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|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 1 | | | | | | | | | | | 18 | | | | | | |
| 1 H 1.008 | | | | | | | | | | | 2 He 4.003 | | | | | | |
| 3 Li 6.941 | 4 Be 9.012 | | | | | | | | | | | 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 138.91 | 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 (267) | 105 Db (268) | 106 Sg (269) | 107 Bh (270) | 108 Hs (270) | 109 Mt (278) | 110 Ds (281) | 111 Rg (282) | 112 Cn (285) | 113 Nh (286) | 114 Fl (289) | 115 Mc (290) | 116 Lv (293) | 117 Ts (294) | 118 Og (294) |

| | | | | | | | | | | | | | |
|--------------------|--------------------|--------------------|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 58 Ce 140.12 | 59 Pr 140.91 | 60 Nd 144.24 | 61 Pm (145) | 62 Sm 150.36 | 63 Eu 151.96 | 64 Gd 157.25 | 65 Tb 158.93 | 66 Dy 162.50 | 67 Ho 164.93 | 68 Er 167.26 | 69 Tm 168.93 | 70 Yb 173.04 | 71 Lu 174.97 |
| 90 Th 232.04 | 91 Pa 231.04 | 92 U 238.03 | 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 (266) |

constants

$R = 0.08206 \text{ L atm/mol K}$

$R = 8.314 \text{ J/mol K}$

$N_A = 6.022 \times 10^{23} / \text{mol}$

$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$

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

$F = 96485 \text{ C/mol e}^-$

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

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

Rydberg Constants

$\mathcal{R} = 2.18 \times 10^{-18} \text{ J}$

$\mathcal{R} = 3.29 \times 10^{15} \text{ s}^{-1}$

$\mathcal{R} = 1.097 \times 10^7 \text{ m}^{-1}$

conversions

$1 \text{ atm} = 760 \text{ torr}$

$1 \text{ atm} = 101325 \text{ Pa}$

$1 \text{ atm} = 1.01325 \text{ bar}$

$1 \text{ atm} = 14.7 \text{ psi}$

$1 \text{ bar} = 10^5 \text{ Pa}$

$1 \text{ in} = 2.54 \text{ cm}$

$1 \text{ mi} = 5280 \text{ ft}$

$1 \text{ \AA} = 10^{-10} \text{ m}$

$1 \text{ lb} = 453.6 \text{ g}$

$1 \text{ ton} = 2000 \text{ lbs}$

$1 \text{ tonne} = 1000 \text{ kg}$

$1 \text{ gal} = 3.785 \text{ L}$

$1 \text{ gal} = 231 \text{ in}^3$

$1 \text{ fl oz} = 29.57 \text{ mL}$

conversions

$1 \text{ cal} = 4.184 \text{ J}$

$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$

$1 \text{ kWh} = 3600 \text{ J}$

water data

$C_{s,\text{ice}} = 2.09 \text{ J/g } ^\circ\text{C}$

$C_{s,\text{water}} = 4.184 \text{ J/g } ^\circ\text{C}$

$C_{s,\text{steam}} = 2.03 \text{ J/g } ^\circ\text{C}$

$\rho_{\text{water}} = 1.00 \text{ g/mL}$

$\rho_{\text{ice}} = 0.9167 \text{ g/mL}$

$\rho_{\text{seawater}} = 1.024 \text{ g/mL}$

$\Delta H_{\text{fus}} = 334 \text{ J/g}$

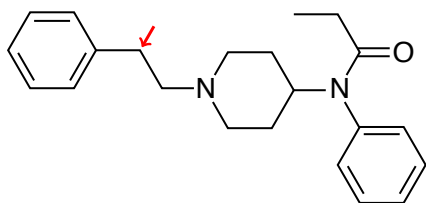
$\Delta H_{\text{vap}} = 2260 \text{ J/g}$

$K_w = 1.0 \times 10^{-14}$

This exam should have exactly 25 questions. Each question is equally weighted at 4 points each. You will enter your answer choices on the virtual bubbleseet after you have finished. Your score is based on what you submit on the virtual bubblesheet and not what is circled on the exam.

1. (Part 1 of 3) The super powerful drug fentanyl is shown below. It is 30 to 50 times more potent than heroin according to the DEA. Let's focus on its structure though. How many sp^2 hybridized carbon atoms are there in fentanyl?

- a. 13
- b. 12
- c. 1
- d. 22
- e. 9



Explanation: Each aromatic ring contains 6 sp^2 carbons and the carbon with a double bond to oxygen is also sp^2 hybridized. This makes 13 total.

2. (Part 2 of 3) What is the molecular geometry of the atom indicated by the arrow?

- a. trigonal planar
- b. trigonal bipyramidal
- c. trigonal pyramidal
- d. linear
- e. tetrahedral

Explanation: The indicated atom is an implied C. It has to have 4 bonds (lines). So 2 more are added with H's on them. That is a total of 4 electron regions and 4 atoms which matches up with tetrahedral for both electronic and molecular geometries.

3. (Part 3 of 3) How many lone pairs are there in fentanyl?

