ANT: PH Sensor  
Testing Report

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*In this report, multiple solutions for ANT’s ph sensor   
will be tested. All results for the tests will be recorded  
and compared.   
  
  
  
  
Note: All tests will be conducted at room temperature*

*so the following results are most accurate in temperature  
range (18℃ to 25℃).*

# 

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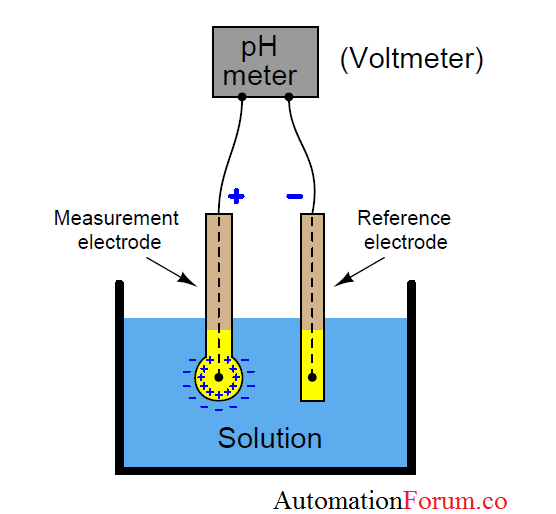
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# **Introduction**

**How does a PH sensor work?**

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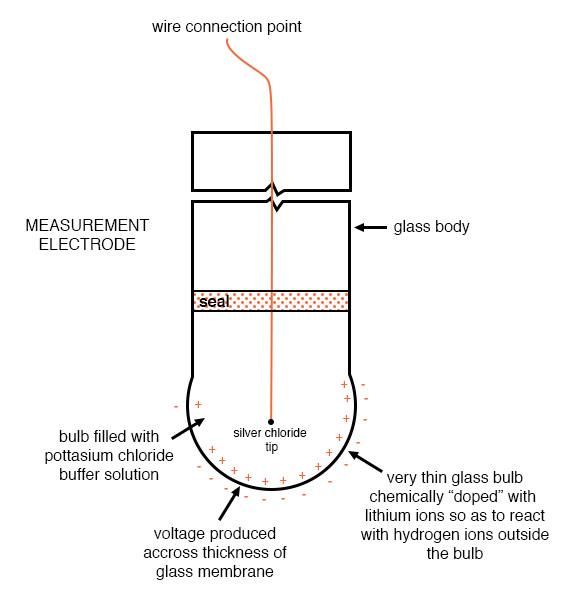
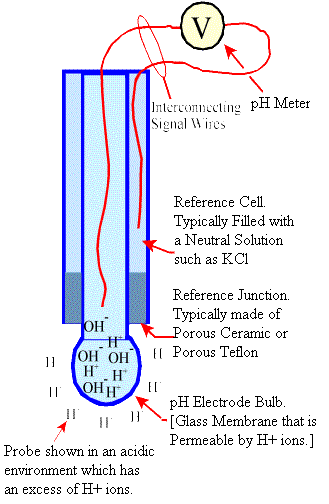
**Photo Diagram of PH Sensor By Automation Forum**

The working of a PH sensor is somewhat like a voltmeter. To obtain PH reading from the PH sensor, we need to read a small voltage value from the probe itself which occurs when there is voltage potential. Inner working of a glass PH probe is as follows.

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**Photo Of Grove PH Sensor**

A glass ph probe is composed of two enclosed glass tubes with a metal wire in each of them. The inner glass tube is the glass electrode portion of the probe with a hydrogen ion sensitive glass bulb at its end which interacts with the testing solution (ph solutions you want to measure). The outer glass tube is called the reference electrode of the probe in which it serves as the reference potential of the readings. Both tubes are filled with a neutral potassium chloride solution(KCL) buffered at PH 7.



**Diagram from Digital Analysis Corporation(left) and All About Circuit(right)**

When the PH probe’s glass bulb is submerged in an aqueous solution, the glass bulb’s external surface reacts with the hydrogen ions of the external solution. Hydrogen ions penetrate the external membrane of the H+ sensitive bulb creating a layer called the gel layer. This also happens internally in the glass bulb with the neutral KCL buffered at PH 7 with a set number of hydrogen ions. This difference in hydrogen ion concentration between external and internal membrane creates an electrical potential. Finally, the difference between the potential obtained at the glass bulb and the reference electrode gives us the voltage reading we need for ph calculations.

**Why do you need a PH sensor in the ANT system?**

The PH sensor is an important environmental sensing device in our system, because its reading helps automate the ph balancing. Depending on the ph readings from this sensor, the ANT system determines whether to not turn on the ph up or ph down dosing pumps. Ex. If our desired PH range is between PH 5.5 and PH 7, and our pH reading from our sensor reads 5, the pump to dose PH up will be turned on until ph reaches our desired range again.

# 

# **PH Sensor: Raspberry PI and Arduino USB Serial communication**

**Goal:**   
Use USB serial communication between Raspberry PI and Arduino to send Ph sensor data from Arduino to Raspberry. The Raspberry PI will take data from the Arduino via serial, process the data to get the ph reading values, and finally print the ph value on the terminal.

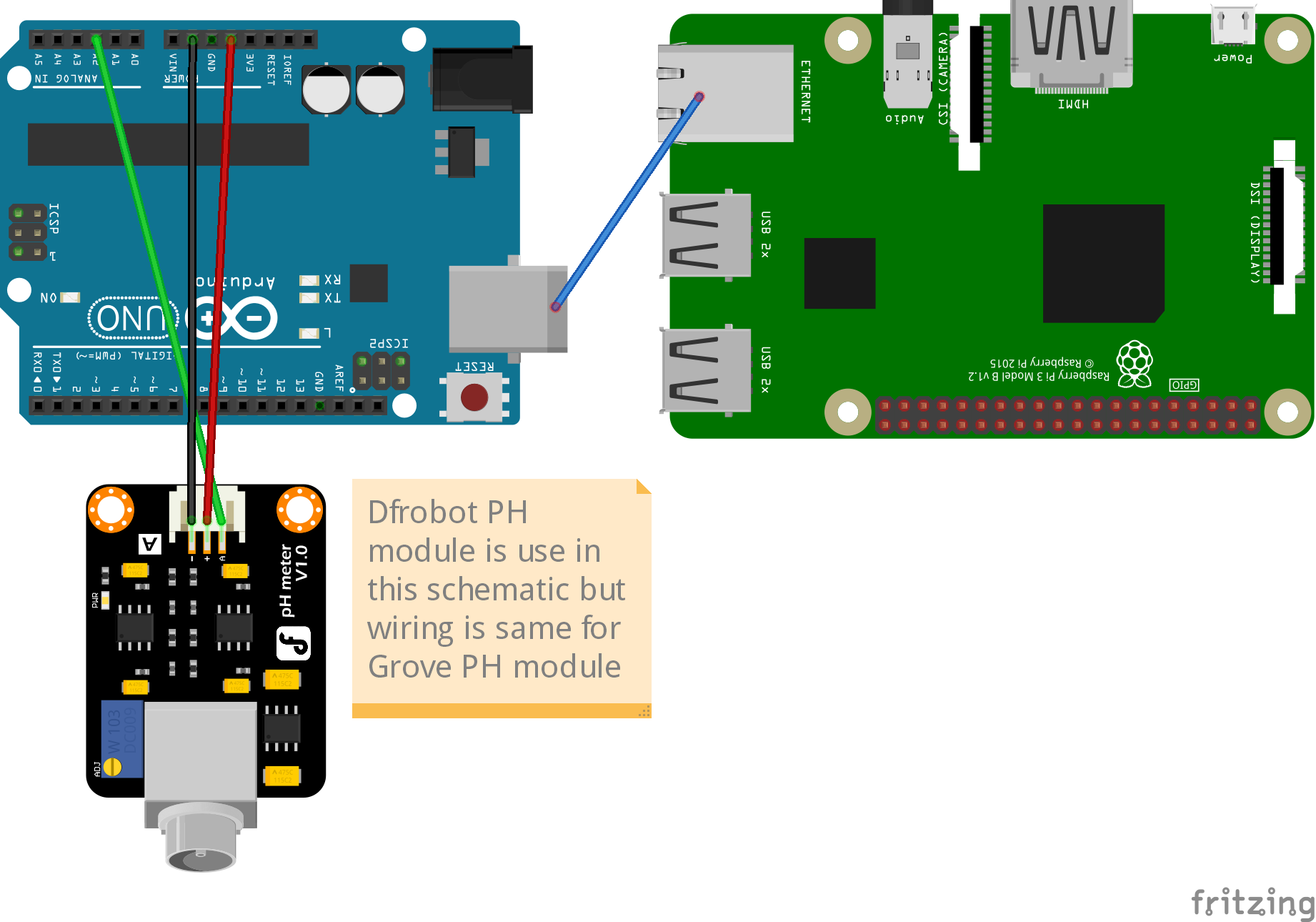
\*Expected result is that a ph reading is printed and max percent error of 5% or less.

