Name ______________________

Section ____________

The last page contains potentially relevant information that may be of use to you. You are welcome to tear that page off and keep it. A periodic table is also distributed, be sure you have one. Please return the periodic table with your exam to your TA. During the exam, adjustments or corrections to the exam will be written on the overhead. Please check the overhead for additional information during the exam. The amount of time left will be written on the overhead during the last 10 minutes of the exam. This is a timed 50 minute exam.

There are 9 pages, be sure you have all pages before you begin.

Useful Information

Gas Constant, \[ R = 8.31451 \text{ J/(mol K)} = 0.08206 \text{ liter-atm/(mol K)} \]

Gravity acceleration rate, \[ g=9.8 \text{ m/sec}^2 \]

Avagadro’s Number, \[ N_A = 6.022 \times 10^{23} \text{ molecules/mole} \]

Boltzmann’s Constant, \[ k = 1.38 \times 10^{-23} \text{ J/K} \]

There are 7 short answer (multiple choice questions) and then 4 longer answer questions (each worth 16 to 18 points). For a total of 102 points. For the multiple choice questions, circle the best single answer (unless explicitly directed otherwise).
I. Short Answer (Multiple Choice Section), each question is worth 4 points, unless specified. Circle the best answer.

a) The fuel cell reaction generates electricity directly from H₂ and O₂. The net reaction is \(2H_2 + O_2 \rightarrow 2H_2O\). What potential should the battery generate (under standard conditions)?

A 0.40  B 0.43  C 0.68  D 0.83  E 1.23  F 1.78 V

b) Of the following species (at std. conditions):

\(Na^+, Cl^-, Ag^+, Ag, Zn^{2+}, Zn\) and \(Pb\)  (2 points each)

The strongest Reducing agent is: \(Na^+, Cl^-, Ag^+, Ag, Zn^{2+}, Zn\)  \(Pb\)

The strongest Oxidizing agent is: \(Na^+, Cl^-, Ag^+, Ag, Zn^{2+}, Zn\)  \(Pb\)

c) The maximum number of electrons the 4d orbitals can hold is:

(2 points)

A 2  B 3  C 5  D 6  E 7  F 10

d) The element Hf (Hafnium) has a smaller atomic radius than either La (Lanthanium) or Zr (Zirconium). (2 pts each) Circle True or False

True or False: This is because atomic radii generally decrease in size as one goes from left to right across the periodic table in any period.

True or False: This is because atomic radii generally decrease in size as one goes down a column from top to bottom.

True or False: This is because Hf has a \([Xe]6s^15d^2\) configuration.

True or False: This is because the electrons in the f orbitals of Hf do not fully compensate for the increased nuclear charge of Hf.

e) Consider the ground state electron configuration of Se (2 points each)

Number of electrons in the 3P orbitals:

A 0  B 2  C 4  D 6  E 8  F 10
Number of electrons in the 4P orbitals:

A 0  B 2  C 4  D 6  E 8  F 10

Number of electrons in the 5P orbitals:

A 0  B 2  C 4  D 6  E 8  F 10

f) Among Ne, Cl and Rb (2 pts each), Circle the best choice
Which one should have the smallest atomic radius:
A Ne  B Cl  C Rb

Which one should have the most favorable (exothermic) electron affinity:
A Ne  B Cl  C Rb

Which one should have the largest ionization energy:
A Ne  B Cl  C Rb

g) When an electron is excited from the n=1 to the n=2 level the
(2 pts each)
The Energy of the electron:
A Increases  B Decreases  C Remains the Same

The Kinetic Energy of the Electron
A Increases  B Decreases  C Remains the Same
II.1) (16 pts) The following is a sketch of a battery. There are two beakers with (inert) platinum electrodes in them. The current flows between the two electrodes. The two reactions are:

<table>
<thead>
<tr>
<th>Beaker</th>
<th>Reaction</th>
<th>( E^\circ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left beaker</td>
<td>( MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O )</td>
<td>1.51 V</td>
</tr>
<tr>
<td>Right beaker</td>
<td>( IO_3^- + 2H^+ + 2e^- \rightarrow IO_3^- + H_2O )</td>
<td>1.60 V</td>
</tr>
</tbody>
</table>

a) The voltage for the cell, \( E^\circ_{\text{cell}} \), is:

\[ E^\circ_{\text{cell}} = 0.09 \text{ V} \]

