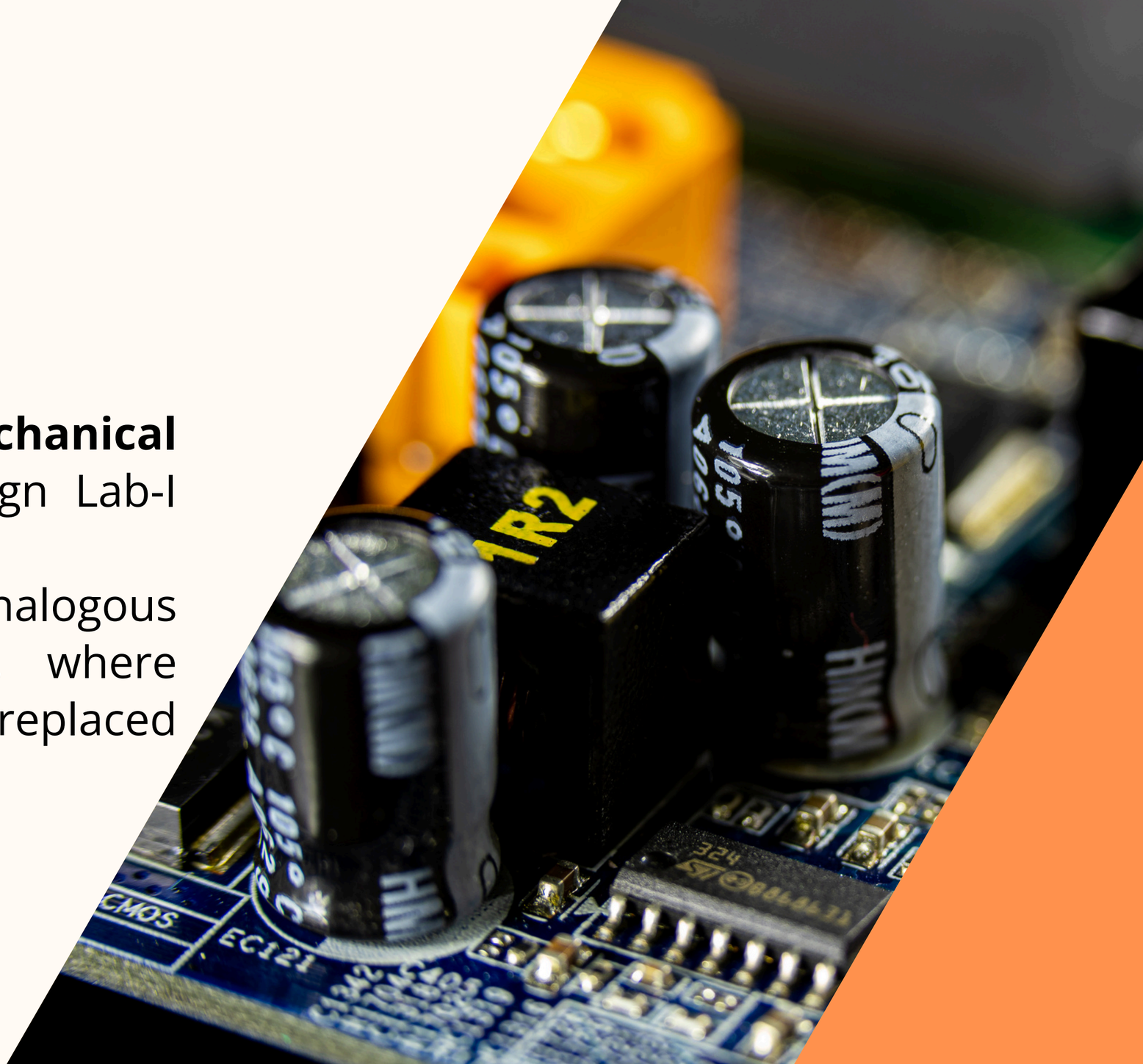
Mechanical Circuits

Presented by:
Friday - Group-D

Problem Statement

We were assigned **Mechanical Circuits** as our ME-205 Design Lab-I project.
In this, we had to design an analogous circuit to electrical circuits, where electrical components were replaced by mechanical components.