**Materials:**

* Raspberry PI 3B+
* Raspberry Pi Micro Usb power supply(output:5V ~ 3000mA)
* Arduino Uno
* Arduino Uno Power supply(output: 9V ~ 1000mA)
* Grove PH Sensor
* Arduino Serial to USB cable
* Jumper Wires
* PH Calibration Liquid (Preferably PH4 and PH7).

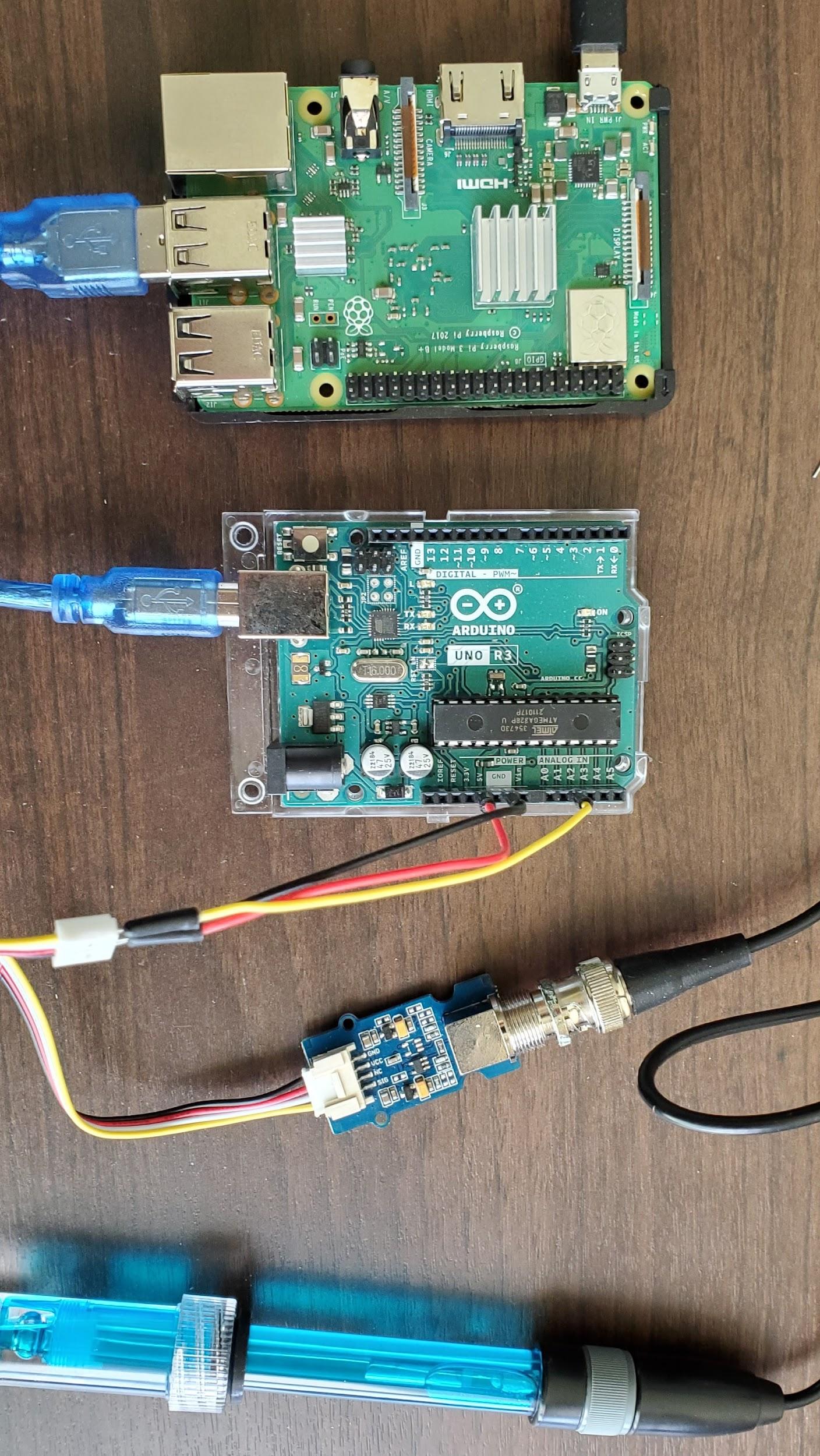
\*PH calibration liquids used are PH4 and PH 7 by Atlas Scientific. Can be ordered [here](https://www.amazon.com/Atlas-Scientific-Calibration-Solution-125ml/dp/B0157DOZ4Q/ref=sr_1_3?crid=OGTKNEXZMHJ7&dchild=1&keywords=atlas+scientific+ph+calibration+solution&qid=1633731345&sprefix=atlas+scientific+ph+cal%2Caps%2C210&sr=8-3).

**Schematic:**

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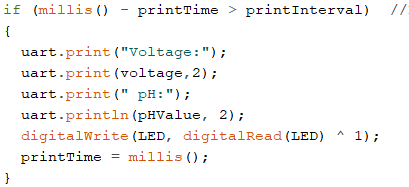
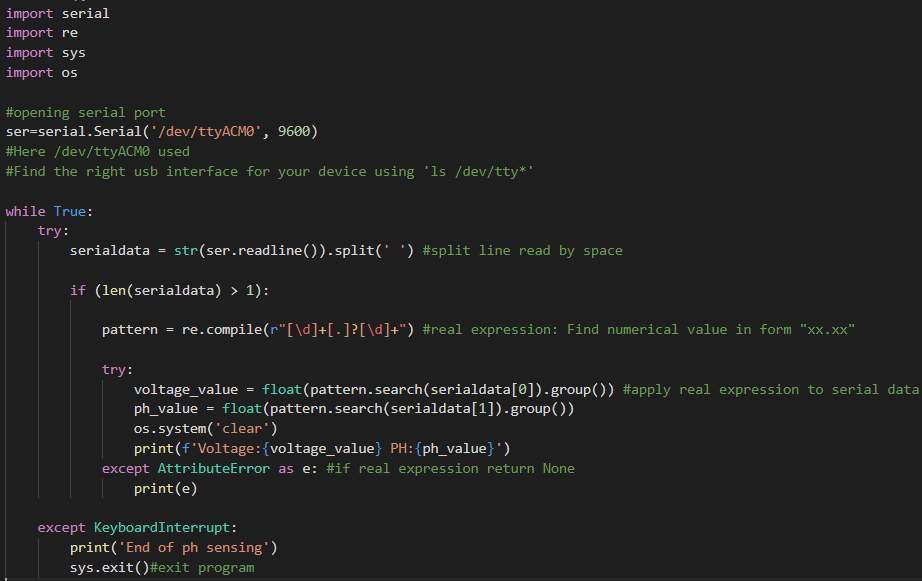
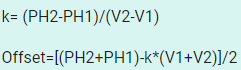
**\* Red - Arduino 5V to PH module positive pin  
\*Black - Arduino GND to PH module negative pin**

