CHEM 133 Exam 1
Mar. 1, 2016
KEY

Equations and constants that you may find useful:
Equation for voltage across resistor in RC circuit as a function of time for a step change of ΔV_{in} at time t = 0:

$$V_R = \Delta V_{in} e^{-t/RC}$$

Standard deviation:

$$S = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$$

Digitization equation for n bit digitizer: decimal # = $(V_{meas} - V_{min})\cdot 2^n / V_{range}$

Noise Equations: 1) Thermal noise: $V_{noise}(rms) = (4kTRB)^{1/2}$
2) Shot Noise: $I_{noise}(rms) = (2eIB)^{1/2}$
k = Boltzmann's constant = 1.38 x 10^{-23} V^2 s Ω^{-1} K^{-1}, T = temperature (K), R = resistance, B = bandwidth, I = current, and e = elementary charge = 1.60 x 10^{-19} C. C = coulombs
F = Faraday's constant = 96,500 C/mol e
Units: 1 A = 1 C/s; 1 J = 1 C·V; 1 W = 1 V·A , A = amps, V = volts, W = watts, J = joules

SHORT ANSWER SECTION: (Each question worth 4 points)

1. A chemist working for a company that sells plant extracts. A particular monoterpene which we will call Compound A in the plant is present at around a 1 % level and is known to have benefits. Unfortunately, the plant extract is known to contain other monoterpenes present at similar levels (0.1 to 2 %) as compound A, and these compounds are structurally very similar to Compound A. The chief difficulty in coming up with a good method to determine the concentration of Compound A will be to have sufficient:
a) accuracy b) precision c) sensitivity **d) selectivity**

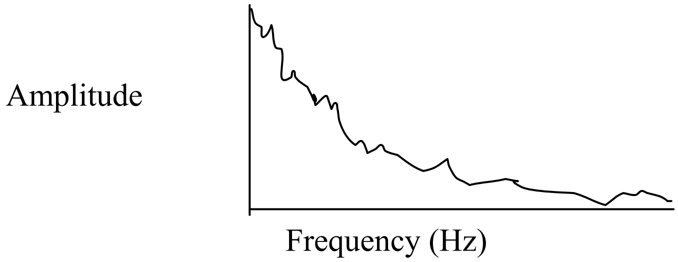
2. Which of the following devices allows current flow in one direction but not in the other detection?
a) diode b) capacitor c) resistor d) photoconductivity cell

3. Give the name of a transducer used to measure charged particle flux and the type of output (current, voltage or resistance). Transducer _Faraday cup, electron multiplier, MCP, FID, PID___
Output __current for all types__

4. Which of the following **analog** electronics parts is most commonly used for signal processing?
a) transducer **b) RC filter** c) analog to digital convertor d) Excel based moving average

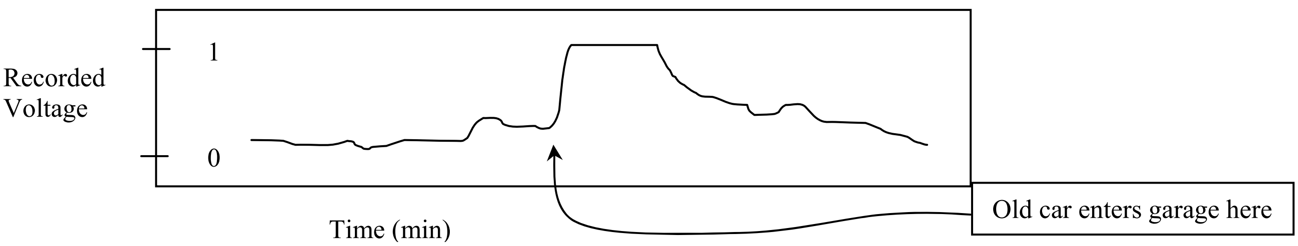
5. Given the following unbalanced redox reaction which has a positive E° value, which compound is being reduced?
$MnO_2(s) + Cr(s) + H^+(aq) \leftrightarrow Mn^{2+}(aq) + Cr^{3+}(aq) + H_2O(l)$
a) MnO_2 b) Cr(s) c) Mn^{2+}(aq) d) H^+(aq)

6. A segment of instrument noise is collected and then subject to Fourier transform. Following Fourier transformation, the frequency distribution is shown below. We can conclude that this noise is primarily:



a) "white" noise **b) 1/f noise** c) interference from 60 Hz power
d) interference from a nearby radio