Hydraulic Circuits

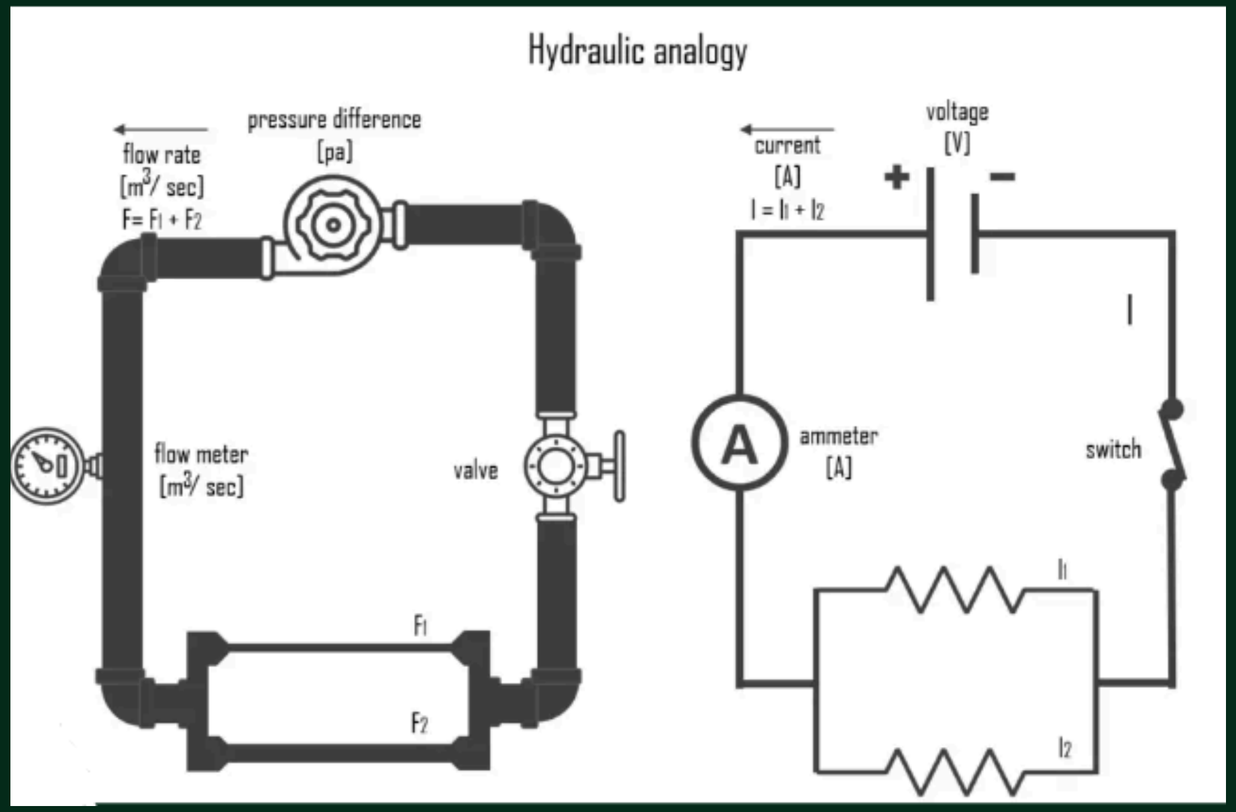
For the analogous electrical circuit, we designed a hydraulic circuit.
We designed two circuits, one works on DC model- includes resistors in series and parallel combinations, and one AC model- LC oscillator.

