Auto-titrating pH Meter

Mechatronics

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1. Abstract

Organophosphates (OPs) are among the most toxic substances known. Examples of these compounds are: (1) parathion and paraoxon (as pesticides), and (2) soman, sarin and VX nerve gas (used as chemical warfare agents). These compounds irreversibly inhibit acetylcholine degradation in the human body and can cause fatality instantly by causing persistent and uncontrollable muscle stimulations. Efforts were made to destroy OPs-based nerve gases under the *Chemical Weapons Treaty*. Compliance to the articles of the treaty regarding OPs destruction has been limited due to the current methodologies used. That is, incineration and chemical hydrolysis are very time consuming, cost inefficient, require highly trained personal, and most importantly they are not amenable to *on-line* process monitoring. Exploiting the biochemical diversity of enzymes, our goal is to develop an auto-titrating system which will monitor the degradation of OPs so that ultimately it enhances the lifetime of the probe.

Hydrolases are a family of enzymes which catalyze the hydrolysis of chemical bonds. This family of enzymes is most often used in biotechnological applications. Phosphotriesterase (PTE), a specific hydrolase, has been shown to have near-diffusion rates of hydrolysis to several different OPs as presented in Schematic 1[1, 2]. Capitalizing on the two protons released for each OPs-molecule hydrolyzed, our goal is to develop a potentiometric enzyme electrode with feed-back controls that will maintain a reaction mixture environment within the optimal pH for the enzyme. BS2 will be utilized as the microcontroller. This detection system offers several advantages over traditional methods of OPs degradation; it is relatively cost efficient, requires minimal technical expertise and maintains the lifetime of the enzyme by preventing acid denaturation. Although this system is designed for the enzymatic degradation of OPs, the degradation reaction mechanism of hydrolases typically generates protons. This detection system is modular and can be used for any hydrolase mediated reaction by the user immobilizing the specific hydrolase on the electrode.

2. Introduction

2.1 Problem Statement

The Auto-Titrating pH (ATpH) meter is designed to be fully automated; it is expected to display the pH of a given solution, adjust the pH to a preset value or maintain the pH within a given range. This instrument is meant for a chemical and biological laboratory. The pH measurement is a fundamental parameter for most chemical and biological reactions. The reproducibility of experimental data is hindered by inconsistently prepared reagents. For example, the industrial significant reaction of lipase hydrolysis is 10,000-fold less active at pH 4 as opposed to pH 7, thus demonstrating the importance of maintaining a desired pH. In addition, the environment around a protein changes with a given pH. As the concentration of hydrogen ion ([H+]) increases or decreases within a solution, a protein's amino acid residues may gain or lose protons, affecting its overall net charge and structure, and therefore influencing its native function. Different proteins have unique pH ranges at which they function optimally. For protein engineers, maintaining a pH within this range may not only save protein functionality but may also increase yield productivity if the protein in question is an enzyme responsible for catalyzing biochemical reactions.

2.2 Background

pH refers to the concentration of [H+] in a solution. In general terms it is a scale of measurement to determine the acidic or alkaline (or basic) state of a solution. The pH scale ranges from 0 to 14. At pH 7, the solution is neutral. For pH units lower than 7, the solution is acidic and at pH units higher than 7 are considered basic. In more technical terms the pH is defined as the negative logarithm of the hydrogen ion concentration in an aqueous solution (Equation 1).

$$pH = -\log [H+] \qquad \text{Equation 1}$$

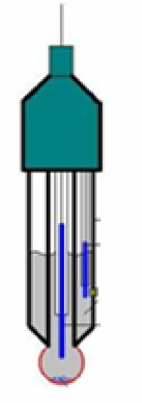

Figure 1. Cartoon representation of standard pH meter

The pH of chemical and biological reactions in aqueous environments is of fundamental importance, it is accurately measured by an instrument aptly named a pH meter. pH meters are digital voltmeters which can accurately measure electrodes with internal resistance in the range of 10 -100M**Ω**. These meters are sensitive to temperature changes, electromagnetic noise and electrostatic interactions. A general pH electrode is composed of two half-cells (in a tube within tube orientation) (Figure 1); an acquisition electrode and a reference electrode. The electrodes are constructed of silver chloride electrodes and housed within a non-conductive polymer or glass. The inner tubes are filled with saturated potassium chloride (KCl) solutions and 0.1 M HCl solutions, generating a electrochemical cell, where the inner tube (reference tube) is isolated from the environment and the outer tube is allowed to interact with the outside environment.

A linear relationship is described to related pH to millivolts (mV), where 1 pH unit is equivalent to 59.2 mV and at pH 7 = 0 mV (Figure 2). pH meters are often employed to measure the change of mV in several industrial important enzymatically mediated reactions.

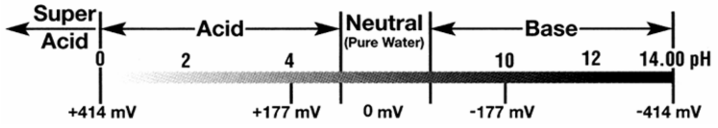

Figure 2 : pH to mV conversion scale

3. Concept Development

3.1 Overall System

The overall design of our instrument is to serve multiple purposes (Figure 3). First, it can be used as low cost alternative to high priced pH meters which may range in the $500 range. Secondly, the ATpH meter is capable of auto-titrating using BS2 as the microcontroller. The system would first allow the user to read the pH of their initial solution and then prompt user to enter a desired pH in the range of 4.0 to 7.0, which is the limit that we set for in our program for the ATpH instrument.

