FALL 2009
MIDTERM

(Total number of pages = 10)
(Total points = 110)
(Total time = 110 minutes)

**Carefully remove the last two pages: Constants and Formulas, and Periodic Table.**

YOUR DISCUSSION SECTION

YOUR TA’s NAME

WRITE IN PEN (Show all your work on this paper, check units and significant figures.)

Box your final answer.

Good Luck
Do not write on this page.

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Q1. Compounds are being developed that can store hydrogen in vehicles. One reaction being studied for hydrogen storage is: \( \text{Li}_3\text{N}(s) + \text{H}_2(g) \rightarrow \text{LiNH}_2(s) + \text{LiH}(s) \)

How many moles of \( \text{H}_2 \) are needed to react with 1.5 mg of \( \text{Li}_3\text{N} \)?

\[
\text{Moles of } \text{H}_2 \text{ needed to react with 1.5 mg } \text{Li}_3\text{N}:
= 1.5 \times 10^{-3} \text{ g Li}_3\text{N} \left( \frac{1 \text{ mol Li}_3\text{N}}{34.83 \text{ g Li}_3\text{N}} \right) \left( \frac{2 \text{ mol H}_2}{1 \text{ mol Li}_3\text{N}} \right) = 8.6 \times 10^{-5} \text{ mol H}_2
\]

Calculate the mass of \( \text{Li}_3\text{N} \) that will produce 0.650 mol \( \text{LiH} \).

\[
\text{Mass of } \text{Li}_3\text{N} \text{ to produce 0.650 mol } \text{LiH}:
= 0.650 \text{ mol LiH} \left( \frac{1 \text{ mol Li}_3\text{N}}{2 \text{ mol LiH}} \right) \left( \frac{34.83 \text{ g Li}_3\text{N}}{1 \text{ mol Li}_3\text{N}} \right) = 11.3 \text{ g Li}_3\text{N}
\]
Q2. A folk medicine used in the Anhui province of China to treat acute dysentery is cha-tiao-qi, a preparation of the leaves of *Acer ginnala*. Reaction of one of the active ingredients in cha-tiao-qi with water yields gallic acid, a powerful antidysenteric agent. Gallic acid is known to contain carbon, hydrogen, and oxygen. A chemist wanting to determine the molecular formula of gallic acid burned 1.000 g of the compound in an elemental analyzer. The products of the combustion were 1.811 g of CO₂ and 0.3172 g of H₂O.

Determine the empirical formula of the compound. (10pt)

\[
\frac{1.811 \text{ g CO}_2}{44.01 \text{ g mol}^{-1}} = 0.04115 \text{ mol CO}_2 \left( \frac{12.01 \text{ g C}}{1 \text{ mol CO}_2} \right) = 0.4942 \text{ g C} \\
\]

\[
\frac{0.3172 \text{ g H}_2\text{O}}{18.02 \text{ g mol}^{-1}} = 0.01762 \text{ mol H}_2\text{O} \left( \frac{2.0158 \text{ g H}}{1 \text{ mol H}_2\text{O}} \right) = 0.03552 \text{ g H} \\
\]

\[
1.000 \text{ g} - (0.4942 + 0.03552)\text{g} = 0.4703 \text{ g O} \\
\]

\[
\frac{0.4703 \text{ g O}}{16.00 \text{ g mol}^{-1}} = 0.02939 \text{ mol O} \\
\]

Dividing each amount of moles by 0.02939 gives a ratio of C:H:O of 1.4:1.2:1 1pt

Multiplying through by 5 gives whole numbers as required for an empirical formula:

\[C_7H_6O_5\] 1pt

The molar mass was found to be 170.12 g mol⁻¹. What is the molecular formula of gallic acid? (2pt)

Since the molar mass of this empirical formula matches the given value of about 170 g/mol, the molecular formula is the same as the empirical formula. 2pt
Q3A. A lamp rated at 32 W (1 W = 1 J·s⁻¹) emits violet light of wavelength 420 nm. How many photons of violet light can the lamp generate in 2.0 s? (6pt)

