CHAPTER 7

Hydrogen Ion: Design and Development of Computer based Measurement System
Chapter 7

Section 7.1

HARDWARE DEVELOPMENT

The measurement of hydrogen ion using a computer can conceptually be described as, when a pair of electrodes namely hydrogen ion sensitive electrode and a reference electrode are dipped in an aqueous solution, it generates an emf which is proportional to the hydrogen ion of the solution\(^1\,^2\). The voltage in fact is of the order of the few millivolts and is generally 59.15 mV/decade at 25 °C. The potential of the hydrogen ion selective electrode\(^3\,^4\,^5\) is slightly dependent upon the temperature of the solution also, which is to be compensated. In the present study, a combination of hydrogen ion selective and reference electrodes in a single unit is used.

The emf generated in the electrochemical cell is given to a high input impedance amplifier since the hydrogen ion selective membrane is made up of glass. The analog output of the amplifier is converted into digital form using an analog to digital converter. The digital information corresponding to hydrogen ion concentration of the solution is stored and displayed with the help of a computer using appropriate interfacing devices. The necessary software to operate the system is developed in C language. The block diagram of the system is shown in Figure 7.1. The system designed in the present study, consists the following functional blocks.

1. Working Electrode
2. Signal conditioner
3. Temperature sensing unit
4. Data acquisition system
5. Analog multiplexer
6. I/O card
7. Personal computer
8. Power supply unit
Figure 7.1 Block diagram of computer based system for Measurement of Hydrogen Ion

- Power Supply
- DAS: Data Acquisition System
- DIOT: Digital Input Output Timer Card
- Personal Computer

Diagram components:
- Hydrogen ISE
- Electrode
- Reference Electrode
- Temperature Sensor
- Analog Mux
- ADC
- Signal Conditioner
- Signal Conditioner

Legend:
- DAS: Data Acquisition System
- DIOT: Digital Input Output Timer Card
WORKING ELECTRODE

The choice of hydrogen ion measuring (pH) electrode depends on the application. Four types are available that cover most industrial requirements. The four types are the antimony electrode, quinhydrone electrode, hydrogen electrode\(^6\) and the glass electrode.

Antimony Electrodes

Antimony electrodes have a limited pH range from 4 to 11.5 pH and should not be operated at temperatures ranges over 60 °C. These electrodes are rugged and durable where the pH of abrasive slurries to be measured. The electrode cell has low resistance, shielding is not required, and special measuring circuits are not necessary. Some disadvantages of these electrodes are that the active surface must be cleaned and scraped regularly, dissolved oxygen must be present to maintain the pH sensitive oxide coating, certain materials such as silver, mercury, lead and copper poison the electrode, and some oxidizing and reducing solutions cause errors in measurements.

Quinhydrone Electrodes

A Quinhydrone electrode releases an equivalent number of hydrogen ions as they are oxidized. The change in voltage of the system is responsive to the hydrogen ion concentration. This type of electrode was used extensively in early pH measurements by electrical voltage methods. These electrodes cannot be used in alkaline solutions or in the presence of strongly oxidizing or reducing agents. They are generally not acceptable for industrial applications because they may change the pH buffered solutions being measured.

Hydrogen Electrodes

Hydrogen electrodes are used only at atmospheric pressure. These electrodes have an unlimited pH range, and they can be used at all reasonable temperatures up to the boiling point of the solution. These electrodes are not useful in the presence of oxidizing and reducing agents. The hydrogen electrode is slow in reaching equilibrium and it is not useful in solution of elements lower in the electromotive series.
Glass Electrodes
Glass electrodes have a wide pH and temperature range. They cover the overall 0 to 14 pH range and can operate at temperatures from 0 to 100 °C and at pressures from 0 to 100 psi. These electrodes are not affected by oxidizing or reducing acids, but like all other types of glass they are attacked by fluoride solutions. They are not affected by dissolved gases or suspended solids in the solutions, and work well in fluid flows except at high velocity.

In the present study, a combination of hydrogen ion selective electrode and reference glass electrode in a single unit is used. The hydrogen ion selective membrane is made up of glass with a composition of 22% Na2O, 6% CaO and 72% SiO2 – which is highly selective to hydrogen ions. The sensing membrane hydrogen ion selective electrode is sealed on to one end of a heavy-walled glass tube fixed into a polymer body. The construction of the electrode is shown in Figure 7.2.