**\*Green - Arduino A2 to PH module analog signal pin**

**\*Blue - Arduino to Raspberry PI USB Serial cable connection  
**

**RPI/Arduino USB Serial Connection(BLK -GND, RED - 5V, YELLOW - A2)**

**Procedure:**

1. Upload the demo code for Grove PH sensor from Seeed’s website as a sketch into the Arduino. Demo code can be found [here](https://wiki.seeedstudio.com/Grove-PH-Sensor-kit/).
2. Modify demo code. Remove or comment out “uart.println("pH meter experiment!");” and print outputs, voltage and ph, in the format: “voltage:xx ph:xx”.   
   
3. Connect Raspberry PI, Arduino, and PH sensor module as shown above.   
   **\*Remember to enable I2C protocol on RPI.**
4. Create file ph\_serial\_sensor.py file in Raspberry PI and input followingRaspberry PI code:  
   
5. Run ph\_serial\_sensor.py using command “python3 ph\_serial\_sensor.py”.
6. PH sensor calibrations:  
   Test two PH calibration liquids and write down the ph/voltage readings. Calculate the k and Offset values using the equations provided by Seeed.  
     
   Modify the k value and Offset in the Arduino code. Reupload Arduino sketch.  
     
   

**Results:**

| K Value | Offset | PH Calibration Liquid | PH Reading | Voltage | Error % |
| --- | --- | --- | --- | --- | --- |
| -17.64705882 | 38.4117647 | PH7 | 7.05 | 1.78V | 0.714% |
| -17.64705882 | 38.4117647 | PH4 | 3.98 | 1.95V | 0.5% |
| -18.05882352 | 39.19470588 | PH7 | 7.1 | 1.78V | 1.4285% |
| -18.05882352 | 39.19470588 | PH4 | 4.01 | 1.95V | 0.25% |
| -17.64705882 | 38.4117647 | Baking Soda  Solution  (Expected:8.3) | 8.04 | 1.72 | 0.12% |
| -17.64705882 | 38.4117647 | White vinegar  (Expected:2.5) | 2.4 | 2.04 | 4% |

\* PH readings may vary due to temperature

\* Percent error = |(Vactual - Vexpected) / Vexpected| \* 100

K and Offset Calculation:

K = (4 - 7)/(1.95 - 1.78) = -17.647058823529411764705882352941

Offset = [(4 + 7) - k(1.78 + 1.95)]/2 = 38.411764705882352941176470588235

K = (3.98 - 7.05)/(1.95 - 1.78) = -18.058823529411764705882352941176

Offset = [(3.98 + 7.05) - k(1.78 + 1.95)]/2 = 39.194705882352941176470588235293

The best K value and Offset from the table above are -17.6470588 and 38.4117647 since the pair have overall lowest percent error. Compared to the expected max error percentage, 5%, our best error percentages are well below one percent.

In terms of this ph sensor solution, Raspberry PI and Arduino serial connection have relatively accurate ph readings(<1% error). The problem with this method is that power usage by the Raspberry PI affects the value read from the Arduino, especially when with a poor power supply (ie.Low voltage error). This is also true when the Arduino is not connected to a power supply, affecting the ph value. Of course when this happens, we could modify the k and offset, but the voltage might fluctuate a lot due to lack of enough power. In conclusion, a good power source is highly recommended for this method (RPI power supply with at least 3000mA and Arduino power supply).

Arduino power supply disconnected:

| K Value | Offset | PH Calibration Liquid | PH Reading | Voltage | Error % |
| --- | --- | --- | --- | --- | --- |
| -18.05882352 | 39.19470588 | PH7 | 6.71~ 6.81 | 1.79 ~ 1.8 | 2.714% ~ 4.142% |

# 

# **PH Sensor: Raspberry PI and Grove PI Hat**

**Goal:**

Use Grove Base Hat’s built in 12 bit 8 channel Analog to Digital Converter(ADC) with Raspberry PI to read analog data from the PH sensor. Since the Raspberry PI has no built-in ADC, an external ADC is necessary for Raspberry PI to read analog data directly which the PI Hat can provide.

\* Grove Base PI Hat also feature Digital/Analog/I2C/PWM/UART ports

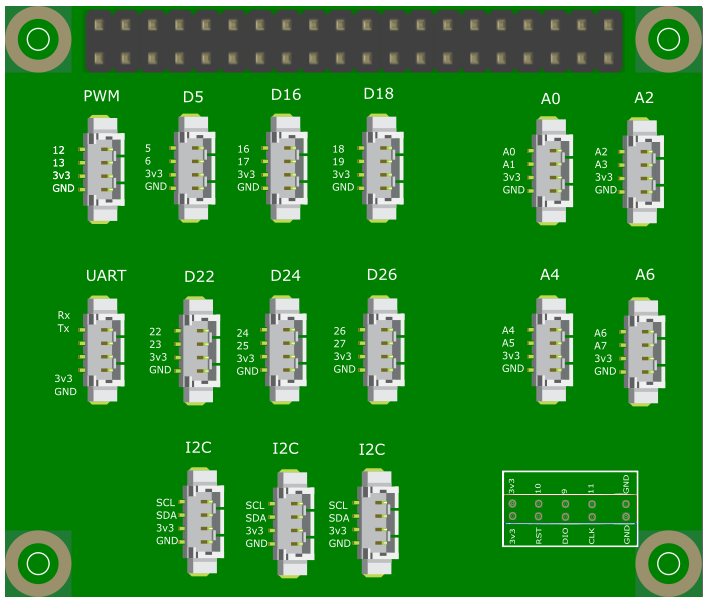
\*Expected result is that a ph reading is printed and percent error 5% or less.

**Materials:**

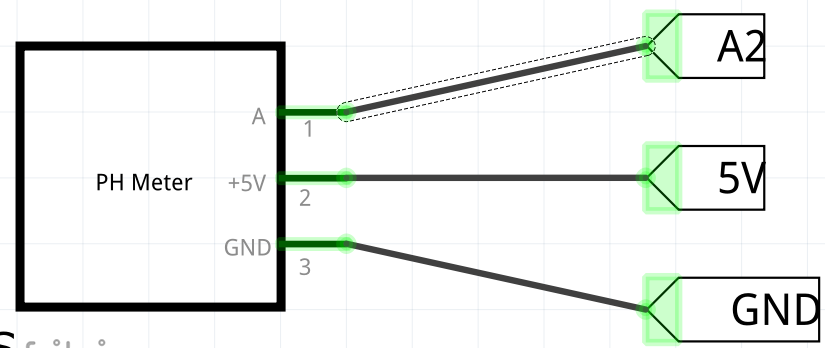
* Raspberry PI 3B+
* Grove PH Sensor
* Grove PI Hat
* Jumper Wires
* PH Calibration Liquid (Preferably PH4 and PH7).