Basic Analogies

Current - Volume Flow Rate
Charge - Volume
Current Density - Velocity
Potential - Pressure
Ohm's Law - Poiseuille's Law

Poiseuille's law $\Phi_V = \frac{\pi r^4}{8\eta} \frac{\Delta p^*}{\ell}$

Ohm's law $j = -\sigma \nabla \phi$

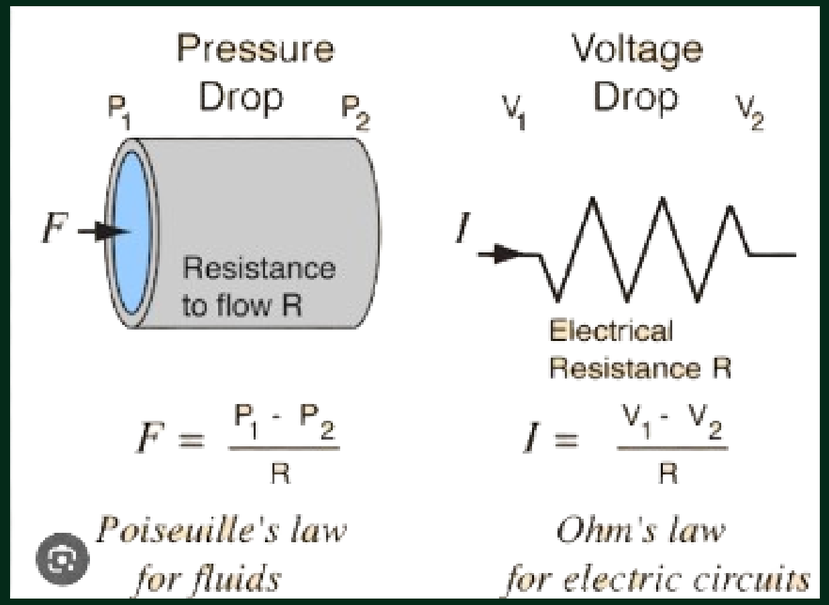


Resistance

A decrease in the diameter of the pipe is analogous to an electric resistor.
Electric- **V=IR**
Hydraulic- **Pressure Difference= Flow Rate * Resistance** (Resistance= $8\mu L/\pi r$^4)

Voltage Source

A pump operates with Power = **Pressure * Flow rate**, and from the analogies seen previously it is equivalent to P=V*I, i.e. analogous to the power supplied by a battery.



Capacitor

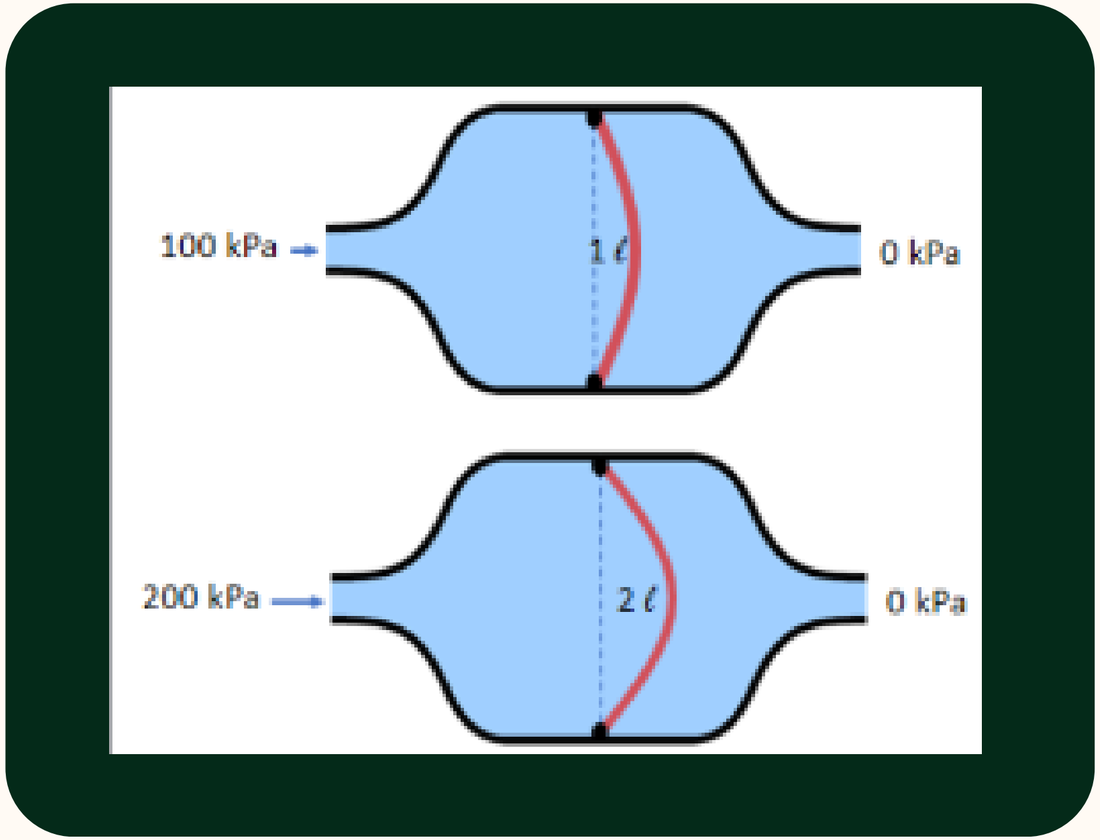
A pipe with a rubber sheet (Diaphragm) would serve as the capacitor

