Transducers & Instrumentation

Module 05 - 02

Measuring Pressure, Flow, and Volume

Flow rate

- Measured as volume flow rate → Volume of substances that crosses an area of cross-section in unit time. (Unit: m^3/s)
- Mass flow rate → Mass that crosses a surface in unit time. (Unit: Kg/s)
- Blood flow is an important physiological parameter of interest.
- Inspiration and expiration rates.

Cardiac Output (CO)

- Amount of blood pumped by the ventricles.

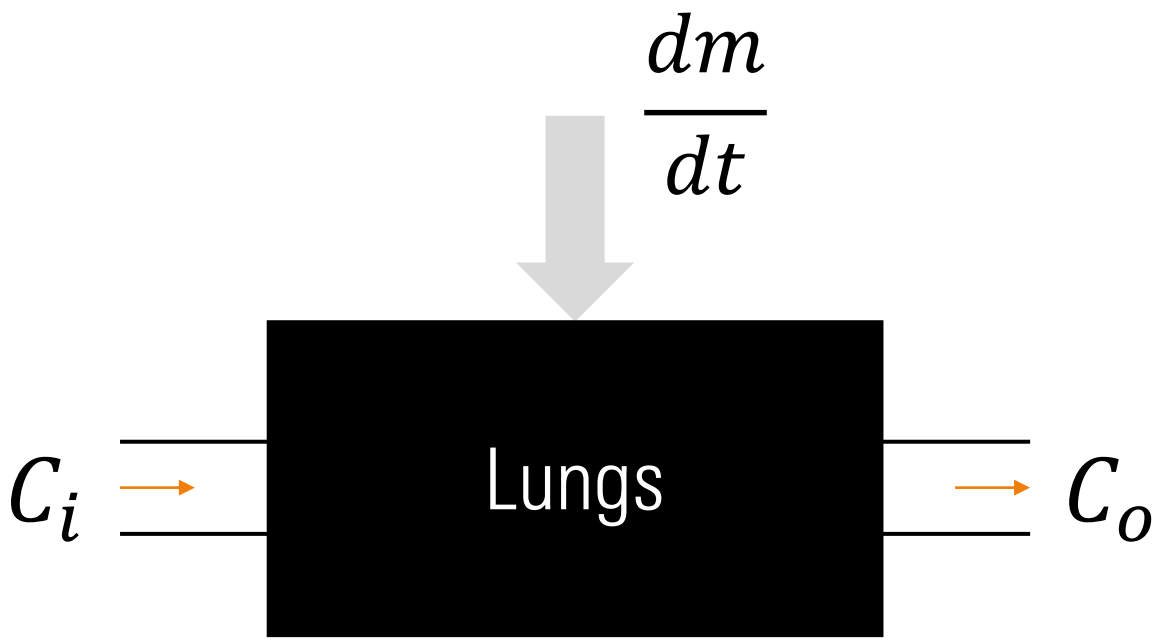
$$CO = SV \times HR$$

- SR: Stroke Volume – Volume of pumped out by the single contraction of the ventricles.
- HR: Heart Rate – Number of heart beats per minute.
- CO is an important parameter of ventricular function.