\*PH calibration liquids used are PH4 and PH 7 by Atlas Scientific. Can be ordered [here](https://www.amazon.com/Atlas-Scientific-Calibration-Solution-125ml/dp/B0157DOZ4Q/ref=sr_1_3?crid=OGTKNEXZMHJ7&dchild=1&keywords=atlas+scientific+ph+calibration+solution&qid=1633731345&sprefix=atlas+scientific+ph+cal%2Caps%2C210&sr=8-3).

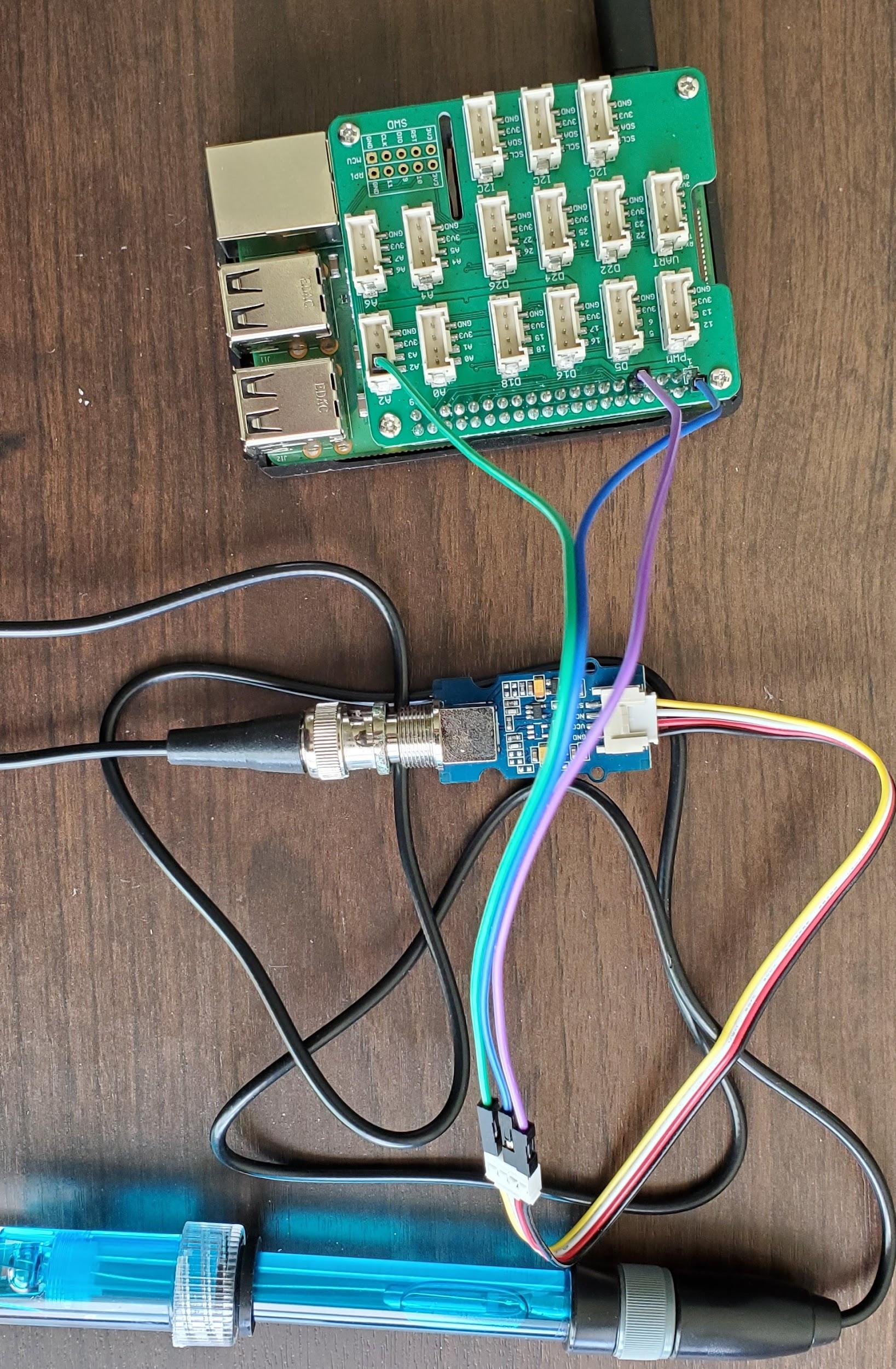
**Schematic:**

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**Grove Base HAT For Raspberry PI**

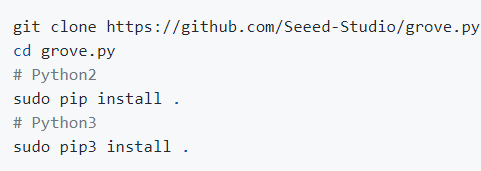
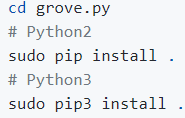
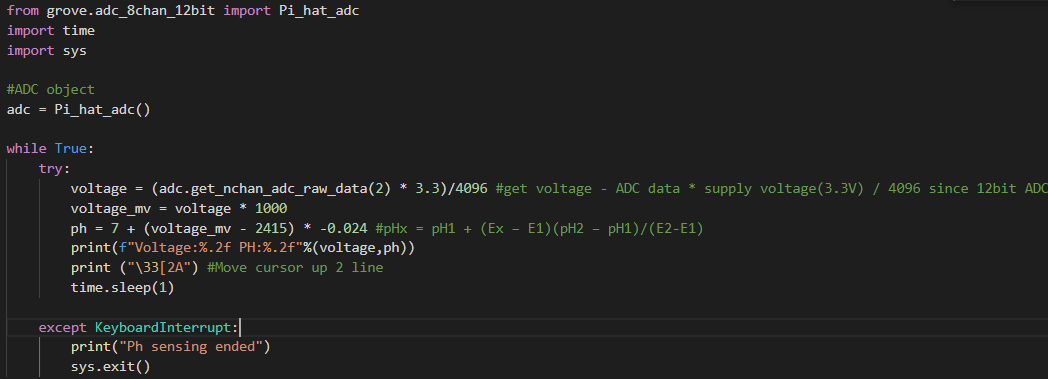
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**Circuit Connection**

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**Grove HAT Actual Connection Photo(BLU - 5V, PUR - GND, GRN - A2)**

**Procedure:**

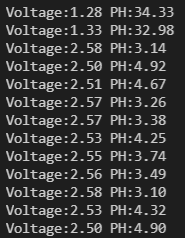
1. Install the Grove PI Base Hat on the Raspberry PI and power on the Raspberry Pi. Connect the Grove Sensor as shown in the schematic. Enable I2C on RPI.  
   \*\*Careful when attaching the Hat if you have a thick heatsink on Raspberry PI. Do not let the heatsink and board touch.
2. For one click install of Grove Base Hat libraries:  
   Enter into the linux terminal “curl -sL <https://github.com/Seeed-Studio/grove.py/raw/master/install.sh> | sudo bash -s -”.  
   \*\*Not recommended since may need to modify i2c address in code
3. For step by step install of Grove Base Hat libraries:  
   
4. The above steps are also available on Seeed’s Wiki page [here](https://wiki.seeedstudio.com/Grove_Base_Hat_for_Raspberry_Pi/#resources) and on their Github [here](https://github.com/Seeed-Studio/grove.py).
5. **\*Important step\* I2C address**Enter “sudo i2cdetect -y 1” to get the i2c address of the PI Hat  
     
   Change directory to the grove folder in grove.py. Enter “cd $HOME/grove.py/grove”.  
   Open adc\_8chan\_12bit.py and change the address to your i2c address.  
     
   adc.py does the same thing, so if you want to use adc module instead. Change the address in that file.  
     