When the electrode is dipped in a solution containing hydrogen ions the external ions diffuse through the membrane until equilibrium is reached between the external and internal concentrations. Thus there is a build up of charge on the inside of the membrane which is proportional to the number of hydrogen ions in the external solution. A sensitive, high impedance millivolt meter or digital measuring system must be used to measure the potential difference accurately.

The potential developed across the hydrogen ion selective electrode is directly proportional to the ion activity revealed by the Nernst equation discussed earlier in chapter 2 and the slope of the electrode can be calculated by plotting a graph between the standard buffer solutions of concentrations pH 4, pH 7 and pH 9.2 versus potential developed in mV of the standard solutions which is shown in Figure7.3.

In the present study the hydrogen ion selective electrode supplied by the pH products company, Hyderabad is used. It possesses the following specifications.
Figure 7.2 Reference Combined Hydrogen Ion Selective Electrode
Figure 7.3 Output Characteristics of pH electrode

Average Slope: 59.3 mV/decade

pH Value of Standard Solutions (pH)

E (mV)
Measuring range : 0 pH to 14pH
Operating temperature range : 0 – 80 °C
Slope range : 54 to 60 mV

The other functional blocks of hydrogen ion measuring system are elucidated in chapter 2. The schematic diagram of computer based system for measurement of hydrogen ion is shown in Figure 7.4.
Figure 7.4 Schematic Diagram of Computer based System for Measurement of Hydrogen Ion
Section 7.2
SOFTWARE DEVELOPMENT

The main role of the software in the present study is to govern the following activities.

1. To make the data acquisition system to convert the analog signal of the hydrogen ion selective electrode and temperature sensor output into corresponding digital information for data processing to personal computer.
2. To measure the temperature of any solution at an accuracy of ±0.5°C.
3. To calibrate the hydrogen ion selective electrode using standard buffer solutions with the help of software, to find the slope of the hydrogen ion selective electrode and to store the slope value.
4. To make the different functional units of system work in a systematic and sequential manner.
5. To compute, display and storage of hydrogen ion concentration and temperature values.
6. To indicate the hardware defects if any.

The necessary software in the present study is developed in C language to implement these tasks for effective functioning of the system.

SOFTWARE ROUTINES
The software program developed in the present study is divided into five parts using functions. Each routine is described below.

Hardware Testing
In the present study, a sub program is developed to check the hardware of the system if there is any defect. This program is used to test the DIOT card and analog to digital converter of the system, which is described in earlier the chapter 2.

Hydrogen ion measurement routine
1. Initialize the I/O card
2. Select the temperature channel by sending 00H data to Port C of 8255 (Use PC0, PC1&PC2).
3. Read the temperature signal from LM335 through ADC and store the value.
4. Select pH channel by sending 01H data to Port C of 8255 (Use PC0, PC1&PC2)
5. Read the hydrogen ion signal from the hydrogen ion selective electrode through ADC and store the value.
6. Compute the temperature and hydrogen ion concentration of the solution in terms of °C and pH units respectively.
7. Store and display the temperature and hydrogen ion concentration of the solution
8. Repeat the steps from 2 to 8. The flow chart diagram for hydrogen ion measurement is shown in Figure 7.5.

Temperature measurement routine
The measurement of temperature for compensation of temperature error in the electrochemical cell is discussed earlier in chapter 2 at software routines section.

Calibration of the system routine
1. Prepare three standard buffers of 4, 7 and 9.2 pH solutions.
2. Dip the electrodes in 4 pH buffer solution and read the corresponding voltage developed in the cell.
3. Dip the electrodes in 7 pH buffer solution and read the corresponding voltage developed in the cell and calculate the slope of the electrode for the first two solutions.
4. Finally dip the electrodes in 9.2 pH buffer solution and read the corresponding voltage developed in the cell and calculate the slope of the electrode for the second and third solutions.
5. Compute and store the average slope of the electrode

The flowchart for the calibration of the system is shown in Figure 7.6.