The pH of the solution is continuously monitored; either acid or base would be pumped into the buffer (i.e. the sample solution) depending upon the users pH input. The titration system includes two reservoirs, one containing an acidic component and the other containing a basic component, which would be used to maintain a reaction or reach to a certain pH at a user given range of pH values. A total of two Basic Stamp microcontrollers are used; one is used to single to control two continuous servo motors which will dispense acid or base at a preset speed. Another Basic Stamp is set to control a third Servo motor which will serve as a magnetic stir plate allowing the reaction spin a constant rate; this will avoid the formation of localized pH reading. Buffers containing different chemical components may present different densities and without proper mixing inaccurate reading will inevitably occur. The ultimate final application of this instrument will be to detect the enzymatic mediated degradation of organophosphates.

3.2 Mechanical Design

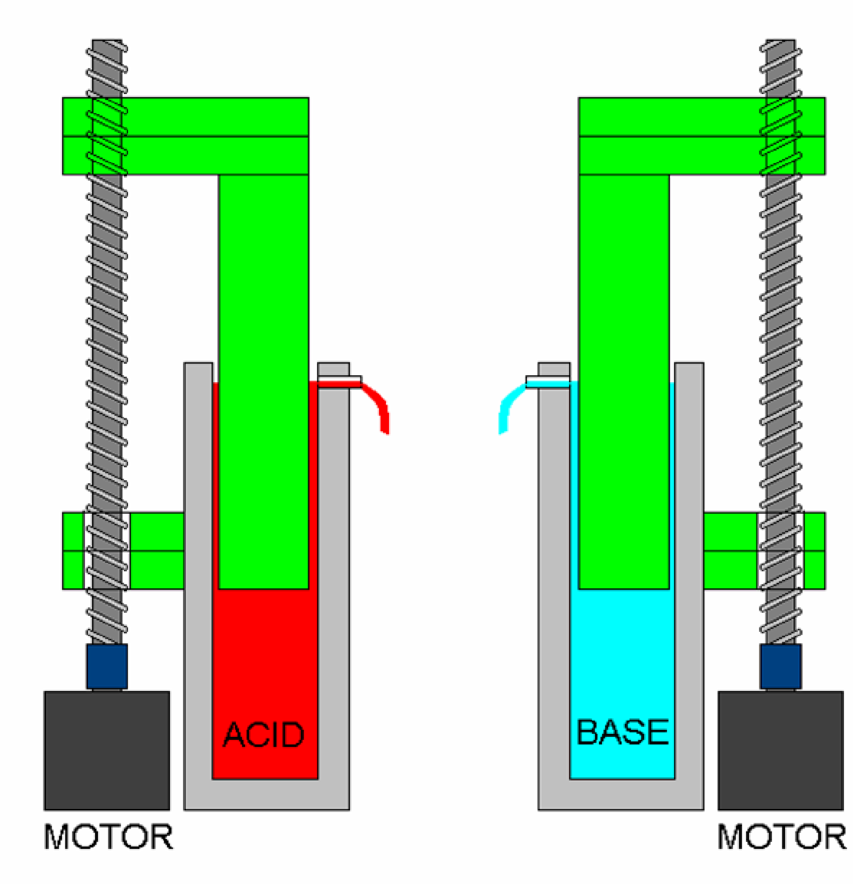

Figure 3 : Initial concept design for titration system

Our initial conceptual design for the titration portion of our system consisted of two servo-controlled plungers which would displace acid or base into the reaction mixture in order to adjust the pH measurement to a desired value (or range). This design progressed passed the conceptual stage as shown in Figure 2. Unfortunately, once the system was designed and the final tests were run, we noticed some flaws. The stability of the unit as a whole was not up to par with our standards. The rotations of the servo motors which were each fastened to a long screw shaft would cause the apparatus to become unsteady. Also, once the plungers were actuated, some leakage would occur at the top of the reservoir chamber in addition to a noticeable residual spill from the spouts connected to the reservoirs once the servos stopped rotating. We placed PVC pipe fittings on top of the reservoirs and introduced a gasket into the chamber to aid with the leakage issue. Unfortunately, this did not entirely address the issue and leakage remained an annoyance. However, the pipe fittings did provide extra stability to our unit. In the end, we arrived at the general consensus that this leakage issue also presented a safety hazard, once acid and base solutions would be placed into the reservoirs. Ultimately, we resorted to incorporating syringes into our design instead of the plungers to deal with this issue.

