PHYS 371

Learn the tools of experimental physics:

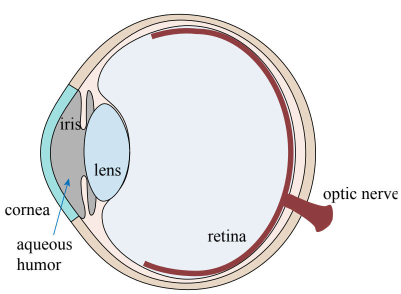
1. Interface with the nature world using digital and analog technologies.
2. Use that interface to do some physics

More specifically:

1. Learn some coding (Arduino, Python/Colab/Jupyter)
2. Learn some circuits (Prototyping and basic circuit design)
3. Deal with data (Python/Colab/Jupyter)
4. Express your scientific thought (LaTeX)

1. Measurements

1.1 Evolution of Measurement Techniques



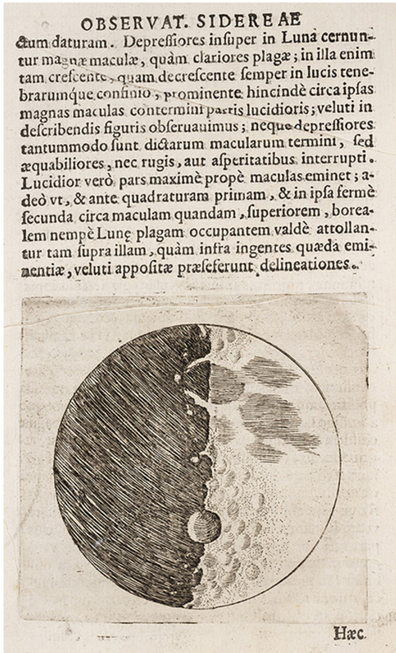
The Earliest Measurement Tool

For centuries, all experimental science (if you could call it that) was done using our senses: sight, hearing, touch, taste, smell. The obvious drawback is that our senses are all different, and not very constant over time. What's heavy to me, might be light to you. Using your fingers to measure the temperature of water obviously will yield different results depending on what your fingers where touching before they measured the water, and you might only have about 3 different temperatures for your scale: hot, regular, cold.

Early 1600's painting featuring a telescope.

The first solution was to try and improve the senses by using technology. The telescope gave us a different set of lenses than evolution. By sacrificing field of view, a simple lens system can greatly improve angular resolution.

On the telescopes in the paintings of J. Brueghel the Elder,
https://arxiv.org/abs/0907.3745



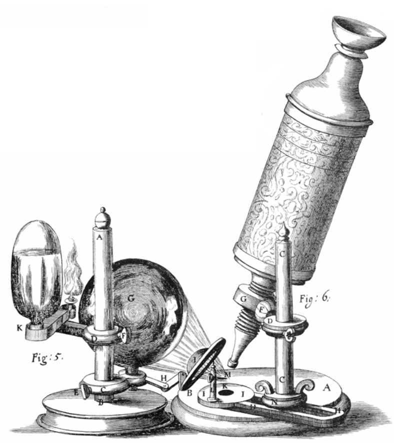
Galileo's Drawing of the moon as seen through a telescope, 1610

[The Face of the Moon]()

Cassini's version from 1692

[The Face of the Moon]()

New discoveries quickly followed. Galileo could make the claim that the moon was not a perfectly smooth object, but in fact had mountains and craters, not unlike Earth.



Hooke's Micrographia was among the first to attempt science using a microscope, 1665.

Hooke's Micrographia: [Image Source]()

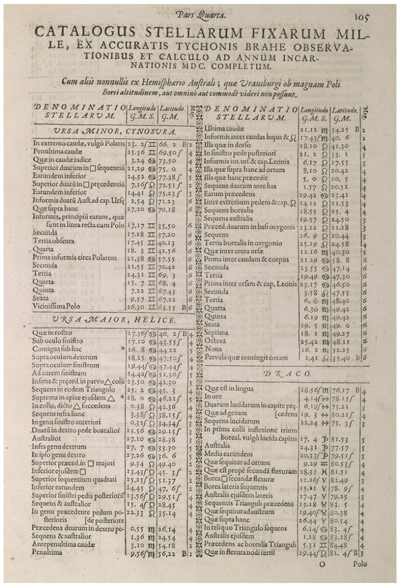
An ant

Hooke's Micrographia: [Image Source]()

And small scale structures were resolved by a similar configuration of polished glass. Microscopes opened up the world that was closer, but too small to resolve with our own eyes.

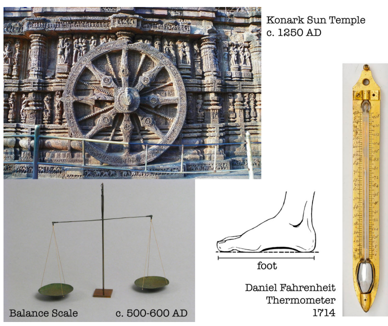
1.2 Quantify and Analyze

The next step is to turn these qualitative observations into information that can be merged with mathematics. Hence, a table of data. Here is the table of fixed stars by Tycho Brahe and Johannes Kepler. A very detailed and accurate list of stellar positions.