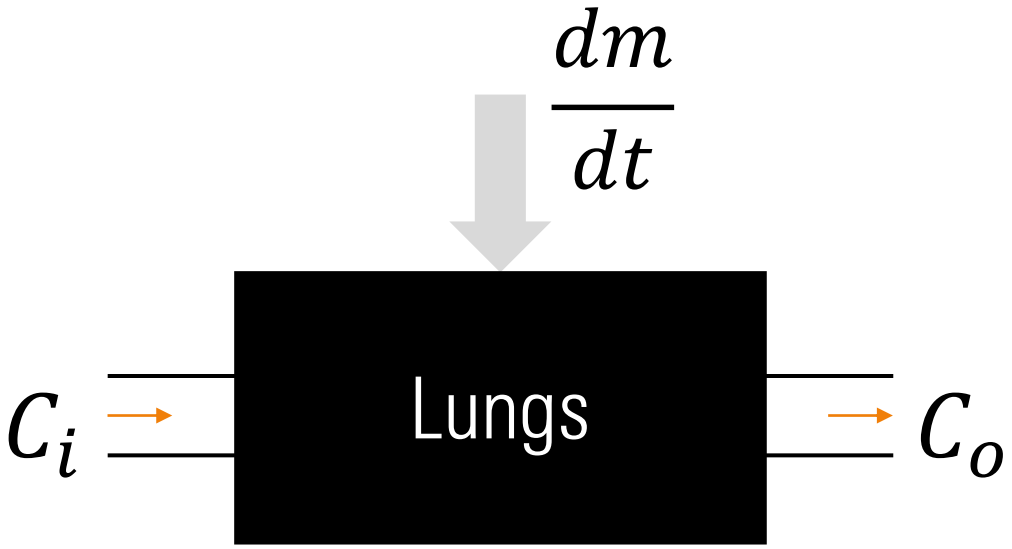
Fick's method

- Proposed by Adolf Fick in 1870.

$$CO = \frac{\frac{dm}{dt}}{C_o - C_i}$$



Fick's method

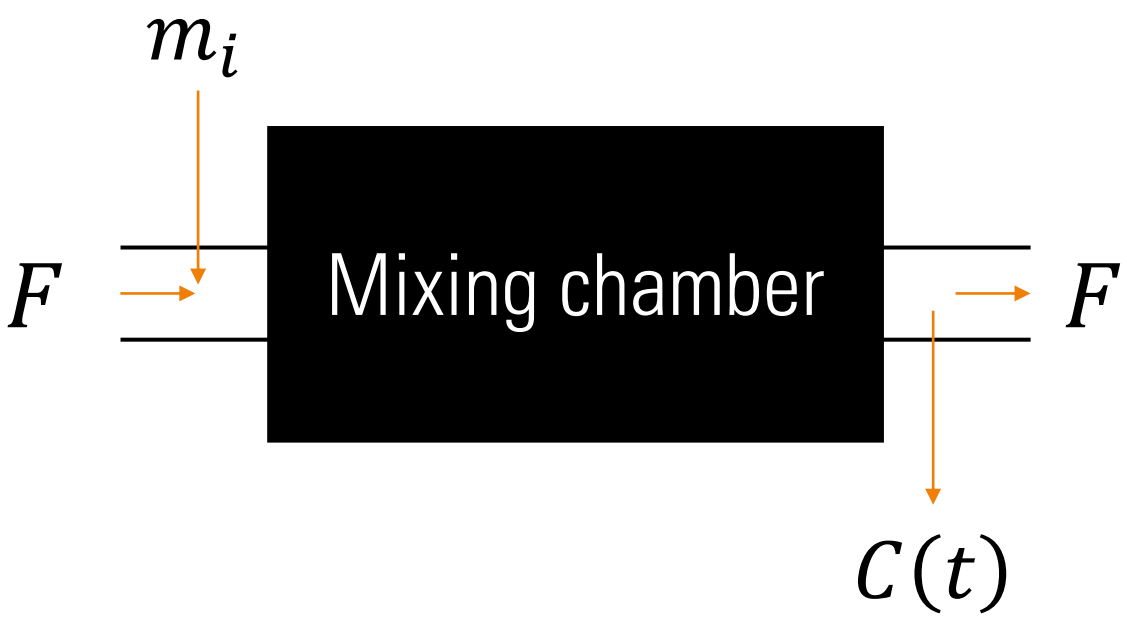


$$CO = \frac{\frac{dm}{dt}}{C_o - C_i}$$

Inspired oxygen = 210 mL/L
Expired oxygen = 160 mL/L
Total volume = 26L
Duration = 3min
Arterial oxygen concentration = 195 mL/L
Venous oxygen concentration = 132 mL/L

