds.

P20. (A) Electric potential is given by $V = \frac{kQ}{r}$. Since the plot is of V versus $\frac{1}{r}$, we can see from the equation that the slope is equal to kQ. To calculate the slope, I'll use the points (1.5m^{-1}, 375V) and (0.5m^{-1}, 125V). Then: $slope = \frac{375V - 125V}{1.5m^{-1} - 0.5m^{-1}} = \frac{250Vm}{1.0} = 250Vm$. Relating the slope to our equation and plugging in the Coulomb constant gives: $kQ = 250Vm = (8.99 \times 10^9)Q \rightarrow Q = 2.8 \times 10^{-8}C = 28 \times 10^{-9}\text{C}$. Thus, the magnitude of the point charge is $Q = 28$nC.