Quit routine
Press key No. 5 on the keyboard to quit from the program. The overall flow chart of the system is presented in Figure 7.7.
The detailed software program of the present system developed in C language is as follows.
Start

Select Temperature Channel

Read ADC output corresponding to the existing temperature

Compute and store the Temperature value

Store and display the Temperature value

Select Hydrogen ion channel

Read ADC output corresponding to the pH value

Compute and store the Hydrogen ion concentration of the sample solution

Figure 7.5 Flow Chart Diagram for Hydrogen Ion Measurement
Start

Dip the Electrode in standard buffer solution of 7 pH value

Read ADC output corresponding to the sodium ions and store its value

Dip the Electrodes in standard buffer solution of 4 pH value

Read ADC output corresponding to the pH value. Compute and store slope value for 1\textsuperscript{st} and 2\textsuperscript{nd} solutions

Dip the Electrodes in standard buffer solution of 9.2 pH value

Read ADC output corresponding to the pH value. Compute and store slope value for 2\textsuperscript{nd} and 3\textsuperscript{rd} solutions

Compute and store the average value of slope

Figure 7.6 Flow Chart Diagram for Calibration of the System
Figure 7.7 Overall Flow Chart Diagram for Hydrogen Ion Measuring System

1. Hardware Testing
   - Tests the DIOT card and ADC Module

2. pH
   - Measures the Hydrogen ion concentration and the temperature, store and display the values

3. Temperature
   - Reads the temperature from LM335 sensor through ADC and displays the temperature in °C

4. Calibration
   - Calibrates the system by using known pH buffer solutions and stores the slope of the electrode

5. Quit
   - Comes out of the program execution

START

Return to Main Menu

STOP
PROGRAM IN DETAIL

/* Software Program for Computer Based System
for Measurement of Hydrogen Ion */

#include<stdio.h>
#include<conio.h>
#include<dos.h>
#include<math,h>
#include<stdlib.h>
#include<graphics.h>

float adc_value,t;
int pa = 0xdfa0, pb = 0xdfa1, pc = 0xdfa2, cr = 0xdfa3, cw = 0x92;
float distl,slope,ph;
FILE *slp,*res;

// MAIN PROGRAM/

void main( )
{
    int opt;
    outportb(cr,cw);
    clrscr();

    again: opt=menu( );
    if(opt==1)
    {
        system(“hardest.exe”);
        goto again;
    }
    else if(opt==2)
    {
        phrot( );
        goto again;
    }
    else if(opt==3)
    {
        temperature( );
        goto again;
    }
    else if(opt==4)
    {
        calibrate( );
        goto again;
    }
    else if(opt==5)
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```c
{
    quit( );
}
else
{
    goto again;
}
}

// SUB ROUTINES //

// MENU SUBROUTINE //

int menu()
{
    int opt;
    clrscr( );
    gotoxy(20,3);
    printf("COMPUTER BASED HYDROGEN ION MEASUREMENT");
    gotoxy(23,6);
    printf("1. HARDWARE TESTING");
    gotoxy(23,7);
    printf("2. HYDROGEN ION MEASUREMENT");
    gotoxy(23,8);
    printf("3. TEMPERATURE MEASUREMENT");
    gotoxy(23,9);
    printf("4. CALIBRATION OF THE SYSTEM");
    gotoxy(23,10);
    printf("5. QUIT");
    gotoxy(23,15);
    printf("SELECT YOUR CHOICE? = ");
    scanf("%d",&opt);
    return(opt);
}