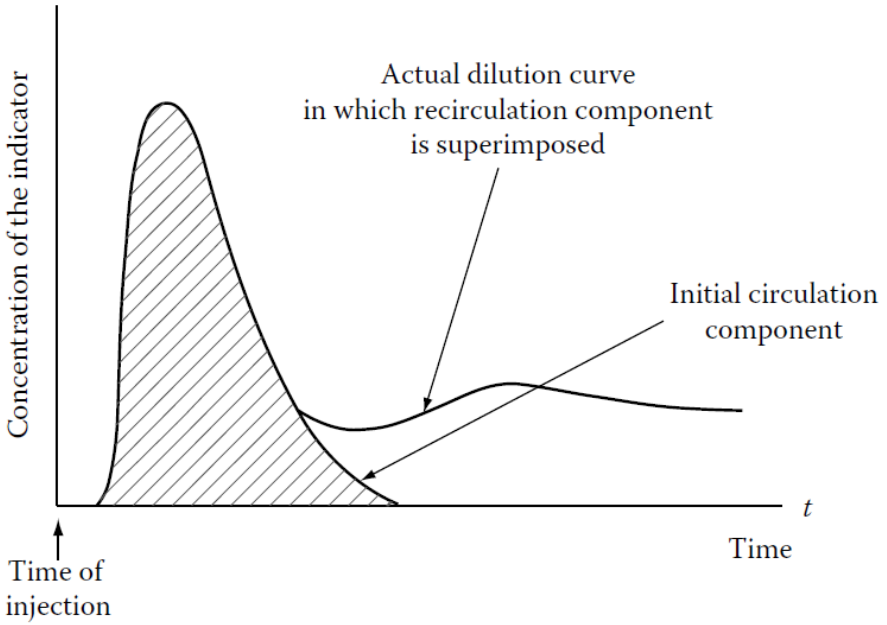
What is the cardiac output?

Indicator dilution method (Stewart-Hamilton Method)



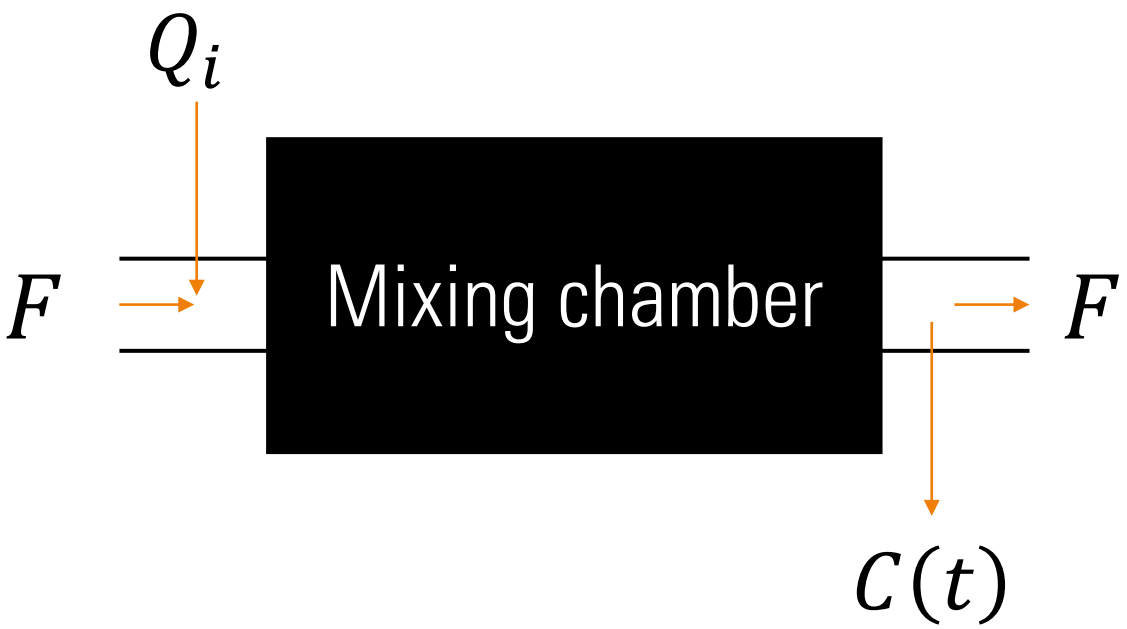
$$CO = \frac{m_i}{\int C(t)dt}$$

- Sudden injection of indicator compound.