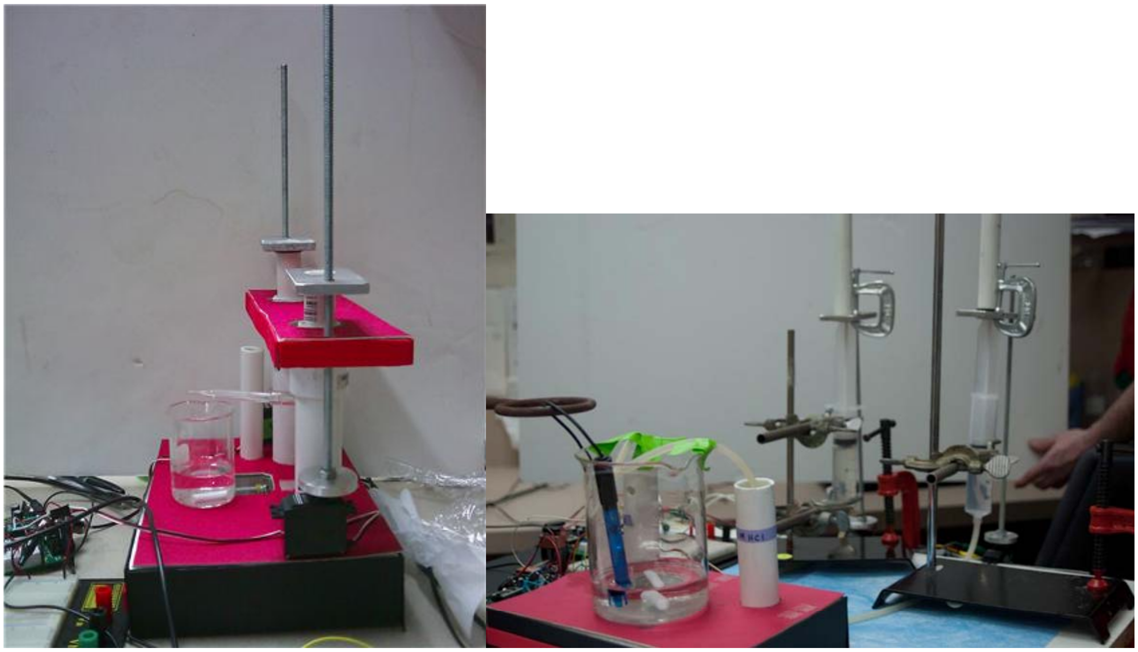

Figure 4: Initial plunger style design (left) and final syringe style design

A secondary and final design was developed incorporating the understanding of the flaws from the initial design. First, the servo motors were metal mounted to the wooden base as opposed to dual lock which would frequently come lose under the torque of the motor. The handcrafted PVC plunger was replaced with traditional laboratory syringes. These syringes provided numerous advantageous over the initial design. These syringes allow for a vacuum tight seal which allows for quick and precise distribution of the acid/base solutions. The clear and calibrated chamber allow for ease of monitoring of amount of reagent left in piston chamber. Two separate pushbuttons were incorporated as human interface to rewind the servo motors. That is if the syringes are wound all the way down by the servo motors (no more acid/base left in the syringes), each syringe can be easily refilled without having to wind out the top plates like the initial design in order to pour liquid in them. This can be easily done by pressing onto the corresponding pushbutton to move the syringe's plunger up while the tube is submerged in either acid/base. Finally, the aesthetical pleasing initial mounting unit was disassembled for a more ergonomically advantageous design. As the reactions are delicate, expensive and potentially harmful it was deemed more important through survey of potential users to sacrifice superficial beauty for practical and safe gain.

3.3 Electrical Design

3.3.1 Materials Needed

- 10K Potentiometer
- TL082 Dual BiFET OP Amp
- ADC0831 A/D convertor
- Three continuous servo motors
- pH probe sensor
- 9V snap connectors
- Various resistors
- Various jump wires
- 3 Normally Open Push-button switches

3.3.2 Cost Estimate

Materials		**Estimated Cost**
10K Potentiometer		*
ADC0831 A/D convertor		*
Three continuous servo motors		*
Various resistors		*
Various jump wires		*
3 Normally Open Push-button switches		*
BS2 kit		$200.00
TL082 Dual BiFET OP Amp x 3		$6.00
pH probe sensor		$60.00
9V snap connectors		$3.00
Ring clamps x 2		$20.00
9V Battery x 2		$10.00
Tools/ misc		$20.00
* = included in BS2 kit	**Total Cost**	$319.00

3.3.3 Summary

The electrical component of our project is based upon measuring very small voltages around the range of a couple hundred millivolts and distinguishing between voltage changes brought about by a change in the concentration of hydrogen ion [H+] in solution. A higher concentration of H+ ion will result in a more acidic environment and a lower pH value. Essentially, a change of approximately 60 mV corresponds to a unit change in pH. A pH of 7.0 is the neutral pH value as this pH has an associated millivoltage reading of 0 mV. As we descend on the pH scale, the voltage readings increase according to the previously stated relationship. For example, a pH of 5.0 has an equivalent voltage reading of approximately 120 mV. A decrease in pH to 4.0 would be accompanied by an increase in the voltage reading by 60 mV resulting in a voltage reading of 120 mV + 60 mV = 180 mV at pH 4.0.

Figure 3 : Oakton pH probe used in our design

Central to our project is our pH probe, which is common in many laboratory settings (See Figure 3). We selected the Oakton pH probe model number 03847K for our project. This probe was selected because of cost and usability. There are a broad range of pH probes available on the market ranging from a few dollars to upwards of a few hundred, with the cost of these probes generally related to lifetime, sensitivity and range. For our applications we selected a mid-range cost as the majority of applications for our instrument will focus on general laboratory applications. The probe is compliant with any pH and/or millivolt meter commercially available which convienently displays the pH and voltage readings on user friendly hardware. We tested the effectiveness of this probe on several laboratory pH meters as well as a digital multimeter (DMM) supplied by the NYU-Poly Mechatronics Laboratory. For our project, we proposed to only use the pH probe, with the Basic stamp as an interface to achieve accurate and reliable pH measurements.