HYDRAULICS

Volume = **Capacitance x Pressure**
Consider the change over time:
(change in Volume over time) = **Capacitance x (change in Pressure over time)**
Flow Rate = **Capacitance x (dP/dt)**

ELECTRICAL

Charge = **Capacitance x Voltage**
Consider the change over time:
(change in Charge over time) = **Capacitance x (change in Voltage over time)**
Current = **Capacitance x (dv/dt)**



Inductor

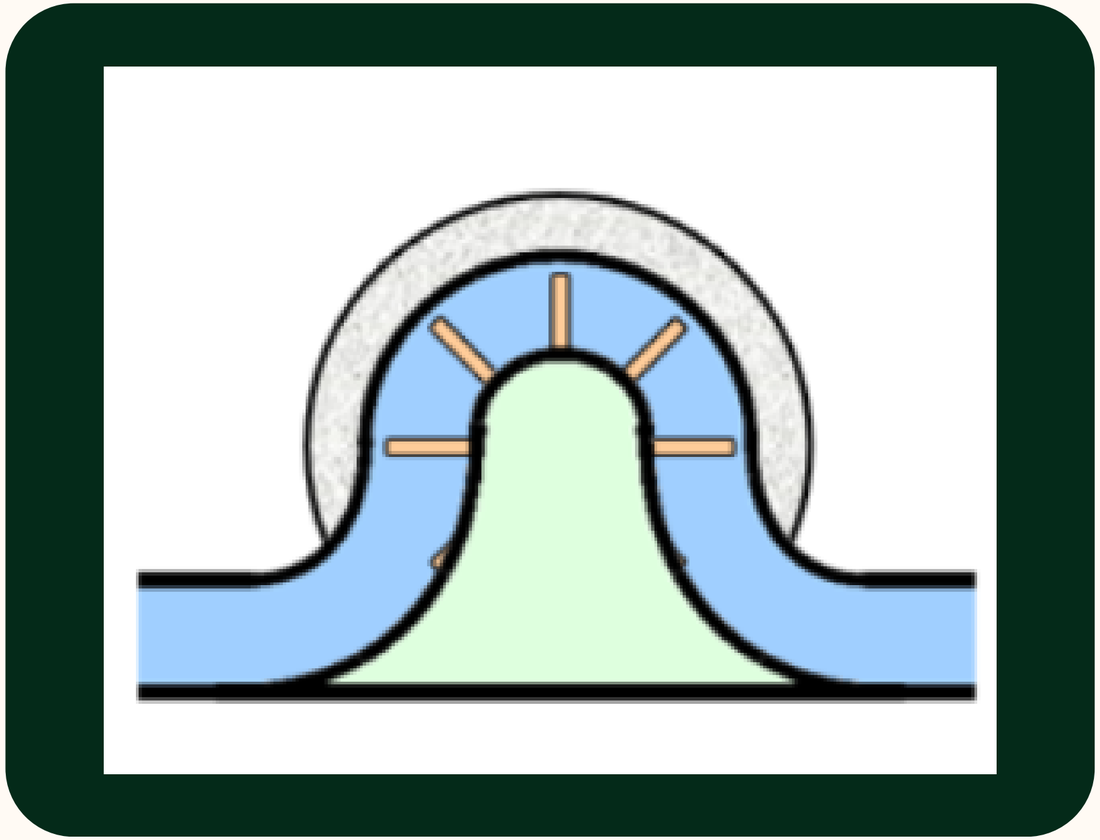
The hydraulic analogy to an inductor would be a heavy paddlewheel.