32 W = 32 J·sec⁻¹, so in 2 seconds 64 J will be emitted. 1pt

(λ = 420 nm = 420 × 10⁻⁹ m) 1pt

The energy per photon is:

\[ E = \frac{hc}{\lambda} \]

= \( \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s}) (2.997 92 \times 10^8 \text{ m}\cdot\text{s}^{-1}) (420 \times 10^{-9} \text{ m})^{-1}}{1} \)

= \( 4.7 \times 10^{-19} \text{ J}\cdot\text{photon}^{-1} \)

1pt

number of photons = \( \frac{64 \text{ J}}{(4.7 \times 10^{-19} \text{ J}\cdot\text{photon}^{-1})} \) = \( 1.4 \times 10^{20} \) photons 1pt

-1sf

Q3B. Which member of each pair has the smaller first ionization energy? Circle your answer. (3pt)

(a) Ca or Mg (b) Mg or Na (c) Al or Na

(a) Ca; (b) Na; (c) Na

Q3C. Give the full ground-state electron configuration for bromine. (3pt)

bromine, Br  \( 1s^22s^22p^63s^23p^63d^{10}4s^24p^5 \)

Q3D. Write the ground-state electron configuration for Cr⁺ and give the first two quantum numbers for the last electron. (4pt)

\[ [\text{Ar}]3d^5 \]  2pt  n = 3  1pt  \( l = 2 \)  1pt

Q3E. What ion with a +1 charge is predicted to have the following ground-state electron configuration? (3pt)

\[ [\text{Ar}]3d^{10}4s^24p^3 \]

Se⁺

Q3F. For an electron in a d-orbital what values can \( m_l \) have? (2pt)

-2, -1, 0, 1, 2
Q4. In the spectroscopic technique known as photoelectron spectroscopy (PES), ultraviolet radiation is directed at an atom or a molecule. Electrons are ejected from the valence shell, and their kinetic energies are measured. Because the energy of the incoming ultraviolet photon is known and the kinetic energy of the outgoing electron is measured, the ionization energy, $I$, can be deduced from the fact that the total energy is conserved.

Show that the speed, $v$, of the ejected electron and the frequency, $\nu$, of the incoming radiation are related by $E = h \nu = I + \frac{1}{2}m_e v^2$. \hspace{1cm} \text{(4pt)}$

The energy of the photon entering, $E_{\text{total}}$, must be equal to the energy to eject the electron, $E_{\text{ejection}}$, plus the energy that ends up as kinetic energy, $E_{\text{kinetic}}$ to give:

$$E_{\text{total}} = E_{\text{ejection}} + E_{\text{kinetic}}$$

$E_{\text{total}}$ for the photon is $h \nu$ \hspace{1cm} 1pt

$E_{\text{ejection}}$ corresponds to the ionization energy, $I$. \hspace{1cm} 1pt

$E_{\text{kinetic}} = \frac{1}{2}m_e v^2$ where $m$ is the mass of the object and $v$ is its velocity. \hspace{1cm} 1pt

Use this relation to calculate the ionization energy of a rubidium atom, given that radiation of wavelength 58.4 nm produces electrons with a speed of 2450 km.s$^{-1}$; recall that 1 J = 1 kg.m$^2$.s$^{-2}$.

$$E_{\text{total}} = h \nu = h c \lambda^{-1}$$

$$= (6.62608 \times 10^{-34} \text{ J} \cdot \text{s}) (2.99792 \times 10^8 \text{ m} \cdot \text{s}^{-1}) (58.4 \times 10^{-9} \text{ m})^{-1}$$

$$= 3.401 \times 10^{-18} \text{ J}$$

$$E_{\text{ejection}} + E_{\text{kinetic}}$$

1pt for equ \hspace{1pt} 1pt for converting nm \hspace{1pt} 2pt for answer

$$E_{\text{kinetic}} = \left(\frac{1}{2} m v^2\right) = \left(\frac{1}{2}\right) (9.10939 \times 10^{-28} \text{ g}) (2450 \text{ km} \cdot \text{s}^{-1})^2$$

$$= \left(\frac{1}{2}\right) (9.10939 \times 10^{-31} \text{ kg}) (2.450 \times 10^6 \text{ m} \cdot \text{s}^{-1})^2$$

$$= 2.734 \times 10^{-18} \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-2} = 2.734 \times 10^{-18} \text{ J}$$