   
6. Reinstall the Grove libraries after changing the addresses  
   
7. Create file ph\_pihat.py and copy the code below. Comment out “print ("\33[2A")” when calibrating to see values better.  
   
8. PH sensor calibrations:  
   Test two PH calibration liquids and write down the voltage readings. Calculate the ph formula using the equation below. It’s recommended in ph calculation steps by Cornel Radu [here](https://www.researchgate.net/post/How-to-Calculate-pH-of-any-solution-using-pH-sensor).  
     
   \*E1 and E2 are the voltage in millivolts read by the sensor while ph1 and ph2 are the PH level of the calibration liquid

**Results:**  
PH Formula Calculations:

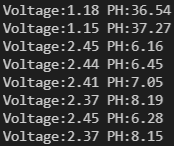
ph = 7 + (Ex - 2415) \* (4 - 7)/ (2540 - 2415) = 7 + (Ex - 2415) \* (-0.024)

| PH Calibration Liquid | PH Reading(Most favorable) | Voltage | Percent Error |
| --- | --- | --- | --- |
| 4 | 4.25 | 2.53V | 6.25% |
| 7 | 7.05 | 2.41V | 0.714% |

PH 4 solution:



PH7 solution:



The resulting readings using the Grove PI Base Hat were not favorable, because the voltage fluctuate a lot during testing affect the ph values by a lot as shown in the two pictures above. In the table above, ph values of the most favorable were recorded since the values can vary a lot between each reading. Results were the same whether using adc\_8chan\_12bit.py or adc.py thus further testing was not needed. No concrete ph values can be recorded.

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# **PH Sensor: Raspberry PI and Waveshare High Precision AD/DA Board**

**Goal:**

Waveshare’s high precision AD/DA board has a built-in 8 channel 24 bit ADC. With a higher bit precision of 24 bit, twice more than the Grove Base Hat, we should expect more accurate sensor reading. Also, since this board only features analog and digital signal conversion, problems should be easier to isolate.

\*Expected result is that a ph reading is printed and margin of ph error offset is 0.5 or less

**Materials:**

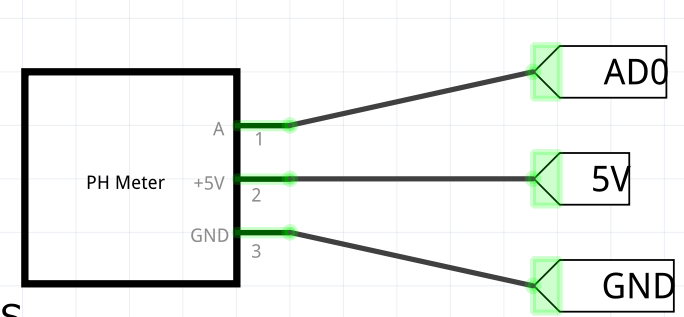
* Raspberry PI 3B+
* Waveshare High Precision AD/DA Board
* Grove PH Sensor
* Jumper Wires
* PH Calibration Liquid (Preferably PH4 and PH7).

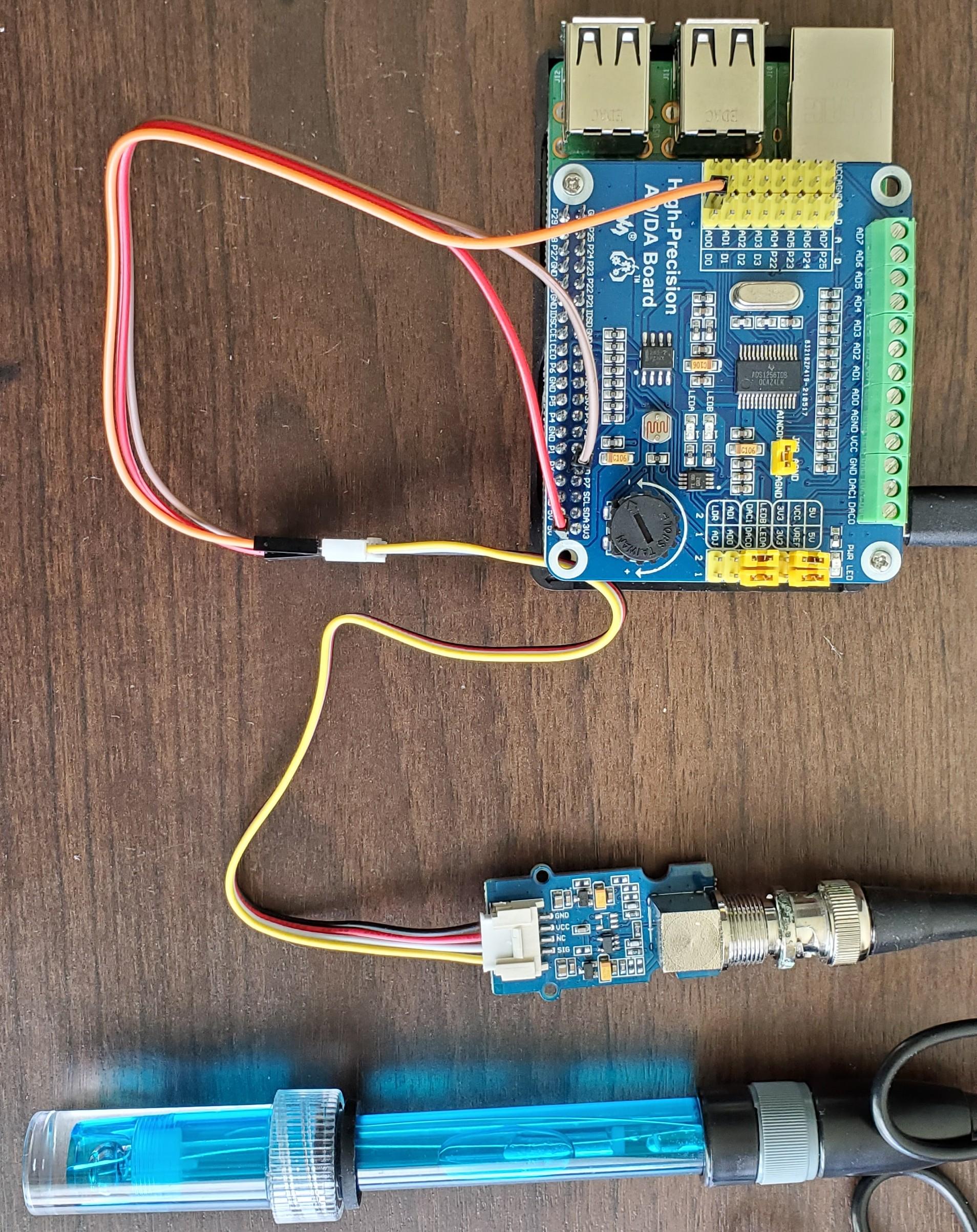
\*PH calibration liquids used are PH4 and PH 7 by Atlas Scientific. Can be ordered [here](https://www.amazon.com/Atlas-Scientific-Calibration-Solution-125ml/dp/B0157DOZ4Q/ref=sr_1_3?crid=OGTKNEXZMHJ7&dchild=1&keywords=atlas+scientific+ph+calibration+solution&qid=1633731345&sprefix=atlas+scientific+ph+cal%2Caps%2C210&sr=8-3).