HYDRAULICS

Momentum = **Inductance x Flow Rate**
Consider change over time:
(change in Momentum over time) = **Inductance x (change in Flow Rate over time)**
Pressure = **Inductance x (dQ/dt)**

ELECTRICAL

Flux = **Inductance x Current**
Consider change over time:
(change in Flux over time) = **Inductance x (change in Current over time)**
Voltage = **Inductance x (di/dt)**



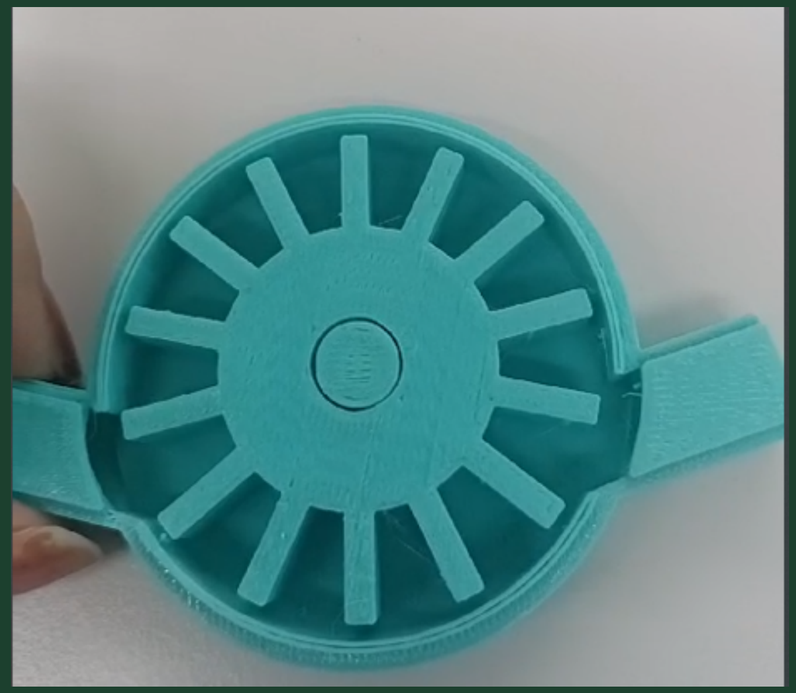
Diode

A diode only allows current in one direction, i.e when it is in forward bias. Similarly a **check valve** allows water to flow in one direction

Switch

The hydraulic analogy to a switch would be a **gate valve**.