// HYDROGEN ION MEASUREMENT ROUTINE

phrot()
{
    clrscr( );
    gotoxy(33,3);
    printf("HYDROGEN ION MEASUREMENT");
    gotoxy(20,4);
    printf("PLACE THE ELECTRODES IN THE SAMPLE SOLUTION");
    do
    {
        float samp_vol;
        temp( );
        outportb(pc,0x01); // Hydrogen ion channel
        delay(100);
    } while (samp_vol < 0.1); // Add condition
```

// SUB ROUTINES //

// MENU SUBROUTINE //

int menu()
{
    int opt;
    clrscr( );
    gotoxy(20,3);
    printf("COMPUTER BASED HYDROGEN ION MEASUREMENT");
    gotoxy(23,6);
    printf("1. HARDWARE TESTING");
    gotoxy(23,7);
    printf("2. HYDROGEN ION MEASUREMENT");
    gotoxy(23,8);
    printf("3. TEMPERATURE MEASUREMENT");
    gotoxy(23,9);
    printf("4. CALIBRATION OF THE SYSTEM");
    gotoxy(23,10);
    printf("5. QUIT");
    gotoxy(23,15);
    printf("SELECT YOUR CHOICE? = ");
    scanf("%d",&opt);
    return(opt);
}

// HYDROGEN ION MEASUREMENT ROUTINE

phrot()
{
    clrscr( );
    gotoxy(33,3);
    printf("HYDROGEN ION MEASUREMENT");
    gotoxy(20,4);
    printf("PLACE THE ELECTRODES IN THE SAMPLE SOLUTION");
    do
    {
        float samp_vol;
        temp( );
        outportb(pc,0x01); // Hydrogen ion channel
        delay(100);
    } while (samp_vol < 0.1); // Add condition
adc( );  // Cx = C2/antilog(VS)
samp_vol = adc_value * (600.0);  // \lambda = \text{delta} = \text{high E-Ex}
slp = fopen("ph.dat","r");
fscanf(slp,"%f %f",&slope,&distl);
fclose(slp);
ph = (7 - ((samp_vol - distl) / slope)) - (0.0002 * t);
res = fopen("phres.dat","w");
fprintf(res,"pH : %f : %f",ph,t);
fclose(res);
gotoxy(20,7);
printf("The H+ ion Conc. in pH : %2.3f",ph);
gotoxy(20,8);
printf("Temperature in degree celcius : %3.2f",t);
gotoxy(20,10);
printf("The Slope of the Electrode : %3.2f",slope);
gotoxy(20,13);
printf("Press any key to stop");
}
while(!kbhit( ));
getch();
return;
}

// TEMPERATURE MEASUREMENT SUBROUTINE

temperature( )
{
clrscr();
do
{

gotoxy(29,5);
printf("TEMPERATURE MEASUREMENT");
temp();
gotoxy(20,8);
printf("Temperature in degree celcius : %3.2f",t);
gotoxy(20,10);
printf("Press any key to stop");
}
while(!kbhit( ));
getch();
return;
}

// CALIBRATION OF THE SYSTEM
calibrate( )
{
float ph4, ph9;
float s1, s2;
clrscr();

do
{
    gotoxy(27, 5);
    printf("CALIBRATION OF THE SYSTEM ");
    gotoxy(14, 6);
    printf("FOR CALIBRATION PREPARE 3 STANDARD BUFFER SOLUTIONS");
    gotoxy(28, 7);
    printf("OF pH VALUES 4, 7 & 9.2");
    gotoxy(18, 8);
    printf("DIP THE ELECTRODES IN 7 pH BUFFER SOLUTION");
}
while(!kbhit());
getch();
clrscr();

do
{
    gotoxy(20, 6);
    printf("DIP THE ELECTRODES IN 7 pH BUFFER SOLUTION");
    temp();
    outportb(pc, 0x00); // Hydrogen ion channel
    delay(100);
    adc();
    adc();
    distl = adc_value * 1000.0;
    gotoxy(20, 12);
    printf("The voltage developed in 7 pH buffer SOLN : %3.2f", distl);
    gotoxy(20, 13);
    printf("Temperature in degree celcius : %3.2f", t);
    gotoxy(20, 15);
    printf("Press any key to continue...");
}
while(!kbhit());
getch();
clrscr();

do
{
    gotoxy(20, 4);
    printf("DIP THE ELECTRODES IN 4 pH BUFFER SOLUTION");
    gotoxy(20, 14);
    printf("Press any key to continue...");
}
while(!kbhit());
getch();
clrscr();
do
{
    temp();
    outportb(pc,0x00); // Hydrogen ion channel
    delay(100);
    adc( );
    adc( );
    ph4 = adc_value * 1000.0;
    s1 = (ph4 - distl)/3;
    gotoxy(20,3);
    printf("DIP THE ELECTRODES IN 4 pH BUFFER SOLUTION");
    gotoxy(20,7);
    printf("Voltage developed in 4 pH buffer SOLN : %3.2f",ph4);
    gotoxy(20,8);
    printf("Temperature in degree celcius : %3.2f",t);
    gotoxy(20,9);
    printf("SLOPE OF THE ELECTRODE : %2.2f",s1);
    gotoxy(20,13);
    printf("Press any key to continue...");
}
while(!kbhit( ));
getch( );
crlscr( );
do
{
    gotoxy(20,4);
    printf("DIP THE ELECTRODES IN 9.2 pH BUFFER SOLUTION");
    gotoxy(20,14);
    printf("Press any key to continue...");
}
while(!kbhit( ));
getch( );
crlscr( );
do
{
    temp( );
    outportb(pc,0x00); // Hydrogen ion channel
    delay(100);
    adc( );
    adc( );
    ph9 = adc_value * 1000.0;
    s2 = (distl - ph9)/2.2;
    slope = ((s1+s2)/2.0) - (0.0002 * t);
    gotoxy(20,3);
    printf("DIP THE ELECTRODES IN 9.2 pH BUFFER SOLUTION");
    gotoxy(20,7);
    printf("Voltage developed in 9.2 buffer SOLN : %3.2f",ph9);
    gotoxy(20,8);
```c
printf("Temperature in degree celcius : %3.2f", t);
gotoxy(20,9);
printf("SLOPE OF THE ELECTRODE : %2.2f", s2);
gotoxy(20,10);
printf("AVERAGE SLOPE OF THE ELECTRODE : %2.2f", slope);
gotoxy(20,15);
printf("Press any key to continue..." );
slp = fopen("ph.dat", "w");
fprintf(slp, "%f %f", slope, dist1);
fclose(slp);
}
while(!kbhit( ));
getch( );
return(slope);
}