(2 pts sign, 2 pts magnitude)

b) The object labeled M in the diagram is: **Salt Bridge**

(2 pts)

c) The overall (or net) reaction in the spontaneous direction is:

\[
5IO_3^- + 10H^+ + 10e^- \rightarrow 5IO_3^- + 5H_2O \\
2Mn^{2+} + 8H_2O \rightarrow 2MnO_4^- + 16H^+ + 10e^- \\
5IO_4^- + 2Mn^{2+} + 3H_2O \rightarrow 5IO_3^- + 2MnO_4^- + 6H^+ \]

(6 pts: reduction, reversal, balance)

d) Use the terms “anode/cathode” and “oxidation/reduction” to complete the following sentences: (1 point each)

The Left beaker is the _____ anode _____ because ___ oxidation ____ is occurring there.

The Right beaker is the _____ cathode _____ because reduction ____ is occurring there.

e) Use the terms “Left/Right” to complete the following sentence:

The electrons flow from the _____ Left _____ side beaker to the _____ Right _____ side beaker.

(1 pt each; if Anode and Cath are reversed -above- then the reverse is correct)
II.2) (16 pts) The overall reaction in the lead storage battery is:

\( Pb(s) + PbO_2(s) + 2H^+(aq) + 2HSO_4^-(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l) \)

where \( E^o_{\text{cell}} = 2.04V \).

a) One of the half reactions is \( PbSO_4(s) + 2e^- + H^+(aq) \rightarrow Pb(s) + HSO_4^- (aq) \)

How many electrons are transferred during the reaction per unit reaction?

\( n = 2 \) {1 pt}

b) Calculate \( E_{\text{cell}} \) (at 25°C, 1Atm) when the concentration of the sulfuric acid is 5M. Assume the sulfuric acid is a strong acid, dissociating the first proton only, therefore \( [H^+]=[HSO_4^-]=5M \).

\[
E_{\text{cell}} = E^o_{\text{cell}} - \frac{0.0591V}{n} \log (Q) \\
= 2.04V - \frac{0.0591V}{2} \log \left( \frac{1}{[H^+]^2[HSO_4^-]^2} \right) \quad \{5 \text{ points}\}
\]

\[
= 2.04V + \frac{2 \cdot 0.0591V}{2} \log (25) = 2.123V
\]

c) For the cell chemical reaction, at \(-40°C\), the free energy of reaction is \( \Delta G = -377.5 kJ \), calculate \( E_{\text{cell}} \) at this new temperature. You may assume that all species are at unit molar concentration.

\[
\Delta G = -nF E_{\text{cell}} \\
E_{\text{cell}} = \frac{\Delta G}{-nF} = \frac{377.5kJ}{2 \cdot 96.84kJ/V} = 1.96V \quad \{5 \text{ points}\}
\]

d) What will be the pH of the lead storage battery when the battery has a measured voltage of 1.5V?

\[
E_{\text{cell}} = 1.5V = 2.04V - \frac{0.0591V}{2} \log \left( \frac{1}{[H^+]^2[HSO_4^-]^2} \right) \\
0.54V = -\frac{0.0591V}{2} 4 \log ([H^+]) = -0.118V \log ([H^+]) = 0.118 \text{pH} \quad \{5 \text{ points; 1 for right start, 3 points for manipulation; 1 point for right answer.}\}
\]

\[
pH = \frac{0.54}{0.118} = 4.6
\]
II.3) (16 points) Hydrogen atom

a) Calculate the wavelength of the light emitted when the electron of the hydrogen atom makes a transition from n=4 to n=2 level.

\[ E = -2.178 \cdot 10^{-18} J \left( \frac{Z^2}{n^2} \right) \]
\[ \Delta E = -2.178 \cdot 10^{-18} J \left( \frac{1}{4} - \frac{1}{16} \right) = -2.178 \cdot 10^{-18} J \left( \frac{3}{16} \right) = -4.08 \cdot 10^{-19} J \]
\[ \Delta E = E_{\text{photon}} = \frac{hc}{\lambda} \]
\[ \lambda = \frac{hc}{\Delta E} = \frac{2.998 \cdot 10^8 m/s \cdot 6.6262 \cdot 10^{-34} J \cdot s}{-4.08 \cdot 10^{-19} J} = 4.85 \cdot 10^{-7} m \]