What we made



Inductor

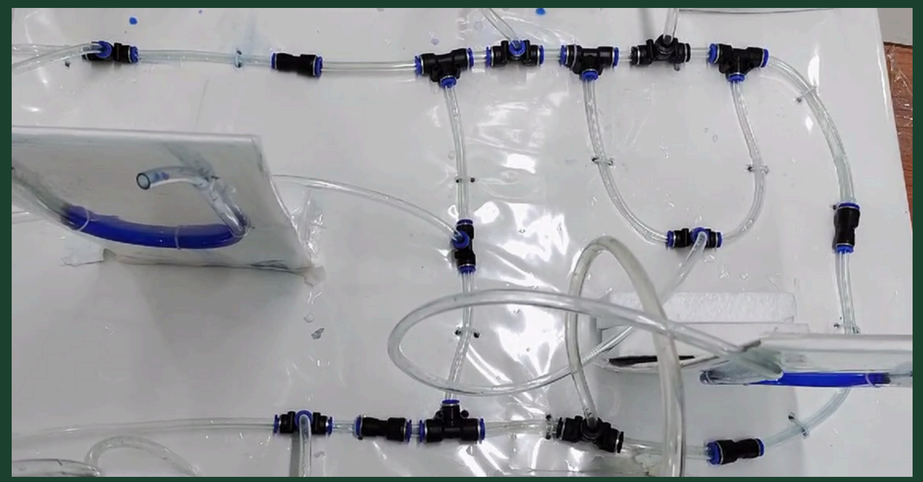
Manometer

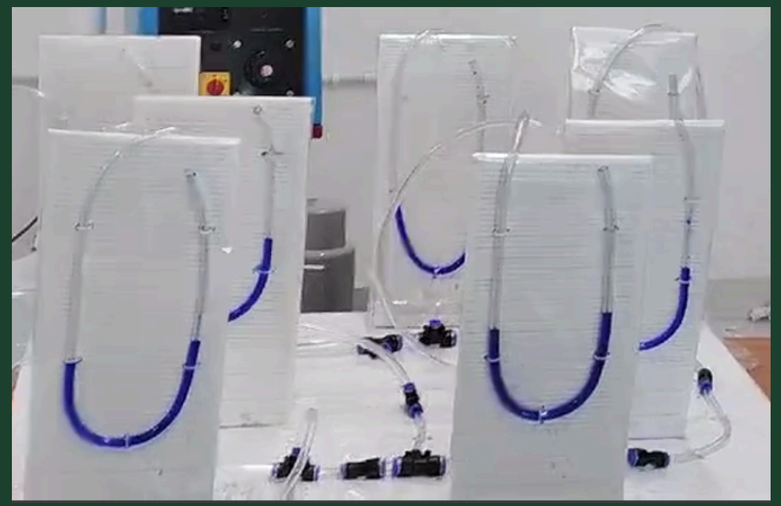
Capacitor

DC Circuit

Combination of pipes in series and parallel.

- Our first project demonstrates the hydraulic equivalent of a DC circuit with various combinations of resistances.
- Pipes of 8mm diameter and 10mm diameter were used.
- An inlet attached at one end to the pipes and other end at a tap acts as the battery.
- Changing the diameter of the pipes at various parts in the pipe setup represented series resistances while splitting the pipes represented parallel resistances.
- Manometers were constructed added at various points in the pipe setup to show the pressure drop(voltage drop) across the circuits.
- It was observed that there was maximum pressure at the inlet and the outlet had the least pressure.
- The pressure drop across the setup was so high that there was negative pressure at the manometer near the outlet(Patm was greater than pipe pressure)