**Schematic:**

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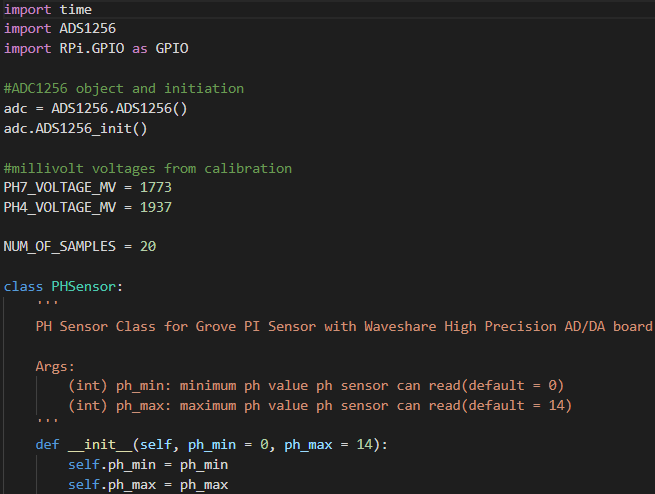
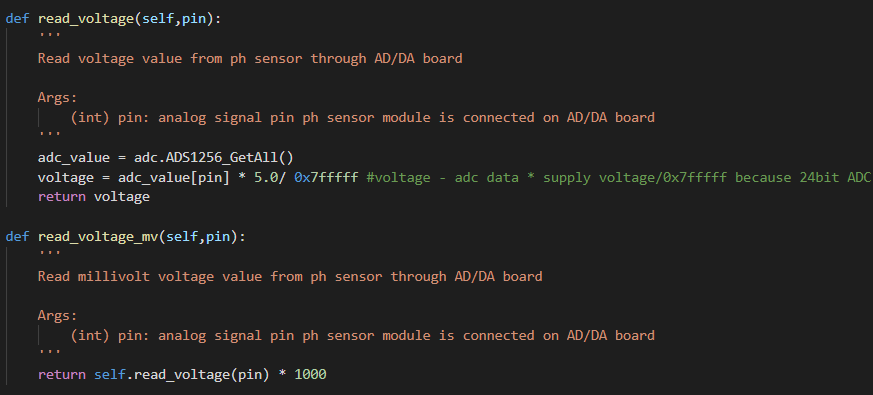
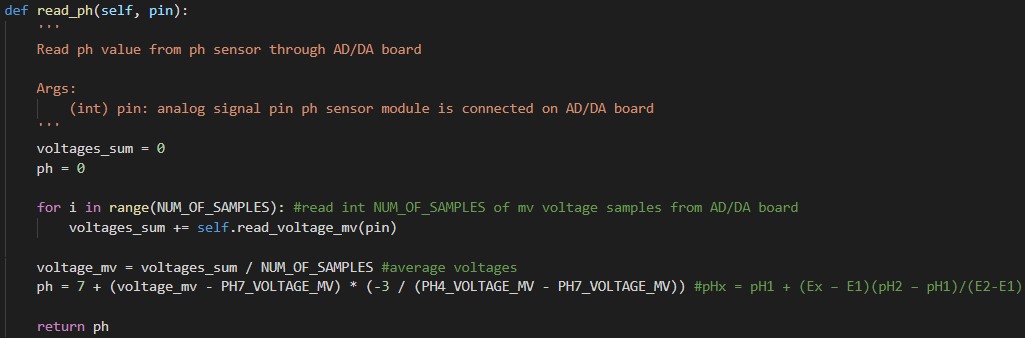
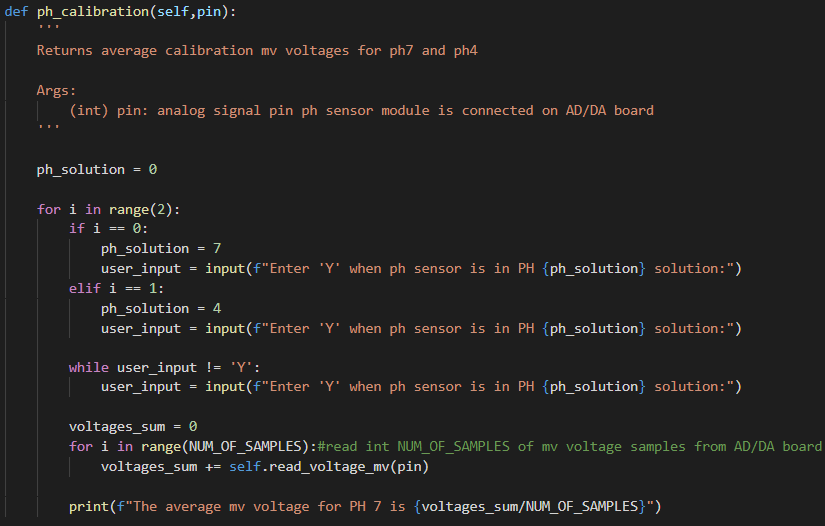
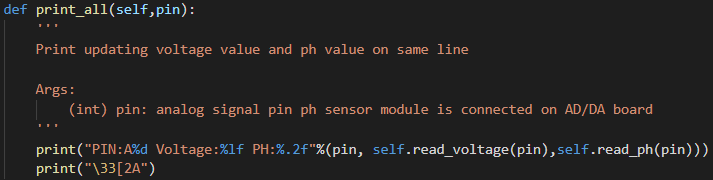
**Waveshare High Precision AD/DA Board**

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**Waveshare AD/DA Board Connection Photo (RED - 5V, BRN - GND, ORG - AD0)**

**Procedure:**

1. Install the Waveshare High Precision AD/DA board on the Raspberry PI and power on the Raspberry PI. Connect the Grove Sensor as shown in the schematic
2. Jumper Configurations:  
   Bridge VCC and VREF with 5V  
   **\*Remember to disconnect AD0 jumper with ADJ.**   
     
     
     
   **\*The bottom four jumpers are for testing AD0, AD1,DAC0, DAC1 respectively during demo, so remove them when you use these pins for actual use/reading with the sensor.**
3. Waveshare High Precision AD/DA board works with [bcm2835-1.39](https://www.waveshare.com/wiki/File:Bcm2835-1.39.tar.gz) or [bcm2835-1.48](https://www.waveshare.com/wiki/File:Bcm2835-1.45.tar.gz) libraries which can also be installed airspayce.com [here](http://www.airspayce.com/mikem/bcm2835/).   
   \*Also python library spidev is needed. To install enter ‘pip3 install spidev’
4. Copy Waveshare High Precision AD/DA board libraries from Waveshare’s wiki page [here](https://www.waveshare.com/wiki/File:High-Precision-AD-DA-Board-Code.7z). Unzip the folder and use a usb to move onto Raspberry PI.
5. Create a new folder folder for your code files (Ex. High\_Precision\_PH). Copy ADS1256.py and config.py from the folder you got from the previous step.  
   \*main.py can also be copied too if you want demo code for ADC
6. To get ADS1256.py and config.py enter:  
   ‘cd $HOME/High-Precision-AD-DA-Board-Code/RaspberryPI/ADS1256’  
   ‘cp ./ADS1256.py path/to/destination/folder’  
   ‘cp ./config.py path/to/destination/folder’
7. Change directory to the folder for your code files. Create a new file,phsensor.py, and copy the following class code:  
     
     
     
     
     
     
   
8. Create a main file to run the code (Ex.main2.py). Copy the following code.  
   
9. Run main2.py. When asked “Calibrate ph probe?(Y/N)”, enter ‘Y’ to get calibration values. Proceed to dip the probe in the specified solution when asked and enter ‘Y’ again to proceed.  
     
