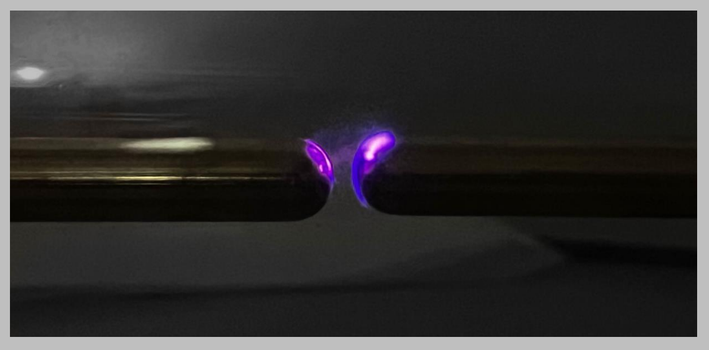
Project-oriented Physics Lab
for Undergraduate Students

Physics Lab
ETH zürich

# Paschen's Law

Breakdown voltages for air and Argon at low pressures



## Effect

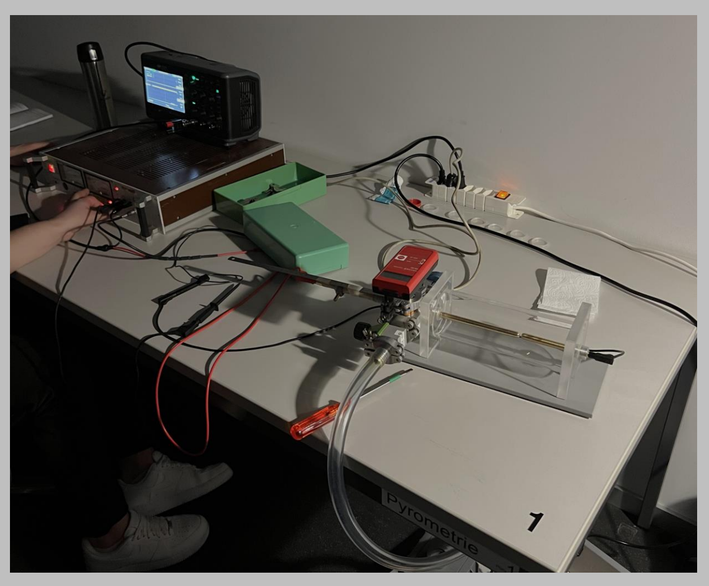
When high voltages are applied to two electrodes, an arc forms at a certain voltage as the gas between them is ionized, allowing current to flow and resulting in a voltage drop.

The breakdown voltage depends on:
- Geometry of electrodes (electric field)
- Gas between electrodes
- The pressure of the gas (and thus density)
- Distance of electrodes

The formula named after *Friedrich Paschen* relates pressure and electrode distance to the breakdown voltage. The experiment seeks to verify the formula and the resulting curves.

$$V_B = \frac{\beta p d}{ln(\frac{\alpha p d}{ln(\frac{1}{\gamma})})}$$

$V_B$ : Breakdown voltage
$\alpha, \beta, \gamma$ : material constants
$p$ : pressure in Pascal
$d$ : distance between cathode and anode in meters

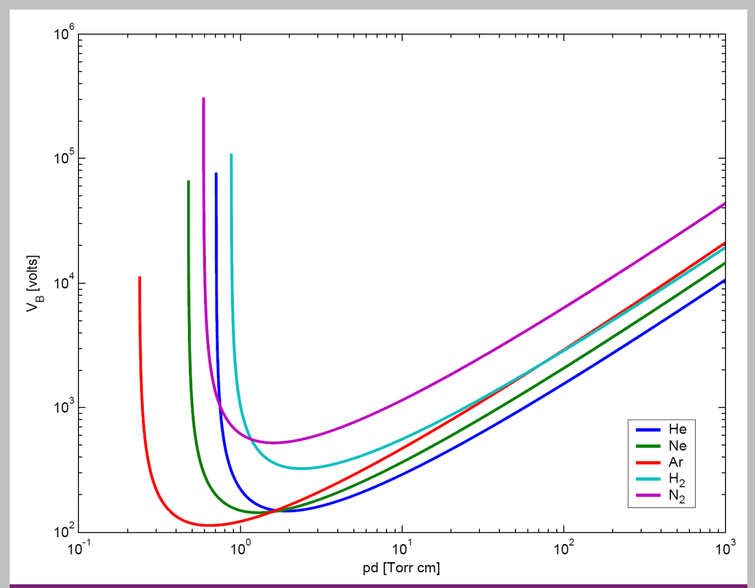



## Setup

The setup consists of a vacuum tube with two hemispherical brass electrodes (inner tube radius: 3.5 cm, electrode radius: 0.5 cm). One electrode is adjustable to vary the distance to the other. A pump, pressure sensor, and valve are connected to the vacuum tube. The pump achieves pressures down to 0.01 mbar. Through the valve, gases different from air can be inserted. A high voltage generator (up to 6 kV) is connected to the electrodes, and a digital storage oscilloscope (DSO) measures the voltage via a voltage divider (~$1000^{-1}$).