4 points

b) What is the maximum wavelength of light that can completely remove an electron from the hydrogen atom in the ground state.

\[ \Delta E = -2.178 \cdot 10^{-18} J \left( \frac{1}{\infty} - \frac{1}{1} \right) = -2.178 \cdot 10^{-18} J \]
\[ \Delta E = E_{\text{photon}} = hv \]
\[ v = \frac{2.178 \cdot 10^{-18} J}{6.6262 \cdot 10^{-34} J \cdot s} = 3.3 \cdot 10^{15} s^{-1} = \frac{c}{\lambda} \]
\[ \lambda = \frac{2.998 \cdot 10^8 m/s \cdot 6.6262 \cdot 10^{-34} J \cdot s}{2.178 \cdot 10^{-18} J} = 9.08 \cdot 10^{-8} m \]

4 points

c) An electron in the hydrogen atom, initially in its ground state (n=1 level), is excited by a photon and ejected from the atom. The kinetic energy (K.E.) of the ejected electron was measured to be \( K.E. = 2.5 \cdot 10^{-18} J \). What was the frequency of the light that ejected the electron?

\[ E_{\text{photon}} = hv = \Delta E = \text{Binding Energy} + \text{Kinetic Energy} \]
\[ hv = 2.178 \cdot 10^{-18} J + 2.5 \cdot 10^{-18} J = \frac{(2.178 + 2.5) \cdot 10^{-18} J}{6.6262 \cdot 10^{-34} J \cdot s} = \frac{2.4 \cdot 10^{-18} J}{6.6262 \cdot 10^{-34} J \cdot s} = 7.1 \cdot 10^{15} s^{-1} \]

4 points: 2 for setup, 2 for manipulation

d) From the kinetic energy of the electron, which is half the magnitude of the total energy, compute the velocity of the electron (using Bohr’s picture). (For comparison, the speed of light is \( 3 \cdot 10^8 m/s \).)

\[ KE = \frac{mv^2}{2} = E = 2.178 \cdot 10^{-18} J \]
\[ KE = \frac{mv^2}{2} = 2.5 \cdot 10^{-18} J \]
\[ v^2 = \frac{2.178 \cdot 10^{-18} J}{9.10 \cdot 10^{-31} kg} = 2.4 \cdot 10^{12} \]
\[ v^2 = \frac{2 \cdot 2.178 \cdot 10^{-18} J}{9.10 \cdot 10^{-31} kg} = 2.4 \cdot 10^{12} \]
\[ v = 1.55 \cdot 10^6 m/s \]

4 points: 2 setup
II.4) (18 points) Orbitals:

a) On the axis system, sketch the 2Px orbital:

![Sketch of 2Px orbital]

b) How many radial nodes does the 2Px orbital have? 0

c) How many angular nodes does the 2Px orbital have? 1

d) Following the Aufbau principle, write the lowest energy state electronic configuration (EC) for the following elements (you may use either shorthand or full notation):

EC(N) = 1s\(^2\)2s\(^2\)2p\(^3\) or [He]2s\(^2\)2p\(^3\)

e) In applying Hund’s rule to N how many unpaired electrons are there? 3

f) What is the electronic configuration (EC) for potassium and calcium:

EC(K) = [Ar]4s\(^1\)

EC(Ca) = [Ar]4s\(^2\)
g) Circle the best answer to complete the sentence in the following 3 sentences.

One would expect the first Ionization Potential of K to be

greater than                            less than                            equal to

that of Ca

One would expect the second Ionization Potential for K to be

greater than                            less than                            equal to

that of Ca.