   Example calibration step. Values above are for demo only
10. If you enter ‘Y’ in the above step, write down the average mv values for ph 7 and ph 4. Modify ‘PH7\_Voltage\_MV’ and ‘PH7\_Voltage\_MV’ in phsensor.py with the written values. Repeated above steps through 9 for necessary recalibration.
11. If you did not enter ‘Y’ in step 9, the program will proceed to print the voltage and ph reading from the ph sensor.
12. Calibrate ph sensor with ph7 and ph4 calibration liquid.
13. PH sensor calibrations:  
    Test two PH calibration liquids and write down the voltage readings. Calculate the ph formula using the equation below. It’s recommended in ph calculation steps by Cornel Radu [here](https://www.researchgate.net/post/How-to-Calculate-pH-of-any-solution-using-pH-sensor).  
      
    \*E1 and E2 are the millivolts voltage read by the sensor while ph1 and ph2 are the PH level of the calibration liquid

**Results:**

PH Formula Calculation:

ph = 7 + (Ex - 1780) \* (4 - 7)/ (1940 - 1780) = 7 + (Ex - 1780) \* (-0.01875)

| PH Calibration Liquid | PH Reading | Voltage | Error % |
| --- | --- | --- | --- |
| PH7 | 7 ~ 7.25 | 1.7V | 0% to 3.57% |
| PH4 | 3.91 ~ 4.12 | 1.932V ~1.944V | 0% to 3% |
| Baking Soda  Solution  (Expected:8.3) | 8.00 ~ 8.16 | 1.717V ~ 1.724V | 1.68% to 3.6% |
| White vinegar  (Expected:2.5) | 2.33 ~ 2.46 | 2.021V ~ 2.028 | 4% to 13.2% |
| Fresh Lemon Juice  (Expected:2) | 2.21~2.33 | 2.029V ~ 2.035V | 10.5% to 16.5% |
| Dawn Soapy Water  (Expected:8.7 ~ 9.3) | 9.04~9.17 | 1.664V ~ 1.6718V | Within expected range |

\*Soapy water pH varies by concentration. In this case, I added a lot of Dawn dish soap. [Dawn ph level](https://findanyanswer.com/what-is-the-ph-of-dawn-dish-detergent).

The ph readings with Wave High Precision AD/DA board aren’t as consistent as the results from Arduino and RPI USB serial connection, because Waveshare’s board has a 24 bit precision ADC thus the sensor values are more sensitive (each ADC channel max value is 7FFFFF or 8388607). Also with higher bit precision, the readings can be more precise like to the hundredth thousandth place.

Compared to the Grove PI Hat method, the pH values are much more stable without a big spike/drop of voltage affecting the actual pH value. This makes the Waveshare AD/DA board much more accurate in readings.

# **Conclusion**

In conclusion, out of all the three solutions, USB serial between RPI/Arduino and Waveshare’s AD/DA board provides the most stable while accurate readings. Even though USB serial connection between RPI/Arduino has the most stable readings, this method has to watch out for power usage and multiple power supplies. Waveshare’s AD/DA board on the other hand is more easy to set up and has only one function AD/DA conversion which makes it easier to debug than PI Hat. It also has a very good bit precision for accurate readings. Finally, Grove Base PI Hat is proven to not be applicable for PH sensor reading at this time since it has the worst fluctuation in voltage and ph values. Although some values read through Grove PI Hat are close to the actual pH, the readings are too inconsistent and hard to debug due to the variety of ports/functionalities of this board.

USB Serial:

Pro:

-Very Stable Accurate Readings

-Working Demo code by ph sensor manufacturer

Con:

-Reading depends on adequate power supply/source

Waveshare High Precision AD/DA Board:

Pro:

-High bit precision readings

-Easy Setup RPI Hat

-Well Written Code Libraries

-One Main Function AD/DA conversion

-Built in demo test(LED and potentiometer)

