Using Arduino – Measuring pH value (Teacher instructions)

What is an Arduino?

An Arduino is a microcontroller, a sort of minicomputer. This microcontroller consists of the hardware, the Arduino board, and related software, Arduino IDE, with which the Arduino device can be programmed. A wide variety of Arduino boards are available. If "the" Arduino is mentioned, usually the Arduino UNO is meant, as is the case here.

The software can be used to program the Arduino, for example, to make an LED flash. It is also possible to connect various sensors whose values can be read using the Arduino.

Figure 1: Arduino UNO.

As a result, the Arduino can also be used as a system to take measurements in science and technology classes. The advantage is that Arduino is an open-source project that is also relatively inexpensive.
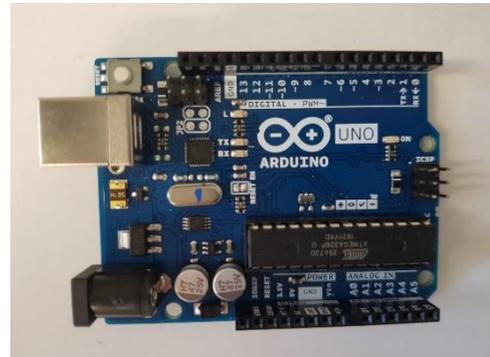
First steps with the Arduino

To be able to use Arduino, you need the Arduino board and the related Arduino IDE software. To load the programming environment on your computer, you can follow these instructions:

1. Go to the Arduino website: www.arduino.cc. On the "Software" tab, select the right software for your system and download it. Then you can install the software on your computer according to the instructions. The software is free and available under a free license.

2. Download the relevant program codes (sketches) from the Media Portal and open them using Arduino IDE.

3. Connect the Arduino to your computer using the USB cable.

4. Click the arrow at the upper left to upload 🔵 the sketches to the Arduino. If the port is not automatically detected, click *Tools → Port*.

5. If you would like to connect an external display, you must also include the corresponding library. Libraries expand the functions of the Arduino software. To do so, click *Sketch → Import library → Manage libraries*.

6. Search for the "LiquidCrystal_I2C" library (exact name!). It is possible that you will have to scroll down a bit until you have found the corresponding library. Install the library.
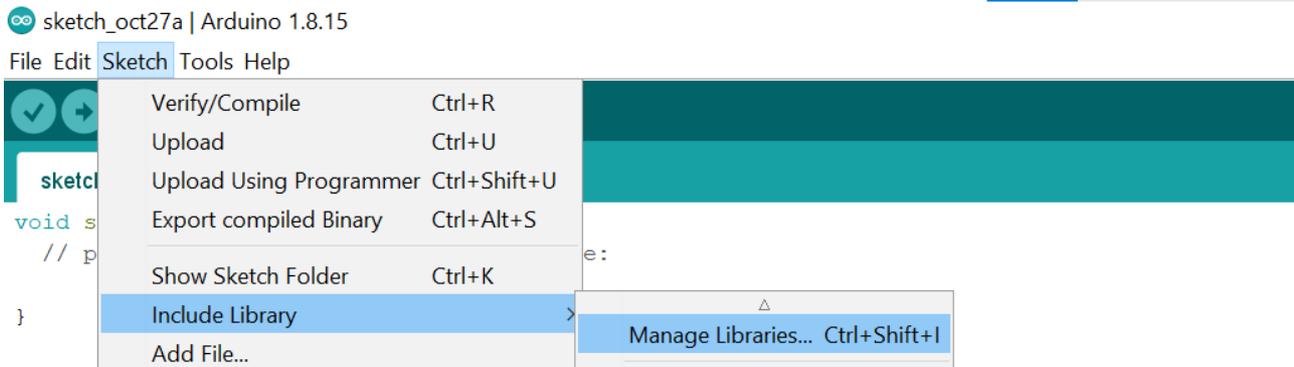
Required materials to measure a pH value

To measure a pH value using the Arduino, you first need an Arduino UNO board. You can also obtain the necessary connection cables and – if desired – the LCD display with built-in I2C port and the breadboard from the mail-order business for electronic components. You can use any pH electrode with a BNC connector. Even inexpensive models provide sufficient accuracy. For example, you can buy the PH-4520C pH sensor used here.

Calibrating the pH sensor

Required materials

- Laptop with Arduino IDE
- Arduino board
- pH sensor (PH-4502C)
- pH electrode with BNC connector
- Four connection cables (female – male)
- Screwdriver

Required chemicals

- Buffer solution with pH = 7.0

Instructions

Use an analog input of the Arduino for the pH measurement. In contrast to the digital input, which recognizes only two values ('on' or 'off'), analog inputs can process voltage values from 0 to 5 V at a resolution of 1,024 steps, thus with values from 0 to 1,023.

You must first calibrate the sensor to be able to cover the entire spectrum of pH values. Because the Arduino cannot read negative voltages, you must set pH = 7 (the "middle" of the pH scale) to exactly the middle of the voltage range, thus to 2.5 V.