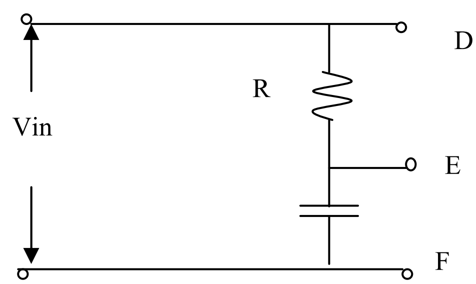
7. A CO monitor, set up to detect CO concentrations in a parking garage, has its output voltage connected to an analog to digital (A/D) convertor in a computer to record values. The A/D convertor has 16 bits and records voltages from 0 to 1 volts. The data below is recorded when an old car enters the garage. What is a likely problem with the A/D convertor?



a) too few bits b) response is too slow
c) insufficient input range d) it is too old

SECTION II. PROBLEM SECTION. Show work – use the back side if needed

1. In the circuit to the right, at t = 0, V_{in} changes from -2.00 V to +3.00 V. R = 185 kΩ and C = 3.0 x 10^{-6} F.



a) What is the current (in μA) from D to E at t = 0.40 s? (7 pts)

From listed equations, $V_R = \Delta V_{in} e^{-t/RC}$

$V_R = [3.00\ V - (-2.00\ V)]e^{-0.40/(185000 \cdot 3.0\ x\ 10^{\wedge}-6)}$

and $I = V_R/R = (5.00e^{-0.721}/185{,}000)(10^6\ \mu A/A) =$

$\boldsymbol{I = 13\ \mu A}$

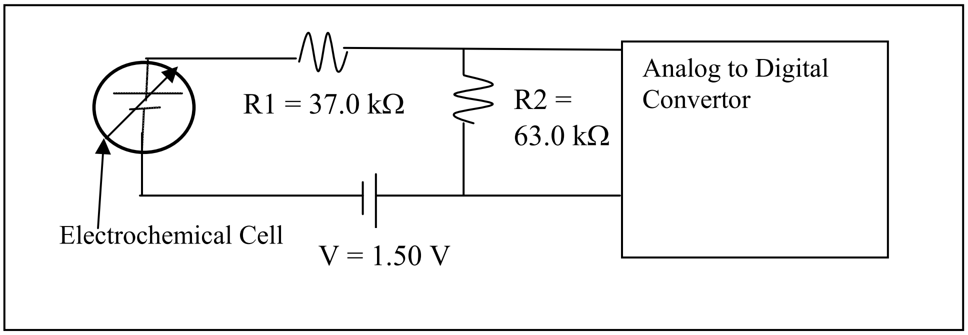
b) At what time will the voltage between E and F reach 0.0 V? (8 pts)

$V_{EF} = V_C = V_{in} - V_R = 0 = 3.00\ V - [3.00\ V - (-2.00\ V)]e^{-t/(185000 \cdot 3.0\ x\ 10^{\wedge}-6)}$ *or*

$3.00/5.00 = e^{-t/(185000 \cdot 3.0\ x\ 10^{\wedge}-6)}$ *or* $\ln(0.600) = -t/(185{,}000 \cdot 3.0\ x\ 10^{-6})$ *or* $t = (0.555\ s)(-\ln 0.6)$

$\boldsymbol{t = 0.28\ s}$

2. The circuit below is used to record the voltage coming from an electrochemical cell using a voltage divider and analog to digital convertor (shown below). Given that the A/D convertor has 12 bits and an input range of 0.00 to 1.00 V, answer the following questions. Assume no current goes to the A/D convertor for questions a) to e).



a) The binary number read by the A/D converter is 011000100110. What is the decimal number corresponding to this? (3 pts)
= 2 + 4 + 32 + 512 + 1024 = ***1574***

b) What is the voltage drop across resistor R2 from the reading in a)? (5 pts)
decimal # = $(V - V_{min})\cdot 2^n/(V_{max} - V_{min})$ *or* $1574 = V\cdot 2^{12}$ *or* $V = 1574/4096 =$ ***0.384 V***

c) What is the Electrochemical Cell voltage based on the reading in a)? (7 pts)
From Kirchhoff's potential law, $V_{EC\ Cell} = I(R1 + R2) + 1.50\ V$ *and* $V(R2) = IR2$
or $I = 0.384\ V/63{,}000\ \Omega = 6.100 \times 10^{-6}\ A$
$V_{EC\ Cell} = (6.100 \times 10^{-6}\ A)(100{,}000\ \Omega) + 1.50\ V =$ ***2.11 V***

d) Based on the significant figures in the voltage and resistor readings, is the digitization error significant? (Does it significantly affect the value calculated in c)? Explain your answer. (5 pts)
uncertainty from digitization is 0.5 bit out of 12 or 0.5 in 4096. This is 0.0001 V so that the voltage would be known to 4 sig fig vs. 3 for the given V and R values. ***So the digitization error is negligible.***

e - bonus) What is the minimum measurable cell voltage? (2 pts)
V(R2) min = 0 V. This means I = 0 and $V_{EC\ Cell\ min} = I(R1 + R2) + 1.50\ V =$ ***1.50 V***

f) If the A/D convertor draws a significant current, how would that affect the answer in c)?(4 pts)
The actual current would be higher. This would cause a greater voltage drop across R1 and R2 so that ***the true voltage would be higher****.*

