CHEM 133 Exam 1
Mar. 3, 2015
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 # = $(V_{meas} - V_{min}) \cdot 2^n / V_{range}$

3σ limit of detection: $C_{LoD} = 3\sigma/m$ where m = slope of response vs. conc. (C) plot and σ = standard deviation of blank or noise data.

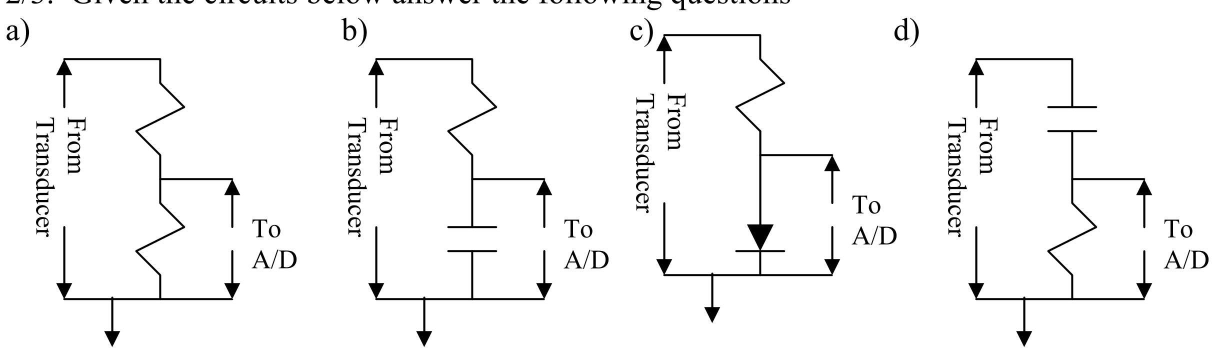
Noise Equations: 1) Thermal noise: $V_{noise}(rms) = (4kTR\Delta f)^{1/2}$
2) Shot Noise: $I_{noise}(rms) = (2eI\Delta f)^{1/2}$
k = Boltzmann's constant = 1.38×10^{-23} V^2 s Ω^{-1} K^{-1}, T = temperature (K), R = resistance, Δf = bandwidth, I = current, and e = elementary charge = 1.60×10^{-19} coulombs.
F = Faraday's constant = 96,500 C/mol e

SHORT ANSWER SECTION: (Each question worth 4 points)

1. Chemist A is investigating the presence of highly toxic mold compounds in processed peanuts, where very small concentrations of mold compounds can have significant effects. Chemist B is measuring the types of oils in the peanuts. Oils are a major fraction of peanut mass. Compared to Chemist B, Chemist A needs excellent:

a) accuracy b) precision **c) sensitivity** d) sample throughput

2/3. Given the circuits below answer the following questions



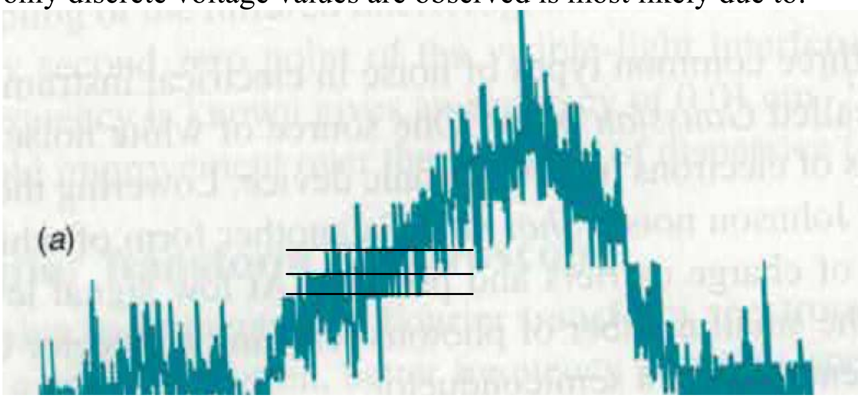
2. Which of the above circuits is best to linearly decrease a transducer voltage output (mainly DC signal) so that it is in the range of an analog to digital input (A/D input)? __**a**__

3. Which above circuit is best for removing high frequency noise? (e.g. a low pass filter) __**b**__

4. Give the name of a transducer and its measured output (e.g. V, R, or I) that can be used to measure temperature. Transducer _thermistor/thermocouple___ Output type _R/V______

5. Which of the following methods is specifically good at reducing 1/f (also known as flicker) noise?
a) cool components
b) use internal amplification
c) use modulation and a high pass filter
d) use a low pass filter

6. The following data was measured by a transducer (in mV), sent to an analog to digital convertor, stored in memory, and then displayed. Looking at the displayed data, the fact that only discrete voltage values are observed is most likely due to:



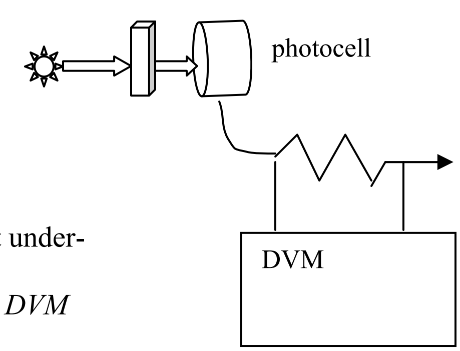
a) transducers (only reads to nearest mV)
b) digitization (insufficient bits to resolve signal more)
c) storage (too much memory would be needed to store data more precisely)
d) display (the dye molecules making up the plot have finite space)

7. In a galvanic cell:
a) oxidation occurs at the anode which is positively charged
b) reduction occurs at the anode which is positively charged
c) reduction occurs at the anode which is negatively charged
d) oxidation occurs at the anode which is negatively charged

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

1. A photocell puts out a current proportional to the photon flux. This is measured using the shunt resistor and digital voltmeter shown below. The shunt resistor is 2200 Ω. (12 pts)

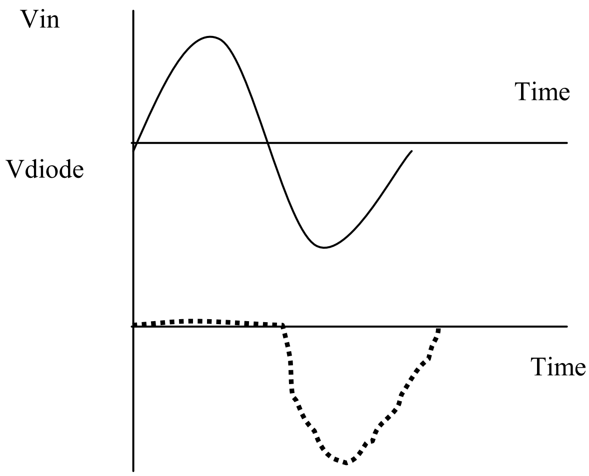
a) When running a blank in the cuvette (near maximum light intensity), the DVM reads 0.199 V. What is the photocell current?

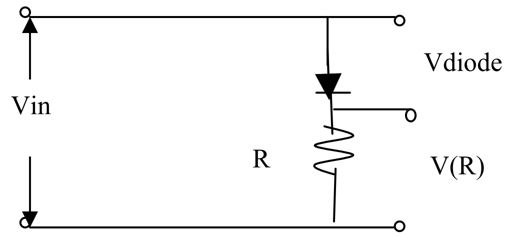


$I = V/R = 0.199\ V/2200\ \Omega =$ ***9.0×10^{-5} A***

b) If the DVM has non-infinite resistance is the current under- or over-estimated? Explain
Underestimated *because some current goes through the DVM (parallel resistor) that is unaccounted for.*

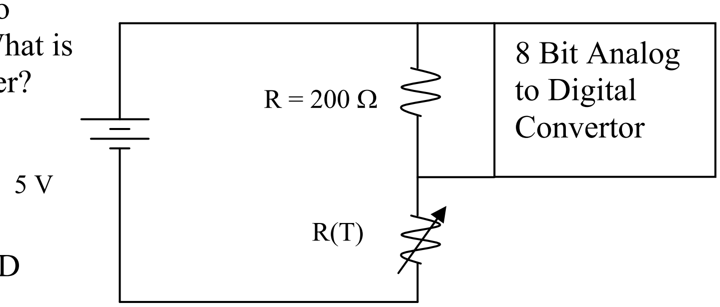
2. Assuming the diode in the figure to the right behaves ideally and V_{in} is as shown to the left, sketch V_R and V_{diode} as a function of time. (6 pts)





Note: when $V_{in} > 0$, $R_{diode} = 0$, so $V_{diode} = 0$ and $V_R = V_{in}$
when $V_{in} < 0$, R_{diode} = large, so $V_{diode} = V_{in}$ and $V_R = 0$

3. The circuit shown below is used to measure temperature with a thermistor R(T). The resistance of the thermistor, R(T), is equal to 192 kΩ·K/T (where T is the absolute temperature in units K), and the input range of the analog to digital convertor is 0 to 2 V.
(26 pts)



a) The binary output of the analog to digital convertor is 10011011. What is the corresponding decimal number?