One would expect that when binding to an electron (i.e. electron affinity) that the magnitude of the energy released for K to be

greater than                            less than                            equal to

that for Ca.
Additional Information:
1 Volt = 1 Joule/Coulomb. \(1 m = 100cm = 10^2 Angs = 10^{12} picometers = 10^9 nanometers\)

<table>
<thead>
<tr>
<th>Expression</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R = 8.3144J / (mol \cdot K))</td>
<td>(= 0.82057 \left( \ell - atm \right) / (mol \cdot K))</td>
</tr>
<tr>
<td>(9\mathfrak{R} = 3.2899 \cdot 10^{15} / s)</td>
<td>(c = 2.998 \cdot 10^8 m / s)</td>
</tr>
<tr>
<td>(h = 6.6262 \cdot 10^{-34} J \cdot s)</td>
<td>(k = 1.3807 \cdot 10^{-23} J / K)</td>
</tr>
<tr>
<td>(N_A = 6.022 \cdot 10^{23} / mol)</td>
<td>(F = 96,480 Coul / mol)</td>
</tr>
<tr>
<td>(e^- = -1.6 \cdot 10^{-19} Coul)</td>
<td>(m_e = 9.10 \cdot 10^{-31} kg)</td>
</tr>
<tr>
<td>(\varepsilon_o = 8.8542 \cdot 10^{-12} Farad / m)</td>
<td>(\varepsilon_o = 8.8542 \cdot 10^{-12} Farad / m)</td>
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\[
\begin{align*}
R &= 8.3144J / (mol \cdot K) \\
    &= 0.82057 \left( \ell - atm \right) / (mol \cdot K) \\

9\mathfrak{R} &= 3.2899 \cdot 10^{15} / s \\
c &= 2.998 \cdot 10^8 m / s \\
h &= 6.6262 \cdot 10^{-34} J \cdot s \\
k &= 1.3807 \cdot 10^{-23} J / K \\
N_A &= 6.022 \cdot 10^{23} / mol \\
F &= 96,480 Coul / mol \\
e^- &= -1.6 \cdot 10^{-19} Coul \\
m_e &= 9.10 \cdot 10^{-31} kg \\
\varepsilon_o &= 8.8542 \cdot 10^{-12} Farad / m
\end{align*}
\]

<table>
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<th>(E^o)</th>
</tr>
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<tr>
<td>(H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O)</td>
<td>1.78V</td>
</tr>
<tr>
<td>(IO_4^- + 2H^+ + 2e^- \rightarrow IO_3^- + H_2O)</td>
<td>1.60V</td>
</tr>
<tr>
<td>(MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O)</td>
<td>1.51V</td>
</tr>
<tr>
<td>(PbO_2 + 2e^- + 4H^+ (aq) \rightarrow Pb^{2+} + 2H_2O)</td>
<td>1.46V</td>
</tr>
<tr>
<td>(Cl_2 + 2e^- \rightarrow 2Cl^-)</td>
<td>1.36V</td>
</tr>
<tr>
<td>(O_2 + 4H^+ + 4e^- \rightarrow 2H_2O)</td>
<td>1.23V</td>
</tr>
<tr>
<td>(Ag^+ + e^- \rightarrow Ag)</td>
<td>0.80V</td>
</tr>
<tr>
<td>(O_2 + 2H^+ + 2e^- \rightarrow H_2O_2)</td>
<td>0.68V</td>
</tr>
<tr>
<td>(Cu^+ + e^- \rightarrow Cu)</td>
<td>0.52V</td>
</tr>
<tr>
<td>(O_2 + 2H_2O + 4e^- \rightarrow 4OH^-)</td>
<td>0.40V</td>
</tr>
<tr>
<td>(Pb^{2+} + 2e^- \rightarrow Pb)</td>
<td>-0.13V</td>
</tr>
<tr>
<td>(Zn^{2+} + 2e^- \rightarrow Zn)</td>
<td>-0.76V</td>
</tr>
<tr>
<td>(Na^+ + e^- \rightarrow Na)</td>
<td>-2.71V</td>
</tr>
</tbody>
</table>
Grade Distribution:
(numbers on the x-axis are labels at the top of each bin)

Absolute grades:

\[
\begin{array}{cccccccccccccc}
0 & 20 & 40 & 60 & 80 & 100 & 120 & 140 \\
\end{array}
\]

Series2 average = 65.27     s.d.= 12.98

Approximate grade for this exam:

\[
\begin{array}{cccccccccccccc}
0.0 & 0.3 & 0.6 & 1.0 & 1.3 & 1.6 & 1.9 & 2.2 & 2.6 & 2.9 & 3.2 & 3.5 & 3.8 & 4.0 \\
\end{array}
\]

Series2 average = 2.6     s.d. = 0.5