- a. 3
- b. 2
- c. 0
- d. 11
- e. 1
- f. 4

Explanation: There is 1 lone pair on each N atom and 2 lone pairs on the O atom.

4. What is the bond order of the reactive cation F_2^+ ?

- a. 1
- b. 1.5
- c. 0
- d. 3.0
- e. 2.5
- f. 2

Explanation: Fluorine's F_2 MO diagram indicates the F has a bond order of 1. We must remove an electron from the π^* orbital to make the cation. This will increase the bond order up to 1.5. Also, as an aside, F_2^+ is paramagnetic, unlike F_2 .

5. Only one of the following species shown below is non-polar. Which one is it?

- a. O_3
- b. PO_3^{3-}
- c. SF_4
- d. SO_4^{2-}
- e. SO_3^{2-}

Explanation: Although sulfate is charged, the negative charges are dispersed across all four O atoms via resonance and the dipoles cancel each other out (no lone pairs on the S) due to being tetrahedral. The other structures all have dipoles due to the asymmetry with lone pairs being present on the central atoms.

6. Which of the following would have the highest melting point?

- a. steel
- b. ice
- c. graphite
- d. KCl
- e. CH_3F
- f. CsF

Explanation: covalent solids have the highest melting points. Graphite is a classic example of a covalent solid.

7. Which of the following statements is true?

- I. bonding orbitals are formed by the overlap of two out-of-phase atomic orbitals
 - II. p orbitals can only form pi bonds
 - III. adding electrons to bonding orbitals stabilizes the molecule
- a. I, II
 - b. III
 - c. I
 - d. all of them are true
 - e. II, III
 - f. I, III
 - g. II
 - h. none are true

Explanation: Bonding orbitals are formed by overlap of in-phase atomic orbitals. p orbitals can form pi and sigma bonds. Adding electrons to bonding orbitals is stabilizing to the molecule.

8. How many double bonds are present in the best line/dot structure for arsenate, AsO_4^{3-} ?

- a. 4
- b. 2
- c. 3
- d. 1
- e. 0

Explanation: Arsenate is exactly like phosphate. The best structure contains 1 double bond and 3 single bonds to the four oxygens.

9. (Part 1 of 2) The organic molecule below was responsible for many birth defects in the 50s and 60s. How many sigma and pi bonds are contained in its organic structure?

a. $\sigma = 22, \pi = 8$

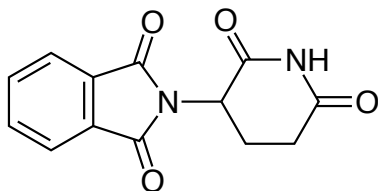
b. $\sigma = 17, \pi = 7$

● c. $\sigma = 31, \pi = 7$

d. $\sigma = 22, \pi = 6$

e. $\sigma = 27, \pi = 7$

f. $\sigma = 31, \pi = 4$



Explanation: Each single and double bond contains 1 sigma bond, each double bond contains 1 pi bond. The implied hydrogens are each bound by a single bond.

10. (Part 2 of 2) What is the empirical formula of the organic molecule?

● a. $C_{13}H_{10}N_2O_4$

b. $C_{13}H_1N_2O_4$

c. $C_{11}H_1N_2O_4$

d. $C_{13}H_5N_2O_4$

e. $C_{11}H_7N_2O_4$

f. $C_{11}H_{10}N_2O_4$

Explanation: Each "corner/bend" in the organic structure represents a carbon. The hydrogens bound to carbons are not shown, but are implied to be there to make each carbon have 4 bonds.

11. When comparing N_2 and Cl_2 , does N_2 have a longer or shorter bond length, a stronger or weaker bond, and is it more or less stable than Cl_2 ?

a. longer, stronger, more stable

b. shorter, weaker, less stable

c. longer, weaker, less stable

d. longer, weaker, more stable

e. shorter, stronger, less stable

● f. shorter, stronger, more stable

Explanation: N_2 has a bond order of 3, while Cl_2 only has a bond order of 1. Higher bond order corresponds to shorter bonds, stronger bonds, and more stable bonds.

12. Rank the following halomethanes in order of increasing vapor pressure at a constant temperature.

● a. $CH_3I < CH_3Br < CH_3Cl < CH_3F$

b. $CH_3Cl < CH_3F < CH_3Br < CH_3I$

c. $CH_3F < CH_3Br < CH_3Cl < CH_3I$

d. $CH_3F < CH_3Cl < CH_3Br < CH_3I$

e. $CH_3I < CH_3Cl < CH_3Br < CH_3F$

Explanation: As you move down the halogen series, polarizability increases and so do dispersion forces. Thus, volatility decreases.

13. Which of the following is paramagnetic?

a. O_2^{2-}

b. F_2

c. Li_2

● d. B_2

e. N_2

Explanation: B_2 is the only option with unpaired electrons in the MO diagram.

