INTRODUCTORY ELECTRONICS

This "experiment" is actually a series of four laboratory exercises designed to provide a basic introduction to electronics in measurements. For grading purposes it counts as two labs and may be selected as the two experiments that are elective in Pchem Lab II.

How do we electronically measure some physical quantity (temperature, pressure, absorption, concentration, etc.) and display/record/use the results?

Virtually all the measurements we do in the laboratory involve some sort of electronics. The measurement of some quantity requires the following two steps:

1) converting the physical parameter (temperature, pressure, concentration, etc.) to an electrical signal (resistance, voltage, current, capacitance, etc.)
2) manipulating (conditioning) and then displaying the electrical signal in terms of the physical units desired, recording the result, and/or using the result to control something.

<u>LIST of TOPICS and EXERCISES</u>

1) Basic Measurements and Sensors
Setting up and using the breadboard and power supply
Resistance and voltage measurements
Loading

2) Signal conditioning (operational amplifiers)
Voltage follower and follower with gain
Inverting and summing amplifiers
Comparator

3)Analog to Digital conversion
Digital counting

4) Microcontrollers
- Programming
- Digital input and output
- Analog input and output

5) Putting it all together.

ELECTRONICS NOTES

This document is a collection of notes relating to the electronics lab lectures and exercises.

REVIEW

I'm assuming you remember the following from basic physics:
Voltage, current, resistance, capacitance, inductance
Ohm's Law
Kirchoff's rules
Thevenin's Theorem

CIRCUIT DIAGRAMS

Circuits are commonly shown in a schematic (symbolic) diagram. This is the easiest way to understand what is happening in the circuit.

A pictorial diagram shows the components as they (more or less) really appear and are interconnected.

A board layout diagram shows where the components are located on the breadboard and may or may not (or only partially) show the interconnections.

For the lab exercises you will get a page showing a schematic diagram of the circuit and a board layout with complete interconnections for the simplest circuits. More complex circuits will have only partial connections shown (major parts placement and power connections at a minimum) and directions for completing the wiring.

RECORDING DATA

Measure or note in the handout means measure <u>and record in your report</u>.

When recording data from an exercise, it is helpful to make it in the form of a table.

LAB EQUIPMENT

The power supply and any signal source (variable voltage source, function generator, etc.) should be turned off before making any changes to a circuit on the breadboard.

There are a number of pieces of wire of different colors and lengths already prepared for use in wiring up the circuits on the breadboards. However they do get bent and damaged with repeated use. Don't hesitate to cut off a damaged end and strip off insulation for a fresh end. There are also spools of wire to make more and/or different lengths as you may need.

Holding the end of the wire with a pair of needle nose pliers or hemostats may make insertion into the breadboard connector easier.

Summary of Materials

1). Basic measurements and sensors

DMM

The basic measuring device used in practical electronics is the multimeter. Its multiple capabilities include functions to measure resistance, DC voltage, DC current, AC voltage, and AC current. In the lab we are using digital readout types some with autoranging, some without. We'll initially use this device to measure DC voltage and resistance.

In the lab we are primarily interested in transducers that convert a physical quantity that we want to measure into an electrical signal that we can display and record. In the thermodynamic experiments you have used thermocouples (temperature to voltage) and capacitance manometers (pressure to voltage.) In general chemistry you used a pH electrode (ion concentration to voltage) and a Spec 20 or Spec 21 spectrophotometer (light intensity to voltage.)

We will look at some transducers as part of the SENSORS section.

VOLTAGE DIVIDER (series resistors)

You should remember Ohms Law from physics: V (or E) = IR.

If two or more resistors are connected in series, the current I is the same through all the resistors. [Kirchoff's rule that all currents at a point (node) in a circuit must sum to zero.] and the sum of the voltage drops across all the resistors is equal to the applied voltage. [Kirchoff's rule that the sum of the voltage drops around a closed loop is zero.] The total resistance of several resistors in series:

$$R_T = R_1 + R_2 + \ldots + R_n$$

LOADING (parallel resistors)

For resistors in parallel, the voltage across them is the same but the currents through them are different.

The total resistance for several resistors in parallel:

$$1/R_T = 1/R_1 + 1/R_2 + \ldots + 1/R_n$$

A voltage measuring device that draws some current from the circuit under test can be treated as a resistor placed in parallel with the resistance of the circuit across which it is connected.

Schematic symbol for a resistor. 