Thermodilution method

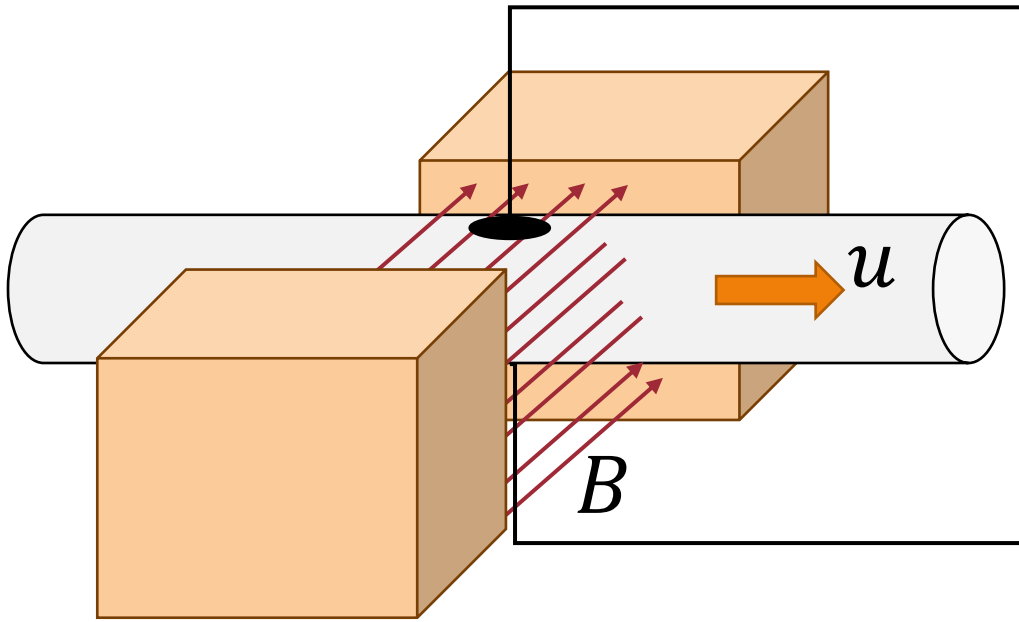
$$\rho_i C_i V_i [T_b(0) - T_i] = \rho_b C_b \int_0^\infty [T_b(t) - T_b(0)] \, F dt$$



$$F = \frac{\rho_i C_i V_i [T_b(0) - T_i]}{\rho_b C_b \int_0^\infty [T_b(t) - T_b(0)] \, dt}$$