One of the first problems that we encountered with the electrical portion of our project was the small voltage output obtained when using solely the pH probe as our sensor. Such small voltages cannot be directly interfaced with the Basic Stamp microcontroller. In addition, all pH probes possess a native high impedance, or resistance to electrical current, stemming from the glass membrane which houses the electrodes. This special glass has tiny pores which cannot support much electrical current. This ultimately results in the impossibility of measuring voltage measurements strictly with a digital multimeter and our pH probe. To overcome this obstacle, we realized that an operational amplifier, such as the LM358 displayed in Figure 7, would be needed to amplify our signal input from the pH probe. In addition to providing amplification of the signal, an op-amp also converts the high source impedance from the pH probe to low source impedance. This enabled us to directly measure output values with a digital multimeter once they have been directed through an appropriate op-amp. As we soon learned, the LM358 is insufficient for our purposes with this circuit. One of the golden rules of op-amp analysis is that no current flows into the two input terminals. In reality, however, a small current does flow into each terminal to bias the input transistors. Unfortunately, this miniscule current gets converted into a voltage by the circuit's local resistors and also gets amplified right along with the signal. The result, although minimal, is an output error in our amplified signal. The LM358 did not work with our setup and we decided to use the popular TL082 op-amp which has a very high input impedance. The pin layout for the TL082 op-amp is shown in Figure 8. The gain, or amount of amplification, is strictly controlled by resistors, R_f and R_i , shown in Figure 9. The non-inverting setup for the op-amp is used when one wants to amplify a positive (>0 V) low voltage signal , such as occurs in the low pH range (pH 0 – pH7).

Figure 4 : LM358 op-amp

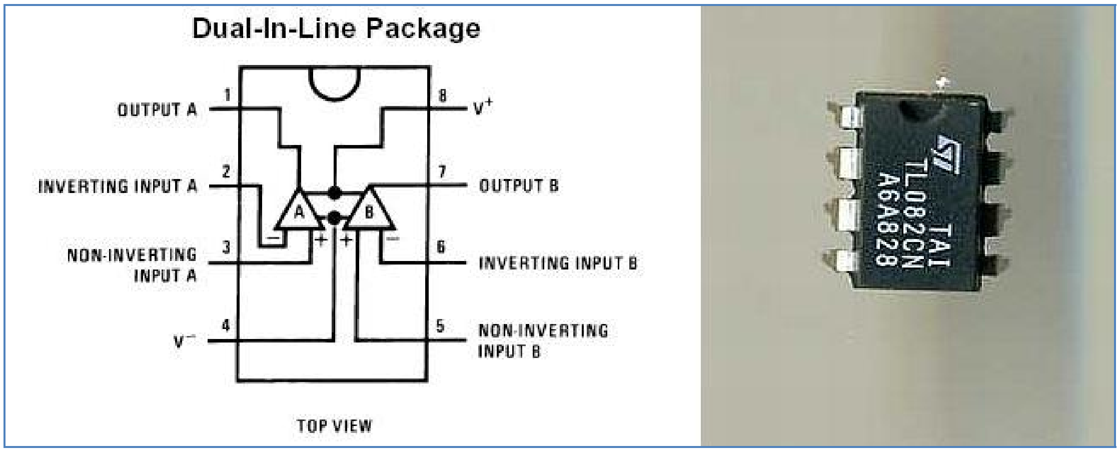

Figure 5 : TL082 op-amp and pin layout

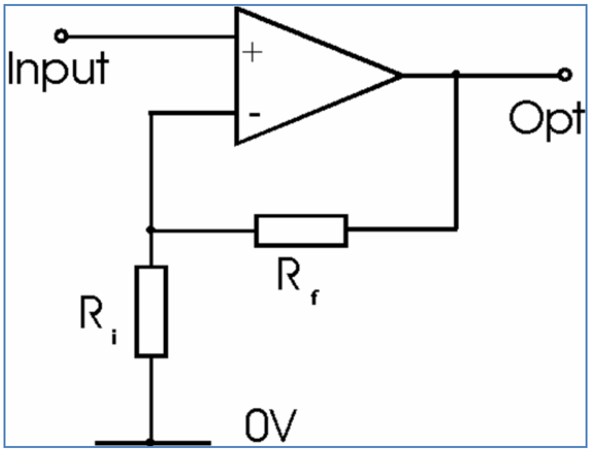

Figure 6 : Non-inverting Op-Amp

In a setup such as that in Figure 9, the gain and the voltage output is given by the following Equation 2

$$V_{out} = V_{in}\,(1+R_f/R_i) \qquad \text{Equation 2}$$

The gain, or the amplification factor, is the term in parentheses. Resistor values Rf and Ri were set to 10 kΩ and 1 kΩ, respectively, which resulted in a gain of 11 for our non-inverting setup. In order to test if the TL082 op-amp was working correctly, we designed a voltage divider circuit incorporating a 10KΩ potentiometer to mimic the voltage values we would expect for a range of pH from pH 1 – pH7 (See Figure 10). We were able to mimic the voltage values that a pH probe would input to the non-inverting terminal of the TL082 op-amp (0.00 V-0.360 V), by rotating the shaft on the 10K pot. This simple circuit also resembled the analog signal that would be coming in from our pH probe sensor. If we shorted our output terminal 1 with our inverting terminal 2 of our TL082 op-amp, then this would now allow us to read voltages using a digital multimeter, which we could not do earlier. This is possible because the only duty that the op-amp is performing without a feedback loop in place is the conversion of the high source impedance signal from the probe to low source impedance, enabling us to now make the readings. Looking back at Figure 9, if we also include resistors Rf and Ri in the non-inverting setup, this will amplify our signal. We set R_f and R_i to 10, 000 **Ω** and 1, 000 **Ω**, respectively to achieve a gain of 11. After amplifying our input voltage signals (0.00 V-0.360 V), the voltages obtained corresponded to those obtained after an amplification by a factor of 11 (.035 V-4.03). Once the op-amp was confirmed in working order, the next task was to digitize the values coming out of the op-amp.