// QUIT ROUTINE
quit( )
{
    return;
}

// temp function

temp( )
{
    outportb(pc, 0x01); //temperature channel
    delay(500);
    adc( );
    adc( );
    t = ((adc_value) * 100);
    return(t);
}

// adc function

adc( ) function program is presented in chapter 3.

*****
Section 7.3

CALIBRATION AND MEASUREMENT PROCEDURES

The individual blocks of the computer based system for measurement of hydrogen ion are designed and constructed. The necessary software is developed in C language. These details are already discussed earlier. Before using the system, the electrode must be calibrated by measuring a series of known standard buffers of 4, 7 and 9.2 pH solutions.

Preparation of the standard pH buffer solutions:
To prepare the standard buffer solutions, first and foremost grind the buffer tablets of 4, 7 and 9.2 pH values separately in a grinder and pour these powders into three individual beakers now add 100ml of distilled water to each beaker and stir the solution until the powder dissolves completely. Now label the beaker with the pH value corresponding to the tablet added. The standard buffer solutions are prepared in the laboratory in accordance with the accepted principles of analytical chemistry\(^8,^9\).

After preparing the standard buffer solutions, run the software program of the system for calibration. When the execution of the program starts, a user menu is displayed on the CRT screen of the computer as shown below.

**Main Menu**
1. ADC Testing
2. pH Measurement
3. Temperature Measurement
4. Calibration of the system
5. Quit

Select the option ‘4’ for calibration of the system by pressing key number 4 on the keyboard and press ‘Enter key’. Now the system is ready to calibrate the system.

The calibration menu itself guides the user to calibrate the system which is shown below (which appears on the Monitor of the PC).
CALIBRATION OF THE SYSTEM
FOR CALIBRATION PREPARE 3 STANDARD BUFFER SOLUTIONS OF pH VALUES 4, 7 & 9.2
(Rinse the electrodes with distilled water thoroughly and blot dry with tissue paper before dipping the electrodes in the solutions every time)

DIP THE ELECTRODES IN pH 7 STANDARD BUFFER SOLUTION
After a stable reading press any key on the keyboard to continue to next step.

DIP THE ELECTRODES IN pH 4 STANDARD BUFFER SOLUTION
After stable reading we can see the slope of the electrode in milli volts/decade for the first two standard solutions. Press any key on the keyboard to continue to next step.

DIP THE ELECTRODES IN pH 9.2 STANDARD BUFFER SOLUTION
After stable reading we can see the slope of the electrode in milli volts/decade, the average slope of the pH sensitive electrode is computed and displayed on the screen. And it automatically switches to main menu after pressing the enter key on the keyboard.

Now the calibration of the system is completed and the system is ready to measure the pH value of the sample. The slope of the electrode tells the sensitivity and linearity of the pH electrode. After making the appropriate adjustments both in the hardware and software and also following the calibration procedure as mentioned earlier, the instrument is tested with the standard buffers of pH solutions. The outputs of the pH measuring system are presented in Figure 7.8 to Figure 7.12. The results of measurements are presented in Table 7.1. The measurements are compared with the literature values and with a pH meter of Elico Make (Model No.L1120) and the results are presented in the same table. The results of the present study are in good agreement with standard and literature values. The system is reasonably fair in measuring the pH values of a solution with a reasonable accuracy of ± 0.01 pH. The results of some more samples are presented in chapter 9.