Pars Quarta. 105

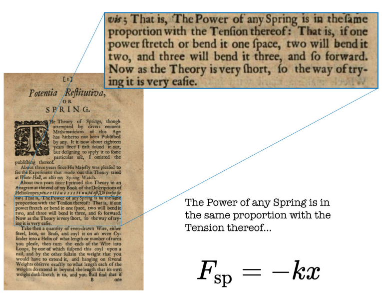
CATALOGUS STELLARUM FIXARUM MILLE, EX ACCURATIS TYCHONIS BRAHE OBSERVATIONIBUS ET CALCULO AD ANNUM INCARNATIONIS MDC. COMPLETUM.

Cum aliis nonnullis ex Hemisphærio Australi; quæ Uraniburgi ob magnam Poli Borei altitudinem, aut omninò aut commodè videri non possunt.



There are many other things to measure, besides simple visual observation.

Balance: [Met]

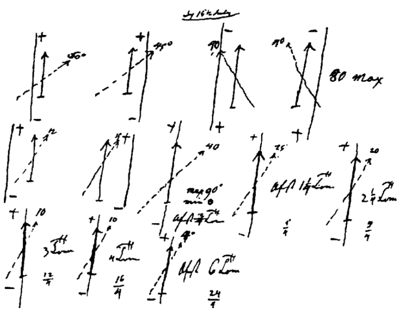


But there are some quantities we employ in physics, that are not quite directly measurable. Consider *Force* for example. How do you measure the force on an object? You need a proxy measurement, or another quantity that has a correlation to force. Relationships like Hooke's law are examples of that. There is a direct relationship between the displacement of the spring, and the force acting. Thus, we can say something about the force, by simply measuring a distance. (To have a *calibrated* measurement, we would of course need to agree on units and understand $\boldsymbol{k}$.)

The Cavendish experiment was able to measure the force of gravitational interaction between two large masses by using a version of Hooke's law modified for torsion springs.

Cavendish Measurement of the gravitational interaction.

Image Source



A sketch from Ørsted's Notebook, c. 1820.

With the discovery that an electric current will make a magnetic needle rotate, the door was cast wide open to an entirely new set of measurement tools. Now, anything that can influence the current in a wire can be 'measured' with a gauge (ammeter).

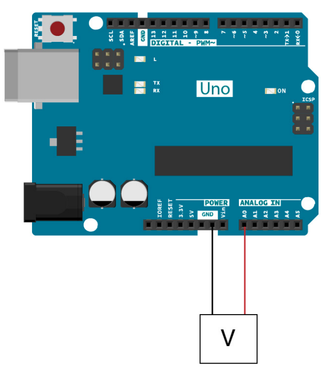
2. Voltage

Almost everything measured in a modern experimental physics lab is measured as a voltage.

Examples:

- Temperature: measure the voltage across a temperature dependent resistor.
- Distance: a digital caliper measures a change in capacitance by measuring $V(t)$
- Magnetic Fields: Measure the Hall Voltage
- Photons: a Charge Coupled Device produces a sequence of voltage values that describe the array of pixels.

Define Voltage




```
void setup() {
  Serial.begin(9600);
}


void loop() {
  int sensorValue = analogRead(A0);
  Serial.println(sensorValue);
  delay(1);
}
```

Primarily, what the arduino will measure is voltages.

2.1 Analog/Digital

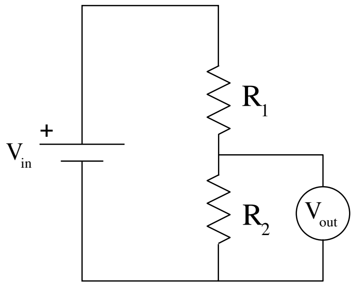
Actually, we'll be measuring what portion of 5V is applied across the analog input.

Since it's a digital measurement (we'll come back to this), it will appear as a value between 0 and 1023.

`0` means 0 V

`1023` means 5 V

This is set by the 'resolution' of the system.

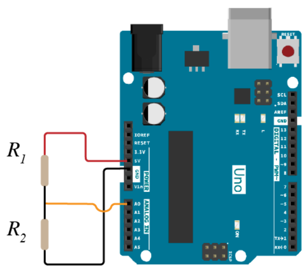


The voltage divider circuit diagram

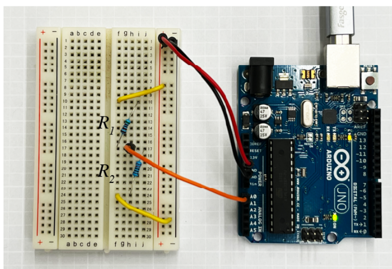
2.2 Voltage Divider

The **Voltage Divider** circuit is the easiest way to measure an unknown resistance. It has some limitations, but will essentially work for many applications

$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\text{in}}$$



Schematic illustration



Photograph of Arduino and Breadboard