AC Circuit

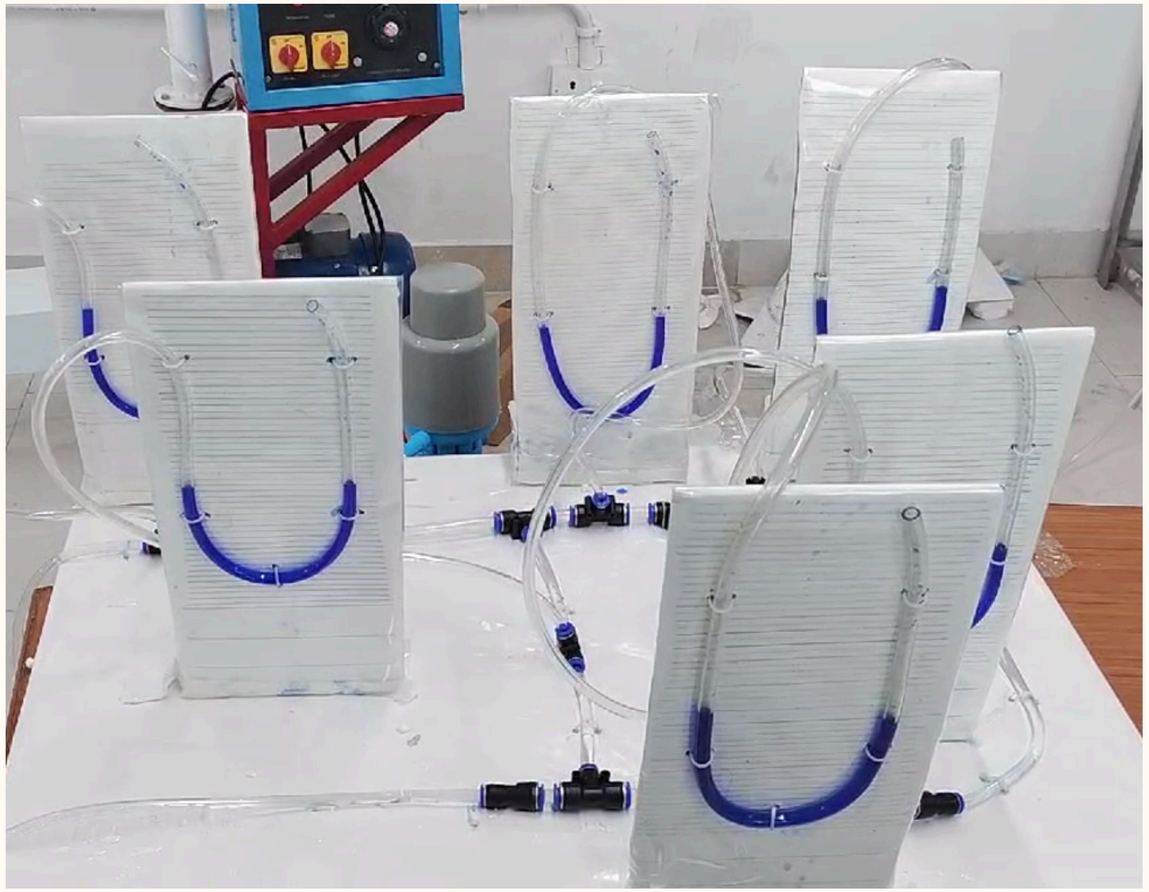
LC - Oscillator

- To demonstrate an AC circuit equivalent we build a circuit to demonstrate LC Oscillations.
- The hydraulic analog of the inductor was a paddle wheel that we designed on SolidWorks.
- For the capacitor we took a soda bottle and cut it in two, attached a stretched balloon on one part and then joined the two parts.
- We had a T junction where the inlet would be connected to(The voltage source)
- As we fill the circuit with water, that is equivalent to charging the capacitor, once enough water is added to the circuit such that the balloon is distended to one side, the inlet is removed and covered(removing the voltage source)
- The balloon pushes the water in the other direction due to the energy stored in it causing the paddlewheel to spin in one direction, then the balloon distends in the opposite direction and the process repeats.
- This was the direction of water keeps flipping

Difficulties Faced-DC Circuit

- Water kept leaking at different point so we had to seal then and test repeatedly.
- The first time we tried pumping the water in all the ink in every single manometer was ejected out as the water from the circuit kept going inside it.
- We thought that this was due to high pressure at the inlet which provided enough pressure to push the water inside the manometers.
- We then removed all of the manometers and thought of holding some pipes vertically(Where the manometers were originally placed) and showing the pressure drop across the circuit by showing the decrease in heights of the water.

- As we were trying that idea we realized that the outlet wasn’t letting out as much water as we expected it to.
- It was then we realized that the check valve before the outlet(representing a forward biased diode) had and orifice so small that it caused pressure to build up in the circuit, hence causing the manometers to fill up.
- We then removed the check valve and re-attached all the manometers and conducted the experiment.
- It worked!



Difficulties Faced-AC Circuit

- The paddle wheel was not sealed properly at first causing water to leak out.
- We tried to use hot glue to seal it but it did not work that well. Then we used fevitite to seal it and it worked.
- The capacitor also had to same problem, and we had to attach the two parts of the bottle with fevitite.
- When pumping the water in the water did not go equally on both sides (while filling). This caused the balloon to be at risk of popping (which it did once). There was also air trapped inside and we had to pause in between to allow the air to rise up.

Group-D

Vaishnavi Chhabra
2022MEB1361
Vaishnavi Gowrishankar
2022MEB1362
Vedant Gupta
2022MEB1364
Vikrant Bankura
2022MEB1365
Vineet Kumar
2022MEB1366

References

- https://www.electricity-magnetism.org/hydraulic-analogy-electric-fluid-analogy/#:~:text=The%20hydraulic%20analogy%2C%20or%20the,applied%20to%20heat%20transfer%20problems.
- https://en.wikipedia.org/wiki/Hydraulic_analogy