Digitization of our "analog" signal coming from our voltage divider circuit was achieved using an ADC0831 analog to digital convertor. The analog amplified output signal coming out of the TL082 op-amp is fed into pin 2 of the ADC0831(Figure 11). Our chip select, digital outputs, and clock pins corresponding to pins 1, 6, and 7 of the A/D convertor respectively, are interfaced with BS2 I/O pins. The offset at pin 3 of ADC0831 was set at 0V while V_{ref} was set close to the max 4.03 V output signal from TL082 (3.83 V) using another voltage divider circuit. The schematic of our circuit is shown in Figure 12.

Once all these components were working cooperatively, only then did we disconnect the voltage divider from the non-inverting terminal of our op-amp mimicking the pH sensor voltage values and replaced it with the positive lead coming from our sensor. The (-) lead was connected to common ground. Once connected, we quickly discovered that the voltage signal coming out of our pH probe was fluctuating greatly. After much frustration, we discovered the root of this problem. Initially, we attached an alligator clip to the BNC adapter used to connect the coaxial pin from the pH probe to the TL-082 op-amp in order to interface the probe with the BS2. This added wire introduced a lot of noise and fluctuation within our signal. Once we eliminated this wire and simply coiled a jumper wire around the BNC connecter, this problem was no longer an issue and we achieved relatively stable voltage readings.