3. A home CO detector is designed to optically measure CO at a specific wavelength and switches between room air and CO scrubbed air (air which passes through a CO scrubber to remove all CO) twice per second so that the concentration is measured every second. The detector is tested at the specified alarm limit of 50 ppm by volume (using a calibrated source gas) and a mean signal and standard deviation in the 1 sec. signal data are found to be 0.521 and 0.083 V, respectively.

a) The manufacturer wants to set the alarm so that it goes off if the alarm limit is reached and the relative standard deviation in the signal is 4% or less. If the noise is random and represented by the standard deviation, what is the shortest time period that could be averaged to meet the above conditions? (10 pts)

Noise desired = (0.04)(0.521 V) = 0.0208 V. 1 s noise = 0.083 V

S/N is proportional to the square root of the number of replicates and thus the square root of time

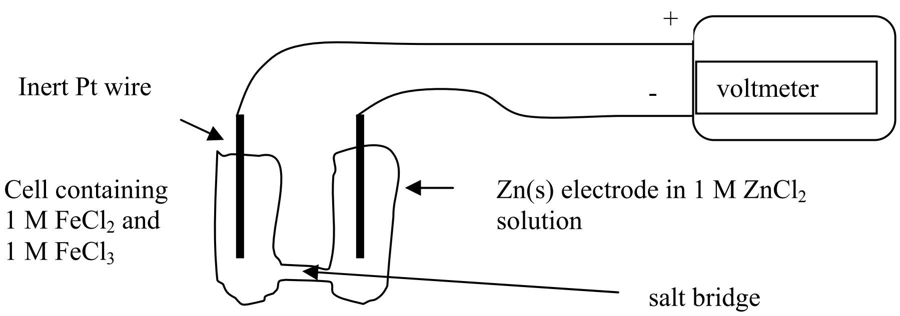
$(S/N)_{desired}/(S/N)_{measured} = (t_{desired}/1\ s)^{0.5} = (0.521/0.0208)/(0.521/0.083)$

$t_{desired}/1\ s = (0.083/0.0208)^2 = \mathbf{16\ s}$

b) What type of noise is reduced by switching between blank and room air? (3 pts)

1/f noise is decreased by modulating

4. From the diagram of a voltaic cell below under standard conditions, answer the following questions:



a) The voltmeter reads + 1.53 V (which is also E° for the net reaction). From this information write the reactions occurring at each half cell and a balanced net reaction. (8 pts)

Since the half cell with Fe in it is attached to the + side and it is reading +, we know this is the reduction:

$\mathbf{Fe^{3+}(aq) + e^- \leftrightarrow Fe^{2+}(aq)}$

The remaining half cell contains Zn which is being oxidized:

$\mathbf{Zn(s) \leftrightarrow Zn^{2+}(aq) + 2e^-}$

If we multiply the Fe reaction by 2 (to get 2 electrons) and add it to the Zn reaction, we get:

$\mathbf{2Fe^{3+}(aq) + Zn(s) \leftrightarrow 2Fe^{2+}(aq) + Zn^{2+}(aq)}$

b) Indicate which is the anode and which is the cathode. (2 pts)

oxidation occurs at the anode: this is the Zn electrode reduction occurs at the cathode which is the Pt wire electrode (Fe half cell)

c) If each half cell contains 20.0 mL and the Zn (AW = 65.4 g/mol) electrode is 1.00 g, determine the limiting reagent and the total amount of energy available for electrical work by the cell (assuming 100% efficiency and total depletion of the limiting reagent). (10 pts)

The limiting reagent gives the smallest number of moles of e:

from Fe^{3+}: n_{e-} = (0.020 L)(1.0 mol/L)(2 mol e/2 mol Fe) = 0.020 mol ***so Fe is limiting***

from Zn: n_{e-} = (1.00 g Zn)(1 mol Zn/65.4 g Zn)(2 mol e/1 mol Zn) = 0.031 mol

work = nFE = (0.020 mol)(96,500 C/mol)(1.53 V) = ***2950 J***