2) Analog Signal Conditioning

THE OPERATIONAL AMPLIFIER

The operational amplifier is a specific type of amplifying device with the following characteristics:

it is an active device that requires an external DC power supply, Vdd and Vss (where Vdd > Vss). The output voltage range of the operational amplifier is determined by the power supply voltages;

it has two inputs, one inverting (usually labeled -) and one non-inverting (usually labeled +), a positive voltage at the + input will drive the output positive and a positive voltage at the - input will drive the output negative;

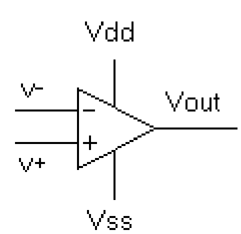
it has very high differential gain, A. (The voltage difference between the two inputs is amplified by a large amount, typically a factor of 10^5 to 10^8.)

$$V_{out} = A(v_+ - v_-);$$

it has a very high input impedance (resistance) typically 10^7 to 10^{12} ohms (virtually no current flows into the input terminals);

the output impedance is relatively low, meaning it is possible for the op-amp to supply reasonable output current.

The extremely high gain of the op-amp allows us to set up circuits that are essentially independent of the internal workings of the op-amp. By applying negative feedback (taking some portion of the output and applying it back to the input to counteract the high gain) we can set gains or perform functions we want by the use of simple external components with the results dependent only on the characteristics of the external components.



Schematic symbol of operational amplifier.

Some uses of the op-amp

The op amp can be configured to perform many different operations:

COMPARITOR

The comparitor makes use of the very high gain of the op-amp to “compare” two voltages by amplifying the small “error” (difference between reference and unknown voltages) to a useable level

VOLTAGE FOLLOWER

The voltage follower does exactly what its name implies. The output voltage is the same as the input voltage. At first this would seem to be a useless setup, but remember that the op-amp has a very high input impedance and draws almost no current from the source. For example, it allows a pH electrode to present its value on an analog meter that requires significant current to operate.

VOLTAGE FOLLOWER WITH GAIN

The follower with gain provides an output voltage that is the input voltage times a set factor (the GAIN) and of the same polarity.

CURRENT FOLLOWER

The current follower provides an output voltage that is proportional to the input current from some device.

SUMMING and INVERTING AMPLIFIERS

The current follower above allows the construction of simple circuits that can sum and/or invert signal(s)

3) Analog to Digital conversion

DIGITAL COUNTER

A counter is a combination of flip-flops and gates that is used to count the number of pulses applied to its input.

With digital circuitry, a value (number) is represented by a group of digital bits (ones and zeros) rather than, say, a voltage level from an op-amp.

4) Microcontrollers

Microcontollers are single chip computers that have interfacing capabilities built into the chip itself and often form the heart of “smart” instruments. Examples include the digital pH meters used in the general chemistry labs, digital analytical balances, and the digital thermometers used in the physical chemistry lab for combustion calorimetry.

These single chip computers are programmed using a PC to develop and compile the software which is then transferred to the chip. The microcontroller’s program memory is static (retains the program even when power is removed from the chip) and automatically starts the program when power is applied.

5) Putting it all together

Take all the pieces (sensor, signal conditioning, analog to digital conversion, microcontroller) and make a simple instrument.

Computer Interfacing

While we won't be doing it as part of the electronics lab, connecting a measuring device to a personal computer allows the creation of powerful data logging and data manipulation devices.

Computer interfacing is a subject with many variations that could easily be a course in itself. There are three methods that account for a lot of the interfacing you may run into. These are 1) the RS-232 (communications serial) interface and the USB interface, 2) the IEEE-488 bus interface system, and 3) a "general purpose" analog and/or digital interface board. The first two require that the laboratory device or instrument be designed to use one of the two systems, which means that they have some level of built-in computer intelligence (usually a microcontroller). The third is used when the device or instrument was not designed for use with a computer but at best provides an analog voltage output proportional to the parameter being measured.

Virtually all personal computers have a COM serial port or USB port that programs can access to send and receive strings of data. Of course, the "remote" device or instrument must have the capability of interpreting the string of data sent to it and respond accordingly. (The computer that is linked to the mass spectrometer used in the CO oxidation experiment and the computer linked to the Fluorescence Spectrometer are also examples.)

The second (IEEE-488, also called GPIB or HPIB) is similar to the first, except that it is faster and allows more than one instrument to be controlled through the interface card that is placed in the computer. (The HPLC instrument used in the Instrumental lab uses this system to allow the computer to control the pump, autosampler, and detector.)

The third method requires more complex equipment connected to the computer, but generally speaking almost any lab device could be interfaced using it. (The naphthalene quenching and stopped-flow kinetics experiments use this method.)