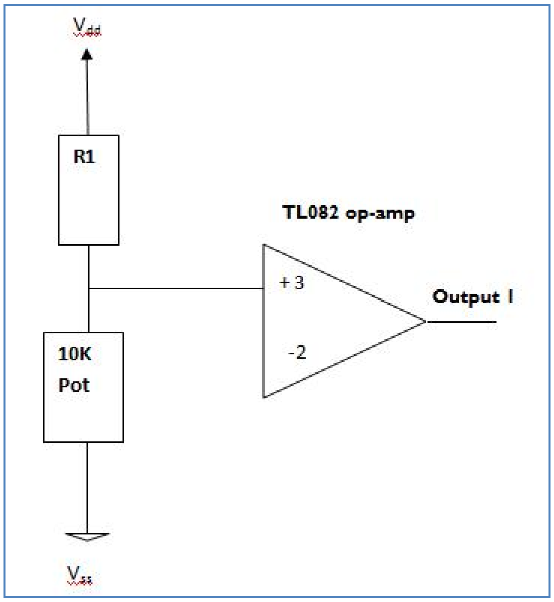

Figure 7 : Voltage Divider Circuit

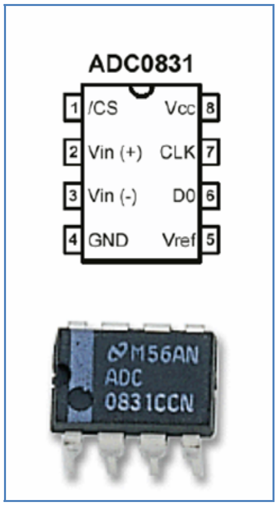

Figure 8 : ADC0831 and pin layout

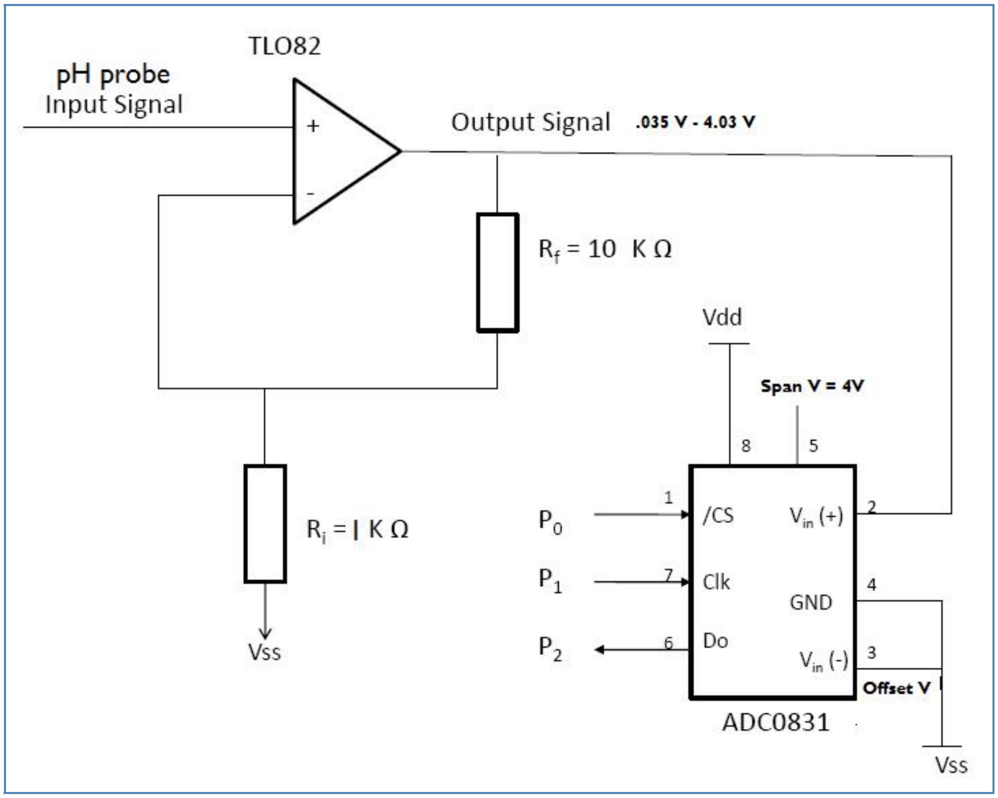

Figure 9 : Circuit diagram

3.4. Programming

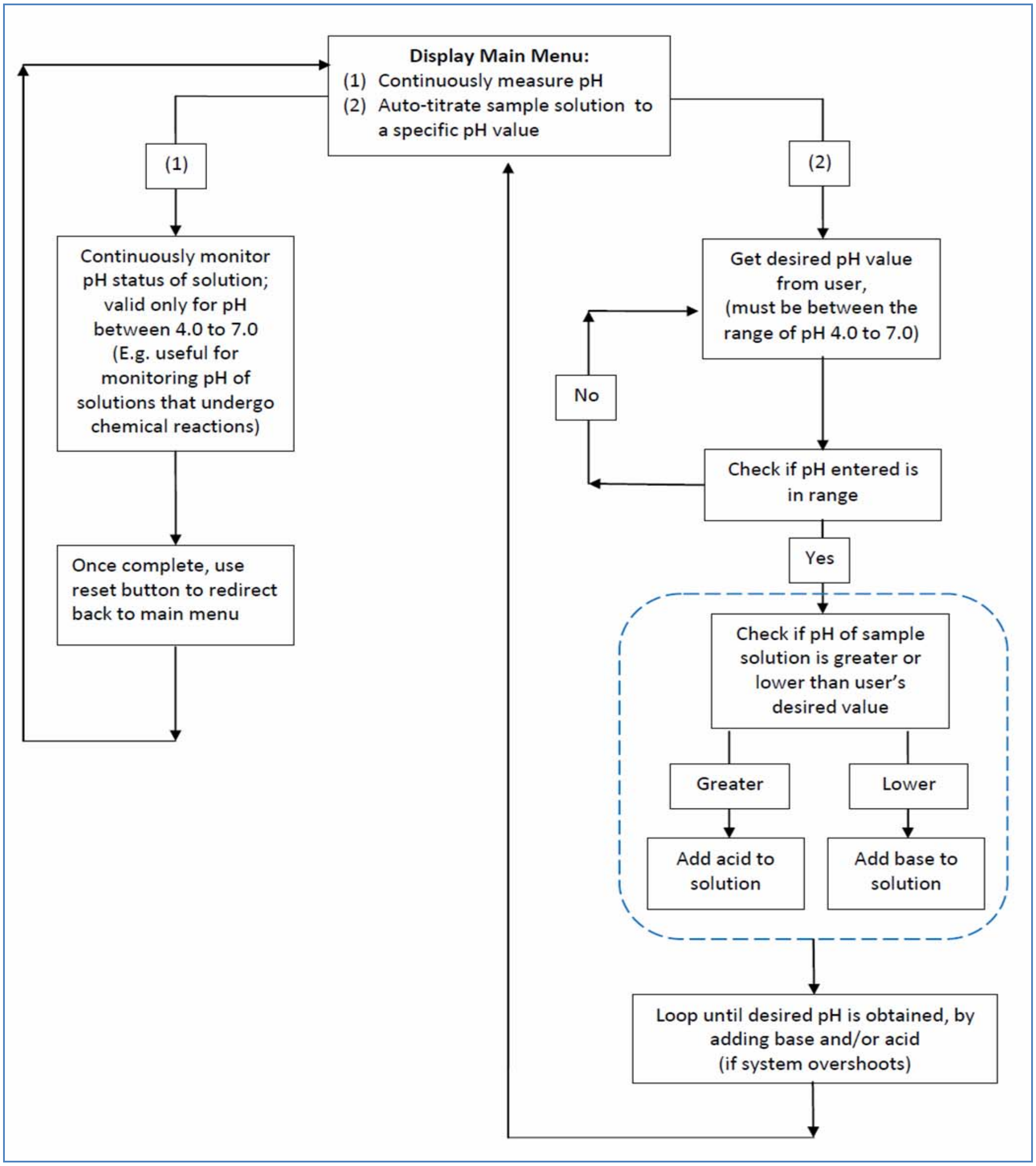

Figure 10 : Flow chart of pH meter program

The program that we use to run our apparatus has the general architecture as shown in the flow chart above. The main menu of the program allows user to choose between two functions: (1) continuously measure pH of solution and (2) user enters a final desired pH for the solution and the program will add either base or acid to the solution and once the desired pH is achieved the program ends and returns to the main menu. See Appendix 9 for programming codes.

4. System Testing and Results

Our initial design showed promise, yet posed a safety hazard during operation. Throughout the testing stages, we made some advances with regards to stability and leakage issues; however we ultimately decided to use the more practical syringe design. Videos of test runs which were successful are available upon request.

Because of the safety and cost issues associated with both the synthesis of PTE and the organophosphates, the initial test were conducted on a separate, more expensive, non-titrating pH meter to determine the optimal parameters for the reaction. Several different buffering capacities and enzyme substrate concentrations were explored. It was determined that a low molar concentration of Tris pH 7.0 in the absence of salt provide the optimal change in mV (Table 1).

Buffer	Salt	pH	mV Start	mV 3 min
50 mM NaPho	500 mM	7.0	49 mV	63 mV
50 mM NaPho	0 mM	7.0	37 mV	53 mV
50 mM Tris	500 mM	7.0	5 mV	10 mV
50 mM Tris	0 mM	7.0	18 mV	55 mV
100 mM NaPho	500 mM	7.0	48 mV	47 mV
100 mM NaPho	0 mM	7.0	46 mV	43 mV

Table 1

5. Conclusion

Our pH meter system was initially designed to function in the positive realm of millivoltage readings. This pH range includes all pH values within the range of pH 0 – pH 7. The associated voltages were amplified using a TL082 op-amp in a non-inverting amplifying setup. In order to design a pH meter system to analyze pH measurements in the basic range of pH 7- pH 14, we would need to use an inverting amplifier setup. This could be done on the same circuit by making use of the second amplifier system on the dual JFET op-amp. However, given the problems that we encountered with the pH probe, we did not have the time to implement this range of pH into our system. We have since discussed what needs to be done in order to measure pH values within this range along with the associated circuitry that needs to be incorporated. Overall we are happy with our system and look forward to exploring more options in order to realize a better overall design. Perhaps, we may be able to correct the original plunger setup which was aesthetically more pleasing.