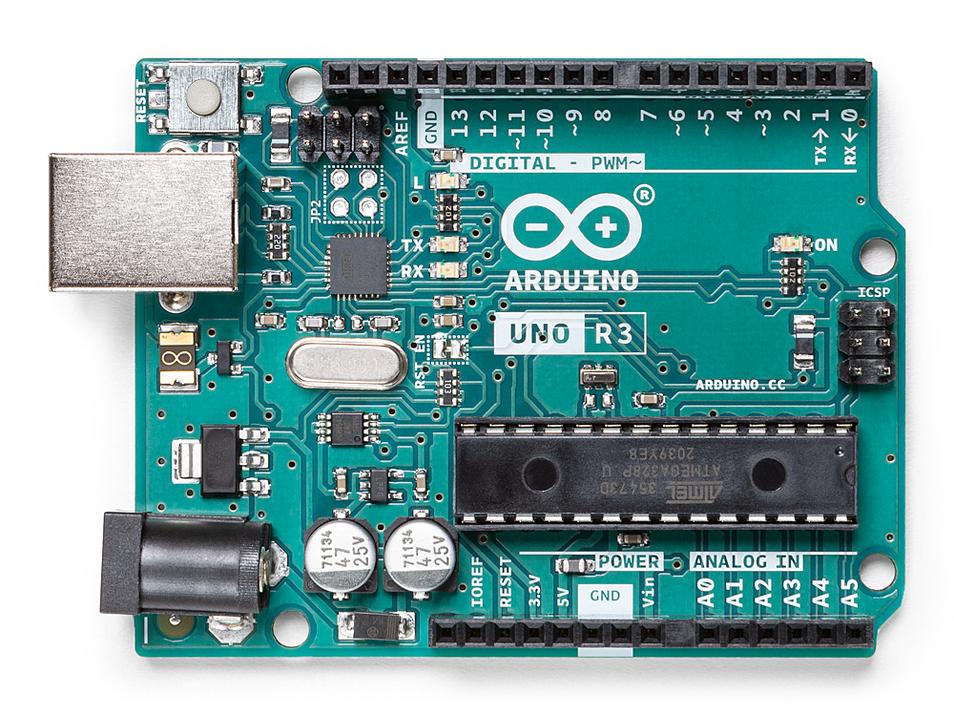
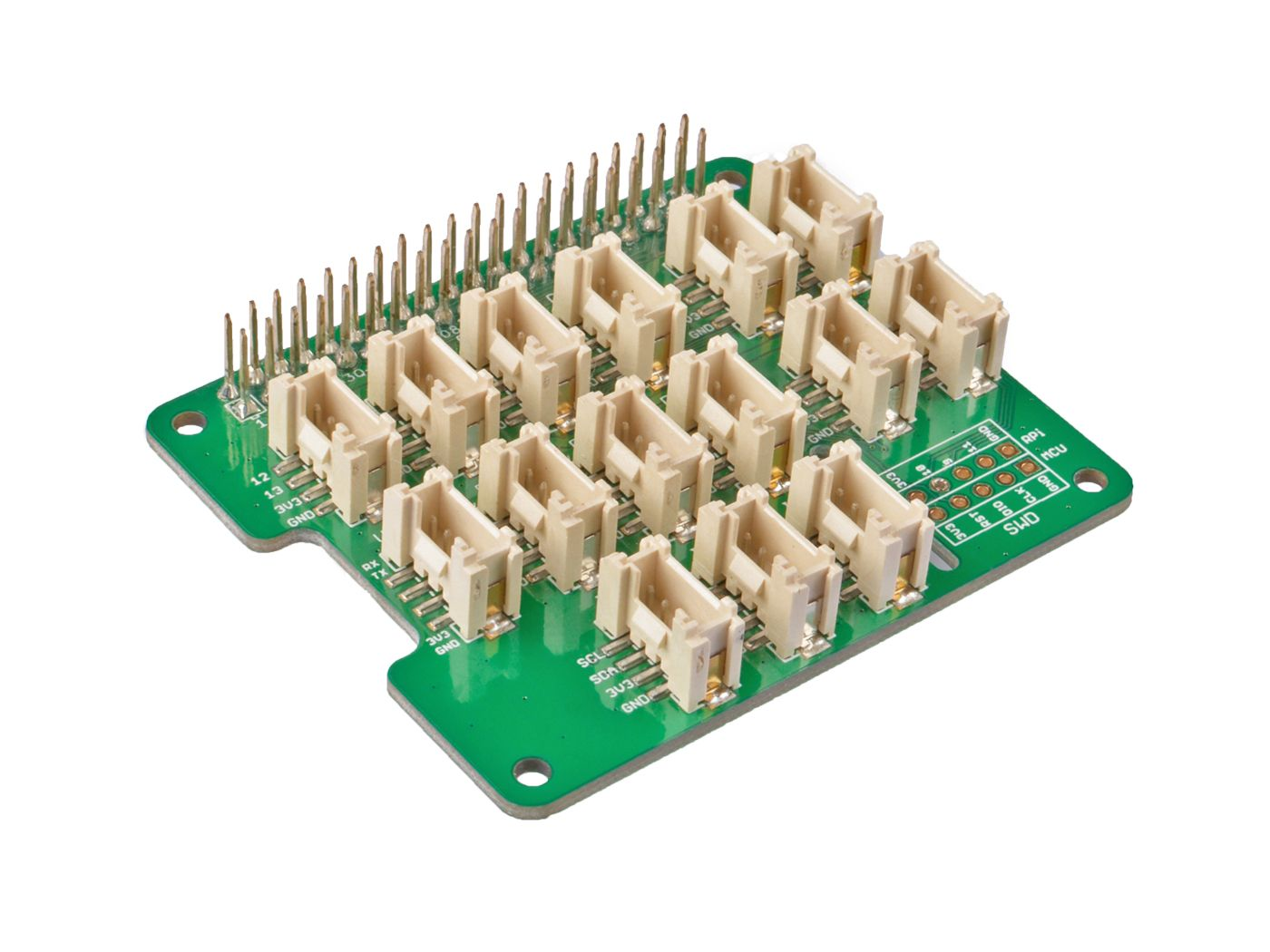
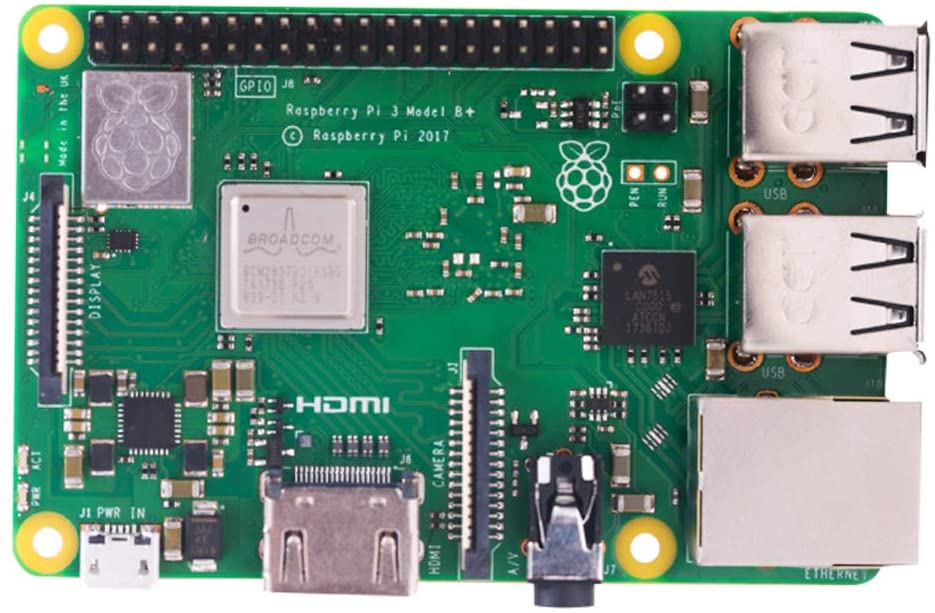
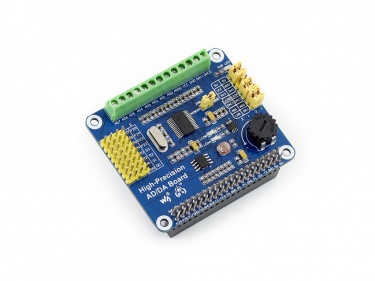
Con:

-Sensitive Reading(slight fluctuation in reading)

Grove Base Hat:

\*Not applicable for PH sensor reading purpose

# **Hardware**

* **Arduino UNO:  
  Arduinos are a popular series of cheap open source development boards that are simple to use. Like Raspberry PI, it can be used with a variety of electronics devices, but Arduino UNO has analog ports great for use with analog sensors/devices. Unlike Raspberry PI though, it does not have a computer interface and can only run one sketch continuously at a time.  
  **
* **Grove Base Hat for Raspberry PI  
  An attachable Hat for Raspberry PI made by Seeed. It features Digital/Analog/I2C/PWM/UART ports and most importantly a built-in 8 channel 12bit ADC since a RPI has no analog conversion. More info at this** [**link.**](https://www.seeedstudio.com/Grove-Base-Hat-for-Raspberry-Pi.html) ****
* **Grove PH Sensor (E-201C-Blue):  
  Seeed’s Grove PH module with a blue ph probe sensor. Since this ph sensor operates at 3.3V and 5V, Seeed claims that it works with Arduino and theoretically with Raspberry with additional ADC conversion with a Hat. No current demo code/instructions are provided at Seeed’s site for Raspberry PI. More details at their** [**site**](https://wiki.seeedstudio.com/Grove-PH-Sensor-kit/)**.  
    
  Features:  
  Operating voltage: 3.3V/5V  
  Resolution:±0.15PH（STP）**
* **Raspberry PI 3B+:  
  Raspberry PI is a popular mini computer board great for developers. It sports GPIO pins to connect variety of circuit and electronic devices (ie. sensor, motors,..etc). Also, with a more powerful processor than Arduino, RPI can run more computation and work like a computer.  
    
    
  RP3B+ features:  
  CPU:Broadcom BCM2837B0 quad-core A53 (ARMv8) 64-bit @ 1.4GHz  
  Network:Gigabit Ethernet (via USB channel), 2.4GHz and 5GHz 802.11b/g/n/ac Wi-Fi  
  Bluetooth: Bluetooth 4.2  
  Storage: Microsd card slot  
  Peripheral: USB, HDMI, Camera Serial Interface (CSI), Display Serial Interface (DSI)**
* **Waveshare High Precision AD/DA Board  
  Raspberry Hat board provided by Waveshare with the primary function of ADC/DAC conversion for the Raspberry PI board. It sports an impressive ADS1256 8 channel 24 bit precision ADC which is great for our application. Available** [**here.**](https://www.amazon.com/waveshare-Raspberry-High-Precision-AD-Board/dp/B0105DPYNO/ref=sr_1_1_sspa?crid=3TZQ6QPGLEAG0&keywords=raspberry+pi+ad+da+board&qid=1636395339&sprefix=raspberry+pi+ad+da+board%2Caps%2C212&sr=8-1-spons&psc=1&smid=A2SA28G0M1VPHD&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEySVY2ME5JMzMxR0dKJmVuY3J5cHRlZElkPUExMDA3NDYxMlNINFVCSVAwWU83MyZlbmNyeXB0ZWRBZElkPUEwMDI1OTE2TVpONEZTWEMxTUNaJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ==#customerReviews) **  
  Features:  
  GPIO: 40 Pin GPIO  
   ADC:ADS1256, 8ch 24bit high-precision ADC (4ch differential input), 30ksps sampling rate  
  DAC:DAC8552, 2ch 16bit high-precision DAC**

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