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### TABLE 7.1
HYDROGEN ION MEASUREMENT IN STANDARD BUFFER SOLUTIONS

<table>
<thead>
<tr>
<th>Standard values</th>
<th>Present study</th>
<th>Elico pH meter</th>
<th>Literature $^{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>In pH units</td>
<td>In pH units</td>
<td>In pH units</td>
<td>In pH units</td>
</tr>
<tr>
<td>4.0</td>
<td>3.995</td>
<td>3.99</td>
<td>4.005 – 4.04</td>
</tr>
<tr>
<td>7.0</td>
<td>7.005</td>
<td>7.08</td>
<td>9.18 – 9.205</td>
</tr>
<tr>
<td>9.2</td>
<td>9.211</td>
<td>9.25</td>
<td></td>
</tr>
</tbody>
</table>
COMPUTER BASED PH MEASUREMENT

1. HARDWARE TESTING
2. pH MEASUREMENT
3. TEMPERATURE MEASUREMENT
4. CALIBRATION OF THE SYSTEM
5. QUIT

SELECT YOUR CHOICE? : 1

Figure 7.8 : Main menu of PH measurement system
HARDWARE TESTING

1. TESTING OF DIGITAL INPUT OUTPUT CARD
2. TESTING OF DATA ACQUISITION SYSTEM
3. QUIT

SELECT YOUR CHOICE? : 1

Figure 7.9 : Main menu of hardware testing of the system

TESTING OF DIGITAL INPUT OUTPUT CARD

Connect the test module to the I/O card connector

Press any key when ready

Observe the test module for ON and OFF of the LED’s

Press any key to stop

Figure 7.9a : Digital Input Output Timer card testing
TESTING OF DATA ACQUISITION SYSTEM

Apply Known DC voltage (+/-1.5V) to channel 0 or 1

Enter the channel No. : 1

The Voltage in V : 0.435

Press any key to stop

Figure 7.9b : Data acquisition system testing

pH MEASUREMENT
PLACE THE ELECTRODE IN THE SAMPLE SOLUTION

The $\text{H}^+$ Conc. in pH Units : 7.005
Temperature in degree celcius : 30.10
The Slope of the Electrode : 58.00 mV/decade

Press any key to stop

Figure 7.10 : pH measurement
TEMPERATURE MEASUREMENT

Temperature in degree celcius : 30.11

Press any key to stop

Figure 7.11 : Temperature measurement

CALIBRATION OF THE SYSTEM

FOR CALIBRATION PREPARE 3 STANDARD BUFFER SOLUTIONS OF pH VALUES 4, 7 & 9.2

DIP THE ELECTRODES IN 7 pH BUFFER SOLUTION

Press any key to continue...

Figure 7.12 : Calibration of PH Measuring System
DIP THE ELECTRODES IN 7 pH BUFFER SOLUTION

The voltage developed in 7 pH buffer SOLN : 102.30 mV
Temperature in degree celsius : 30.11

Press any key to continue...

Figure 7.12a : Voltage developed in 7 pH Buffer Solution

DIP THE ELECTRODES IN 4 pH BUFFER SOLUTION

The voltage developed in 4 pH buffer SOLN : 276.50 mV
Temperature in degree celsius : 30.10
SLOPE OF THE ELECTRODE : 58.06 mV

Press any key to continue...

Figure 7.12b : Voltage developed in 4 pH Buffer Solution
DIP THE ELECTRODES IN 9.2 pH BUFFER SOLUTION

The voltage developed in 9.2 pH buffer SOLN : -28.50 mV
Temperature in degree celcius : 30.10
SLOPE OF THE ELECTRODE : 59.09 mV
AVERAGE SLOPE OF THE ELECTRODE : 58.65 mV

Press any key to continue...

Figure 7.12c : Voltage developed in 9.2 pH Buffer Solution
REFERENCES

5. Material on Ion-selective Electrodes prepared by Wojciech Wrobiewski in the web site, with address www.ch.pv.cdo.pl/~dybko/csrg/tutorials/ise/ion selective electrodes.htm