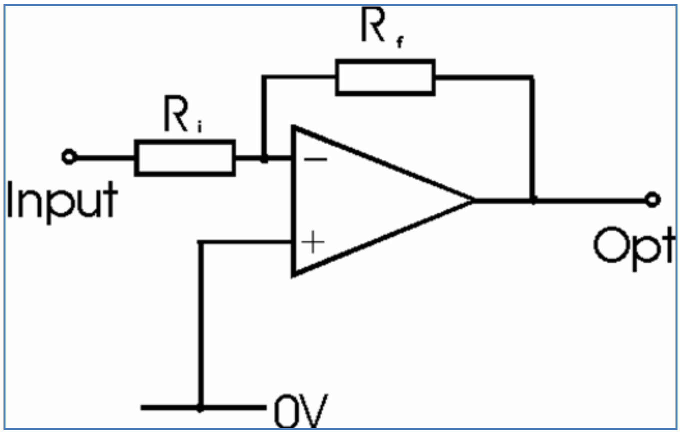

Figure 11 : Inverting Op-Amp Schematic

$$A_V = -\frac{R_f}{R_i}$$

Figure 12 : Gain for Inverting Amplifier Schematic

8. References

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- BASIC Stamp Syntax and Reference Manual, Version 2.2, 2005 by Parallax
- Robotics with the Boe-Bot, Student Guide, Version 2.2, 2004 by Parallax
- V. Kapila, Mechatronics Course Lecture Notes, 2009
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- http://www.66pacific.com/ph/simplest_ph.aspx
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- http://www.radio-electronics.com/info/circuits/