1pt for converting km.s$^{-1}$ \hspace{1pt} 2pt for answer

$$3.401 \times 10^{-18} \text{ J} = E_{\text{ejection}} + 2.734 \times 10^{-18} \text{ J}$$

$$E_{\text{ejection}} = 6.67 \times 10^{-19} \text{ J}$$

3pt for answer \hspace{1pt} -1units
Q5. Draw the Lewis structure for each of the following compounds:
(a) methanethiol, CH$_3$SH, one of the compounds found in bad breath and some cheeses  
(b) carbon disulfide, CS$_2$, which is used to make rayon  
(c) dichloromethane, CH$_2$Cl$_2$, a common solvent

1pt each for giving the correct total number of valence e-.  
2pt each for the correct structure.
Q6A. Compounds having bonds with a high covalent character tend to be less soluble in water than similar compounds that have low covalent character. Predict which of the following compounds is the more soluble in water. (3pt)

AlCl₃ or KCl

Using the trends in electronegativity, and that K and Cl are further away from each other in the periodic table, the electronegativity difference between K and Cl is greater than that between Al and Cl. Therefore KCl should be more soluble in water than AlCl₃.

Q6B. Ozone, O₃, in the stratosphere protects us from harmful radiation by absorbing ultraviolet radiation from the Sun. Are there one or two different bond lengths in ozone? Does ozone, O₃, or molecular oxygen, O₂, have longer bonds? Draw Lewis structures to justify your answers. (10pt)

Due to resonance, ozone (O₃) has only one observed bond length. 2pt

The bond length in ozone is longer than that of oxygen. 2pt

This can be explained by looking at the Lewis structures for these two species:

\[
\begin{align*}
\text{Ozone (two resonance forms)} & : \begin{array}{c}
\text{O} \\
\text{O} \\
\text{O}
\end{array} \\
\text{Oxygen} & : \text{O=O}
\end{align*}
\]
Q7. Give the VSEPR formula, name the molecular shape, give the hybridization of the central atom, state if the molecule is polar or non-polar, and estimate one bond angle.

(a). AsCl₅

VSEPR formula: AX₅
molecular shape: trigonal bipyramidal
hybridization of central atom: sp³d
polar or non-polar: non-polar
give one bond angle: 90°, 120°, 180°

(b). NF₃

VSEPR formula: AX₃E
molecular shape: trigonal pyramidal
hybridization of central atom: sp³
polar or non-polar: polar
give one bond angle: less than 109.5°

(c). HCBr₂Cl

VSEPR formula: AX₄
molecular shape: tetrahedral
hybridization of central atom: sp³
polar or non-polar: polar
give one bond angle: 109.5° or ~109.5°

(d). H₂SiO

VSEPR formula: AX₃
molecular shape: trigonal planar
hybridization of central atom: sp²
polar or non-polar: polar
give one bond angle: 120° or ~120°

1pt for each correct answer.
Q8A. Describe and draw the structure of the formaldehyde molecule, CH$_2$O, in terms of hybrid orbitals, bond angles, and $\sigma$- and $\pi$-bonds. (6pt)

Both the C and the O are sp$^2$ hybridized. 2pt

All the bond angles are $\sim$120°. 1pt

3 sigma bonds (one each connecting the two H’s and O to the C) 1pt

1 pi bond (between the C and the O). 1pt

Q8B. Draw the Lewis structure and VSEPR formula and identify the molecular shape and bond angles in IF$_6^+$. (5pt)

VSEPR Formula: AX$_6$ 1pt

Shape: octahedral 1pt

Bond angles: 90° and 180° 1pt

2pt