To do so, connect the pH sensor to the Arduino as shown in the figure:

Arduino	pH sensor
5 V	V+
GND	G
GND	G
A0	P0

Figure 2: Connecting the pH sensor (schematic created using Fritzing).

The other pins on the pH sensor are not needed.

Attach any pH electrode with BNC connector to the pH sensor; connect the Arduino to a computer using a USB cable.

Next, place the pH electrode in a buffer solution with pH = 7.0. Finally, load the "calibration" sketch onto the Arduino (File → Open →…) (in IDE, click the arrow at the upper left):

```
void setup()                    // This function is executed once at the beginning.
{
  Serial.begin(9600);           // Initialization of communication with the Arduino, 9,600 bits per second.}
}
void loop()                  // The function is continuously executed again and again.
{
  int sensorValue = analogRead(A0); // The sensor value at pin A0 is to be read.
  float voltage = sensorValue * (5.0 / 1024.0); // The analog values (from 0 to 1023) are converted to voltage values (from 0 to 5 V).
  Serial.println(voltage);       // The voltage value is output to the serial monitor.
  delay(1000);                 // Brief delay.
}
```

The voltage values can now be read on the serial monitor (Tools → Serial monitor).

To calibrate the sensor, adjust the potentiometer (blue "box") that is closer to the BNC connector. To do so, use a small screwdriver to rotate the screw on the potentiometer until a voltage value of 2.50 V is shown for pH = 7.
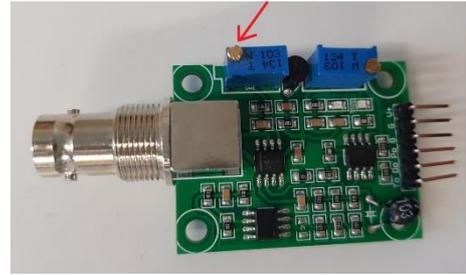
Figure 3: Screw that must be rotated on the pH sensor.

Preparing to measure the pH value

Required materials

- Laptop with Arduino IDE
- Arduino board
- pH sensor (PH-4502C)
- pH electrode with BNC connector
- Eight connection cables (female – male)
- Two connection cables (male – male)
- LCD display with built-in I2C port
- Breadboard
- Power bank, if applicable

Required chemicals

- Buffer solution with pH = 7.0
- Buffer solution with pH = 4.0
- Buffer solution with pH = 10.0
- Beverages to be tested, or similar liquids

Background

To measure a pH value, we use reference electrodes that output different voltage values depending on the pH value.

The pH value is thus not measured directly, but it must be calculated from the observed voltage.

pH electrodes exhibit a nearly linear behavior in the range between 0 and 14. Therefore, to convert the voltage values to pH values, we need a linear equation in the form of $y = mx + b$ (linear equation). To calculate the slope m of the straight line, we need the corresponding voltage values of at least two pH values.

We already know the first pair of values from the calibration: pH = 7; U = 2.5 V

Now we measure the voltage at another pH value, for example, at pH = 4.

We calculate m as follows:

$$m = \frac{\Delta \text{ voltage}}{\Delta \text{ pH value}} = \frac{\text{voltage (pH=7) - voltage (pH=4)}}{7 - 4}$$

For pH = 4, we measured a voltage of 3.0 V, for example =>

$$m = \frac{2.5 - 3.0}{7-4} = -0.167$$

To increase the accuracy, we can use two-point calibration in which we also measure the voltage for pH = 10 and calculate the mean value of m accordingly.
An understanding of how we arrive at m is important for comprehending how the voltage values are converted to pH values in the program code ("sketch"):

```
pHvalue = (7 + ((2.5 - voltage)/0.167));
```

The value of m just calculated appears here again. You can adjust it according to your own measured values.
The proper conversion of the formulas encourages interdisciplinary collaboration with colleagues in mathematics.

Side note

$$m = \frac{\Delta \text{ voltage}}{\Delta \text{ pH}} = -0.167$$

$$-0.167 = \frac{2.5 - \text{voltage}}{7 - \text{pH}}$$

$$0.167 = \frac{\text{voltage} - 2.5}{\text{pH} - 7}$$

$$\text{pH} - 7 = \frac{\text{voltage} - 2.5}{0.167}$$

```
pHWert = (7 + ((2.5 - spannung) / 0.167));
```

The constant **b** in the equation for a linear function is initially disregarded, but you can set it manually to any value if systematic deviations occur.

Instructions

Load the relevant program code onto the Arduino. If necessary, adjust the value for m. Measure the pH values of various solutions.