1 + 2 + 0 + 8 + 16 + 0 + 0 + 128
= 155

b) What is the voltage read by the A/D convertor?
$155 = (V_{meas} - V_{min})\cdot 2^n / V_{range} = (V_{meas} - 0)\cdot 2^8/(2 - 0)$
$V_{meas} = 155*2V/256 =$ ***1.211 V***

b) What is the value of R(T) in Ω based on the calculation from part a)?
$R(T) = V_{R(T)}/I$ *and* $5.00\ V = V_{R(T)} + V_R$ *or* $V_{R(T)} = 5.00 - 1.211\ V = 3.789\ V$
Also, $I = V_R/R = 1.211\ V/200\ \Omega = 0.006055\ A$
$R(T) = 3.789/0.006055 = 625.8 =$ ***626 Ω***

c) What temperature (in K) does this resistance correspond to?
626 = 192,000 Ω K/T or T = 192,000/626 = 306.8 K = ***307 K***

Bonus problem – with 3: What is the average error in temperature from digitization at 298K? (3 pts)
The average voltage error from digitization = $0.5(1/2^8)2V = 0.00391\ V$
Now we need to translate this to an error in T.
$5.00\ V = I(R + 192000\ \Omega K/T)$ *and* $I = V_{meas}/R$ *so* $5.00\ V = (V_{meas}/R)(R + 192000\ \Omega K/T)$
$(5.00\ V)(200\ \Omega)/V_{meas} = 200\ \Omega + 192000\ \Omega K/T$
At this point we can 1) calculate V_{meas} *at 298 and then add 0.00391 V to* V_{meas} *, recalculate T (e.g. as T + ΔT) and take the difference or 2) solve the above equation for T and differentiate T with respect to V, and do a calculus based propagation of uncertainty calculation*
From method 1) $V_{meas} = 1000/(200\ \Omega + 192000\ \Omega K/298K) = 1.18442\ V$ *and* $V + \Delta V = 1.1883\ V$
$1000/1.18833 - 200 = 192000\ \Omega K/(T + \Delta T)$*, where* $T + \Delta T = 299.3\ K$ *and* $\Delta T =$ ***1.3 K***
In method 2) $dT/dV_{meas} = 1.92 \times 10^8/(10^6 - 4 \times 10^5 V_{meas} + 4 \times 10^4 V_{meas}^2) = 330.6$
And $dT = 330.6(dV_{meas}) =$ ***1.3K***

4. A mass spectrometer is used to analyze a sample for a 2.0 s run. A peak at 95 mass units is observed with a signal to noise of 26.3. The number of scans performed is proportional to the time. It is suspected that the compound has one S atom in it which would give a 97 peak with 4.5% of the mass 95 signal. How long of a run is needed to see the 97 peak with a signal to noise ratio of 3? Assume the noise is random. (12 pts)

Peak at 95 has S/N of 26.3. If the noise is the same for each peak (not specified but assumed), Peak at 97 should have a signal of 0.045(signal for 95 peak). With noise assumption,
S/N(97 peak) = 26.3(0.045) = 1.18
We know that $[S/N(97\ \text{peak desired})]/[S/N(97\ \text{peak 2 s run}] = [n(\text{desired})/n(2\ \text{s run})]^{0.5}$
and also that n = kt so that n(desired)/n(2 s run) = t(desired)/2 s
$3/1.18 = [t(\text{desired})/2\ s]^{0.5}$ *or* $t(\text{desired}) = (3/1.18)^2(2\ s) =$ ***13 s***

5. A chrome plating bath uses CrO_4^{2-} in an acidic solution, which is reduced to Cr(s) in the reaction. If a muffler requires 38 g of Cr (atomic weight = 52.00 g/mol), and a constant current of 30.0 A is used. (16 pts)

a) Calculate the time in hours needed for the chrome plating.
We can start by relating the mass of Cr to the moles of electrons. Method 1) Cr in CrO_4^{2-} *has an oxidation state of +6 vs. 0 for Cr in Cr(s), so we need 6 electrons. Method 2) create balanced half reaction:* $CrO_4^{2-} + 8H^+ + 6e^- \rightarrow Cr(s) + 4H_2O(l)$
$Q = \text{charge} = n_eF = 6n_{Cr}F = (6\ \text{mol e/mol Cr})(38\ \text{g Cr})(1\ \text{mol Cr}/52.00\ \text{g Cr})(96{,}500\ \text{C/mol e})$
$Q = 423{,}115\ C = I \cdot t$ *where I = current and t = time*
$t = 423{,}115C/(30.0C/s) = (14100\ s)(1\ min/60\ s)(1\ hr/60\ min) =$ ***3.9 hr***

b) If the plating requires an applied voltage of 2.85 V, what is the power consumption of the chrome plating operation?
$P = IV = (30.0\ A)(2.85\ V) =$ ***85.5 W***