9. Appendix

9.1 Programming Code

Program 1: pH meter & auto-titration

```
' {$STAMP BS2}
' {$PBASIC 2.5}

'TEAM 5: MECHATRONICS (FALL 2009), PROF. KAPILA
'Carole Chen
'Michael Hernandez
'Peter Baker
'WHAT IT DOES
'Version 1.0

'-------------- [I/O Configurations] -----------------
'P0          CS             output
'P1          CLK             input
'P2          DATAOUTPUT       input
'P3          SERVO_A         output
'P4          SERVO_B         output
'P5          SERVO_C         output
'P6          REWIND_A         input
'P7          REWIND_B         input
'P8          LCD             input
'P9          BUTTON_START      input
'P10          BUTTON_STOP       input
'P11          FREE
'P12          FREE
'P13          FREE
'P14          FREE
'P15          FREE

'-------------- [PIN INITIALIZATIONS] -----------------
CS            PIN 0
CLK            PIN 1
DATAOUTPUT      PIN 2
SERVO_A         PIN 3
SERVO_B         PIN 4
SERVO_C         PIN 5
REWIND_A        PIN 6
REWIND_B        PIN 7
LCD            PIN 8
BUTTON_START    PIN 9
```

```
BUTTON_STOP     PIN 10

'-------------- [variable declarations] -----------------
choice              VAR      Nib
ADC_VOLTAGE             VAR      Byte    'value "representing" voltage after converted from analog to
digital (after ADC)
v                   VAR      Byte    '-----define this
r                   VAR      Byte    '-----define this
pH                  VAR      Byte
pH_test             VAR      Word
desired_pH          VAR      Word
desired_pH1             VAR      Byte
desired_pH2             VAR      Byte
counter                 VAR      Word    'counter for servo

menu:
'---------- [Debug & Select Programming Choices] ---------------
DEBUG "Enter your choice of function: ", CR,CR,
     "1. Measure pH only.", CR, CR,
     "2. Make buffer of desired pH value. *Choose between pH 4-7.", CR,CR



DEBUG CR, CR, "You've entered: "
DEBUGIN DEC1 choice              'get user's choice selection
PAUSE 1500                       'wait for 1.5 s before clearing screen and show user's choice
DEBUG CR, CR

GOTO check_choice

DEBUG CLS

check_choice:                    'check user's choice
IF choice = 1 THEN
  DEBUG CLS
  GOTO measure_pH

ELSEIF choice = 2 THEN
  DEBUG CLS
  GOTO make_buffer

ELSE
  DEBUG "Invalid entry. Please try again."
  DEBUG CR, CR, "You've entered: "
  DEBUGIN DEC1 choice            'get user's choice selection
  DEBUG CR, CR
  GOTO check_choice

ENDIF
```

```
'--------------- [Main Subroutines ] -------------------

measure_pH:
 DO
   GOSUB ADC_Data
   GOSUB Calc_Volts
   GOSUB Display
   GOSUB Calc_pH
 LOOP
 'RETURN

make_buffer:
 GOSUB get_desired_pH
 GOSUB check_desired_pH
 PAUSE 1500                    'wait 1.5 before clearing screen
 DEBUG CLS

   DO
   GOSUB ADC_Data
   GOSUB Calc_Volts
   GOSUB Display
   GOSUB Calc_pH
   GOSUB check_pH_stat
   LOOP


stay_in_range:

 RETURN

'---------------- [Subroutines] ------------------------

ADC_Data:
   HIGH CS
   LOW CS
   LOW CLK
   PULSOUT CLK, 210
   SHIFTIN DATAOUTPUT,CLK,MSBPOST,[ADC_VOLTAGE\8]
   RETURN

Calc_Volts:
   v = 5 * ADC_VOLTAGE / 255 '.. new line
   RETURN

Display:
   DEBUG HOME
```

```
   IF (ADC_VOLTAGE > 140) OR (ADC_VOLTAGE < 0) THEN
    DEBUG "pH is out of range; not within pH 4.0 to 7.0.", CR,CR          'makes sure voltage doesn't
read ph < 4
   ELSE
    DEBUG "Voltage measured by pH probe, [mV]: ", DEC3 ADC_VOLTAGE
    DEBUG CR, CR,"The 8-bit binary value of this voltage is: ", BIN8 ADC_VOLTAGE
   ENDIF

  RETURN

Calc_pH:
  IF (ADC_VOLTAGE >= 0) AND (ADC_VOLTAGE <=20) THEN
   DEBUG CR, "pH = 7.0 ", CR, CR
   pH = 70

  ELSEIF (ADC_VOLTAGE >= 21) AND (ADC_VOLTAGE <=40) THEN
   DEBUG CR, "pH = 6.5", CR, CR
   pH = 65

  ELSEIF (ADC_VOLTAGE >= 41) AND (ADC_VOLTAGE<=60) THEN
   DEBUG CR, "pH = 6.0", CR, CR
   pH = 60

  ELSEIF (ADC_VOLTAGE >= 61) AND (ADC_VOLTAGE <=80) THEN
   DEBUG CR, "pH = 5.5", CR, CR
   pH = 55

  ELSEIF (ADC_VOLTAGE >= 81) AND (ADC_VOLTAGE<=100) THEN
   DEBUG CR,"pH = 5.0", CR, CR
   pH = 50

  ELSEIF (ADC_VOLTAGE >= 101) AND (ADC_VOLTAGE <=120) THEN
   DEBUG CR,"pH = 4.5", CR, CR
   pH = 45

  ELSEIF (ADC_VOLTAGE >= 121) AND (ADC_VOLTAGE <=140) THEN
   DEBUG CR,"pH = 4.0", CR, CR
   pH = 40

  ELSE
   DEBUG "Out of Range"

  ENDIF
  RETURN

get_desired_pH:
  DEBUG "Enter the desired pH for your sample: "
   DEBUGIN DEC1 desired_pH1
```

```
   DEBUG "."
     DEBUGIN DEC1 desired_pH2
   desired_pH = (desired_pH1*10) + desired_pH2
   RETURN

check_desired_pH:
   IF (desired_pH >= 40) AND (desired_pH <= 70) THEN
     DEBUG CR,CR, "The pH will now be change to: "
     GOSUB neat_pH_display
     PAUSE 1500
     RETURN
   ELSE
     DEBUG CR, "pH entered is out of range. Please try again. "
     DEBUGIN DEC desired_pH
     GOSUB check_desired_pH
   ENDIF
   RETURN

neat_pH_display:
   DEBUG DEC1 desired_pH1,".", DEC1 desired_pH2, CR,CR
   RETURN

check_pH_stat:
   'DO WHILE ( pH <>  desired_pH)
     IF (pH <> desired_pH) THEN
       DEBUG CR,"Checking if lower or higher",CR
       GOSUB check_lower_or_higher
       RETURN
     ELSE
       DEBUG CR,"You have reached your desired state",CR
       PAUSE 5000
       GOTO menu
     ENDIF
   'LOOP
   'RETURN

check_lower_or_higher:

   IF (pH < desired_pH) THEN
     DEBUG CR
     DEBUG "Adding Base" , CR
     GOSUB add_base
     RETURN
   ELSEIF (pH > desired_pH) THEN
     DEBUG CR
     DEBUG "Adding Acid", CR
     GOSUB add_acid
     RETURN
```

```
  ENDIF
  RETURN

add_acid:
'ADD ACID - plunger controlling acid goes down (corresponds to plunger1)
counter = 1
FOR counter = 1 TO 150 'Rotate right 1 FULL ROUND if 1-48, *CHANGE THE RANGE TO CONTROL THE AMOUNT OF ROTATIONS
PULSOUT SERVO_A, 800
PAUSE 20   'DO NOT CHANGE THIS VALUE
NEXT
RETURN

add_base:
'ADD BASE - plunger controlling base goes down (corresponds to plunger2)
counter = 1
FOR counter = 1 TO 150 'Rotate right 1 FULL ROUND if 1-48, *CHANGE THE RANGE TO CONTROL THE AMOUNT OF ROTATIONS
PULSOUT SERVO_B, 800
PAUSE 20   'DO NOT CHANGE THIS VALUE
NEXT
RETURN
```

Program 2: rewind syringe

```
' {$STAMP BS2}

' {$PBASIC 2.5}



REWIND_A       PIN 6

REWIND_B       PIN 7





DEBUG "REWIND SERVO PROGRAM", CR

DEBUG "PRESS BUTTON 1 or 2 to START THE REWIND", CR



DO
```

```
 IF (REWIND_A=1) AND (REWIND_B=1) THEN
 DO
  PULSOUT 3, 650
  PULSOUT 4, 650
 LOOP UNTIL (REWIND_A=0) OR (REWIND_B=0)

 ELSEIF (REWIND_A=1) THEN
  DO
   PULSOUT 3, 650
  LOOP UNTIL (REWIND_A=0)
 ELSEIF (REWIND_B=1) THEN
  DO
   PULSOUT 4, 650
  LOOP UNTIL (REWIND_B=0)
 ENDIF
 PAUSE 20
LOOP
```