## Results

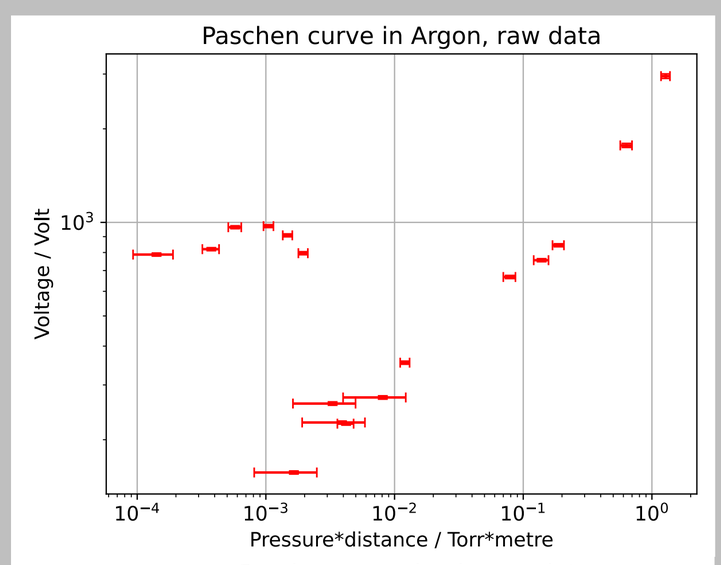
The experiment reproduces Paschen curves for air and Argon with varying accuracy. Air data matches well, while Argon shows the key features (minimum with slope to the left steeper than to the right).
Our fit parameters are on the correct scale, but lack accuracy compared to literature values:

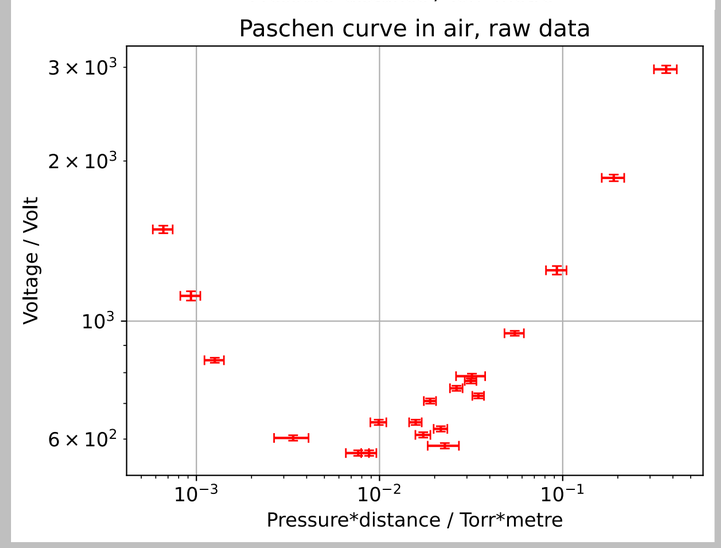



This shows the theoretical Paschen curves for several gases. Notice that $N_2$ should be close enough to air for a qualitative consideration. (image from [1])

## Applications

- Protection in electrical devices
- Gas discharge lamps (neon lights)
- Ionization detectors for charged particles




| Medium | $\alpha'$ ($\mathrm{Torr^{-1}\,m^{-1}}$) | $\beta$ ($\mathrm{Torr^{-1}\,m^{-1}}$) |
|---|---|---|
| *scipy.odr* | | |
| Air | $300 \pm 300$ | $60'000 \pm 50'000$ |
| Argon | $200 \pm 800$ | $20'000 \pm 50'000$ |
| *scipy.curve_fit* | | |
| Air | 360 ±50 | 43000 ±6000 |
| Argon | 280 ±20 | 13000 ±2000 |
| Literature value | | |
| Air | - | 36000 |
| Argon | - | 18000 |

The first constant α‘ includes α and γ from the formula and can therefore hardly be compared, as there are no suitable literature values for γ.

The image below shows glow discharge. Our assumption is that the electrodes are too close to the plexiglass compared to the distance between them. This results in a glow that is highly different from the otherwise observed arc.

*[1] Harlock81. Paschen-Gesetz. Accessed: 2024-18-04. 2009. url:* `https://de.wikipedia.org/wiki/Paschen-Gesetz#/media/Datei:Paschen_Curves.PNG`.

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