Connecting a display

Required materials

- laptop with Arduino IDE
- Arduino board
- pH sensor (PH-4502C)
- eight connection cables (female – male)
- two connection cables (male – male)
- LCD display with built-in I2C port
- breadboard
- power bank, if applicable

Instructions

In everyday school life, it is frequently impractical to use the serial monitor on a laptop. Therefore, integrating a display is useful. We recommend using an LCD display with an I2C port. Thanks to the built-in I2C port, far fewer cables are required than would be needed for a normal LCD display for Arduino.
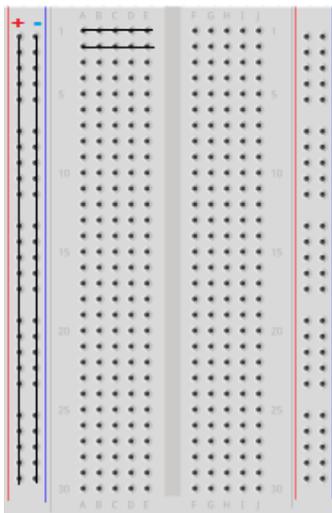
Figure 4: Breadboard (schematic created using Fritzing).

If you integrate a display, you can no longer connect all cables directly to the Arduino; rather, you must include a breadboard in the circuit. This is the only way to provide power to the display and the sensor simultaneously (5 V and GND connection).
The breadboard is divided into two halves. Connections for the power supply are found on each edge. These connections are conductively interconnected vertically.
In the center area, the rows are each conductively interconnected horizontally (see schematic in figure 4).

Accordingly, you can now connect the components according to the following schematic (figure 5):
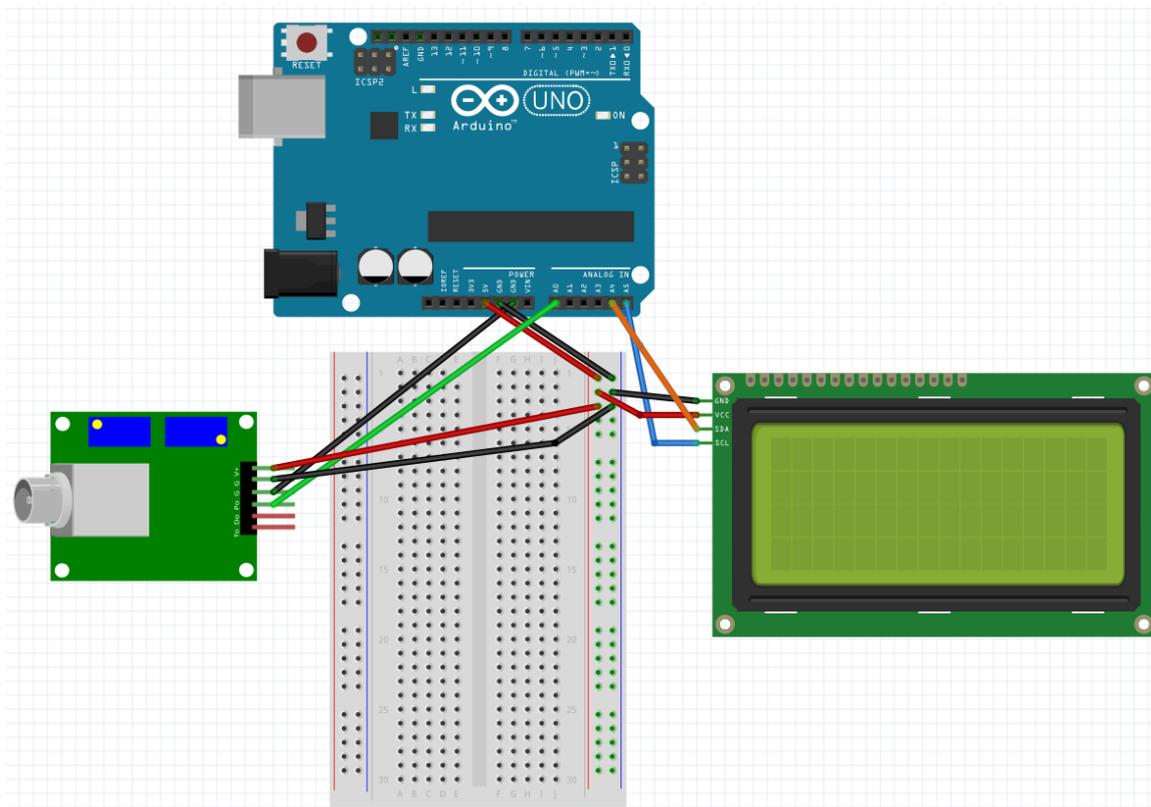
Figure 5: Connecting the display and the pH sensor using a breadboard (schematic created using Fritzing).

pH sensor	Arduino board	
V+	5 V	Via the bread-board
G	GND	Via the bread-board
G	GND	Direct
P0	A0	Direct

Display	Arduino board	
GND	GND	Via the bread-board
VCC	5 V	Via the bread-board
SDA	A4	Direct
SCL	A5	Direct

Code

To be able to use a display, you must download the "LiquidCrystal_I2C" library and import it accordingly into Arduino IDE (see general instructions on page 1). The additional coding lines that are needed to communicate with the display are already included in the provided sketch (e.g., "pH_Sketch_mitDisplay").

If you use a power bank as the power supply, you can also conduct the pH measurement without using a laptop after uploading the corresponding sketch.