14. What is the correct electronic configuration for N_2^- ?

a. $\sigma_{1s}^2 \sigma_{1s}^{*2} \sigma_{2s}^2 \sigma_{2s}^{*2} \pi_{2p}^4 \sigma_{2p}^2$

b. $\sigma_{1s}^2 \sigma_{1s}^{*2} \sigma_{2s}^2 \sigma_{2s}^{*2} \pi_{2p}^4 \sigma_{2p}^2 \pi_{2p}^{*2}$

● c. $\sigma_{1s}^2 \sigma_{1s}^{*2} \sigma_{2s}^2 \sigma_{2s}^{*2} \pi_{2p}^4 \sigma_{2p}^2 \pi_{2p}^{*1}$

d. $\sigma_{1s}^2 \sigma_{1s}^{*2} \sigma_{2s}^2 \sigma_{2s}^{*2} \sigma_{2p}^2 \pi_{2p}^4 \pi_{2p}^{*1}$

e. $\sigma_{1s}^2 \sigma_{1s}^{*2} \sigma_{2s}^2 \sigma_{2s}^{*2} \pi_{2p}^4 \sigma_{2p}^1$

Explanation: This is found using MO theory. N_2^- is a special case which has the bonding pi orbitals lower in energy than its sigma bonding orbital. N_2^- also has one more electron than its neutral counterpart N_2 .

15. diamond, dry ice (solid CO_2), and chalk (calcium carbonate) are examples of what types of solids, respectively?

- a. covalent, covalent, ionic
- b. covalent, molecular, ionic
- c. covalent, molecular, covalent
- d. molecular, covalent, ionic
- e. ionic, covalent, metallic
- f. covalent, covalent, metallic

Explanation: diamonds are a covalent solid, dry ice is CO_2 molecules held together by intermolecular forces, and calcium carbonate is an ionic solid.

16. What is the molecular geometry of ICl_4^- ?

- a. octahedral
- b. square planar
- c. see-saw
- d. square pyramidal
- e. tetrahedral

Explanation: The central I atom has 4 single bonds and 2 lone pairs around it, making it AX_4E_2 . This corresponds to the square planar geometry.

17. Which of the following alkanes would be expected to have the highest boiling point?

- a. octane
- b. nonane
- c. butane
- d. hexane
- e. pentane

Explanation: Boiling point increases with greater dispersion forces. As the alkanes increase in length and size, they become more polarizable and thus experience stronger dispersion forces.

18. Which one of the molecules listed has dipole-dipole interactions as its strongest IMF?

- a. XeF_2
- b. BeH_2
- c. N_2O
- d. CCl_4
- e. SF_6

Explanation: N_2O is the only polar molecule listed, dipole-dipole forces occur between polar molecules.

19. Which of the following bonds would be most polar?

- a. C—P
- b. C—H
- c. C—N
- d. C—O
- e. C—I

Explanation: Bond polarity increases with greater differences in electronegativity. Oxygen has the 2nd highest EN value on the periodic table, so it is the bond that is the most polar of those listed with carbon.

20. What is the bond order of an S—O bond in a sulfite ion?

- a. 2.00
- b. 1.00
- c. 1.50
- d. 1.67
- e. 1.33

Explanation: There are 3 resonance structures for the sulfite ion, the double bond can be drawn between S and each O atom. Averaging these resonance structures gives a S—O bond order of 1.3333...

21. The common basilisk, also known as the “Jesus Lizard” is famous for its ability to run on water. What property of liquid allows this behavior?

- a. paramagnetism
- b. surface tension
- c. adhesive forces between water molecules
- d. intramolecular forces
- e. refractive index

Explanation: In order to break the surface tension of a liquid, forces applied to the surface must be strong enough to disrupt the net set of IMFs within the surface. The other answers are important chemical properties, but are not responsible for IMFs present at the surface of water.

22. Which of the following is not capable of hydrogen bonding?

- a. H₂O
- b. CH₃CH₂NH₂
- c. CH₃CH₂F
- d. HF
- e. CH₃CH₂CH₂OH

Explanation: CH₃CH₂F is the only option which does not have a hydrogen bound to one of the 3 most electronegative elements: N, O, F. An H bound to one of these atoms is necessary to hydrogen bond.

23. What is the total number of valence electrons that should appear in the dot formula of the phosphite ion?

- a. 26
- b. 22
- c. 30
- d. 24
- e. 25
- f. 28

Explanation: The formula of phosphite is PO₃³⁻. Each O atom brings 6 valence electrons to the party, plus 5 for the P and 3 more for the charge equals a total of 26 electrons.

24. What is the molecular geometry of BrF₅?

- a. trigonal bipyramid
- b. square pyramid
- c. octahedral
- d. square planar
- e. tetrahedral

Explanation: BrF₅ has 5 bonds and one lone pair. This points to square pyramid geometry.

25. Which of the following is not an intermolecular force?

- a. dispersion forces
- b. hydrogen bonding
- c. dipole-dipole forces
- d. ion-ion forces

Explanation: ion-ion forces is an intramolecular force for ionic compounds.

After you are finished and have all your answers circled, go to the front of the room and then use the QR code there to pull up the virtual answer page. Enter the appropriate info plus all your answers - click the SUBMIT button. Make sure you get the confirmation screen and show it to the TA or proctor. After that, turn in your exam and scratch paper. You're free to leave after that.



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