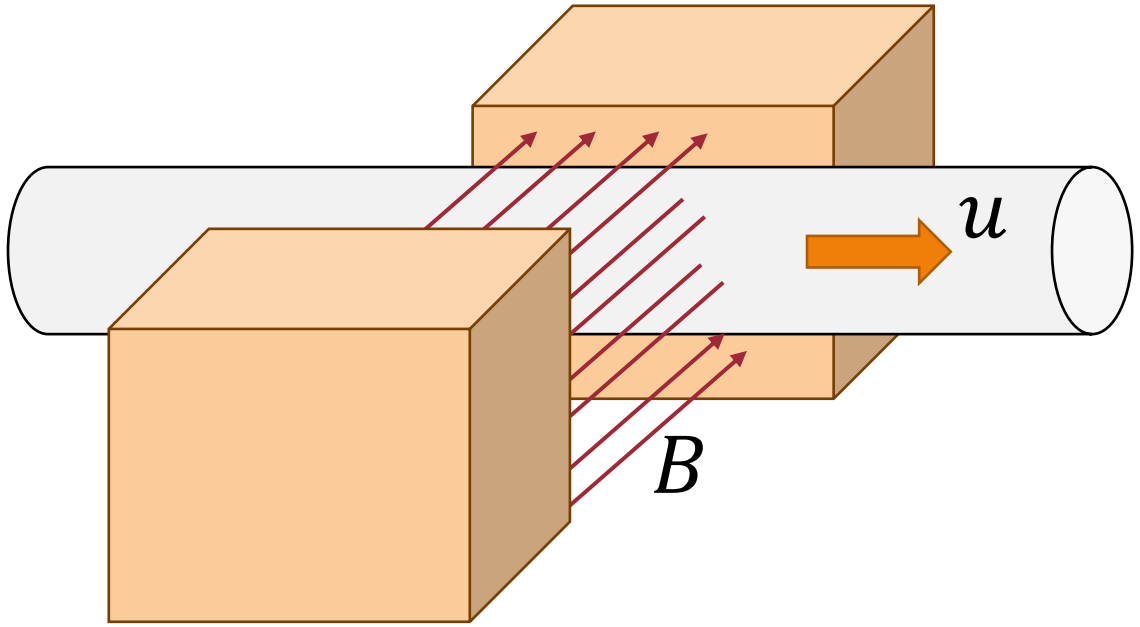
Electromagnetic flow meter

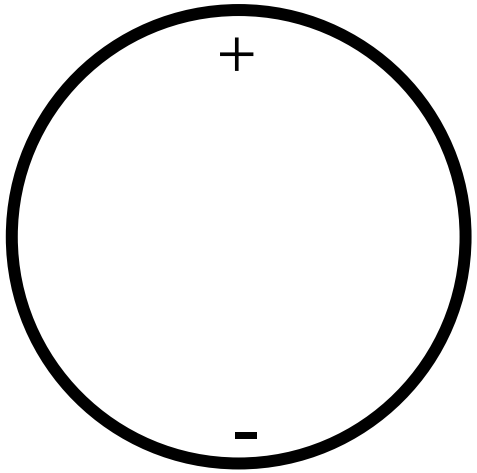
- Blood is a conducting fluid.
- Applying a magnetic field perpendicular to the flow will induce an EMG.



$$e = \int_0^L u(l) \times B dl$$

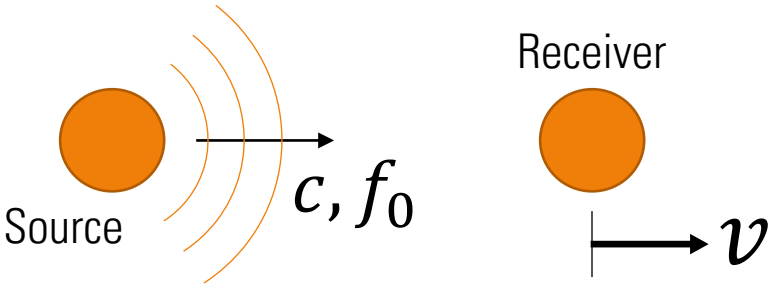
Electromagnetic flow meter



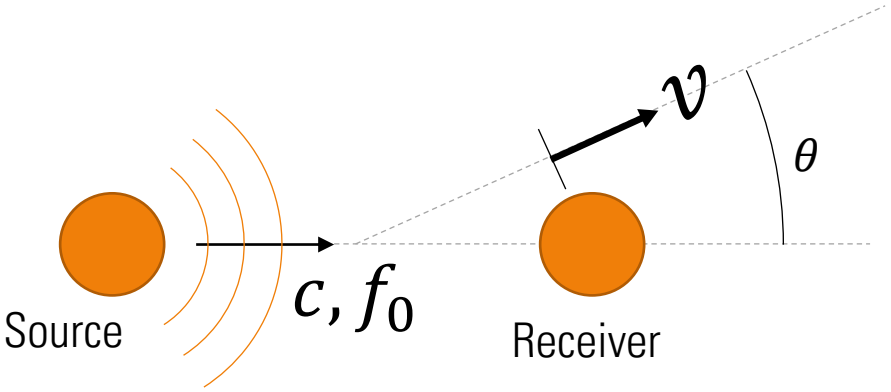


Ultrasound continuous Doppler flow sensing

- Use the Doppler effect to determine flow rate.

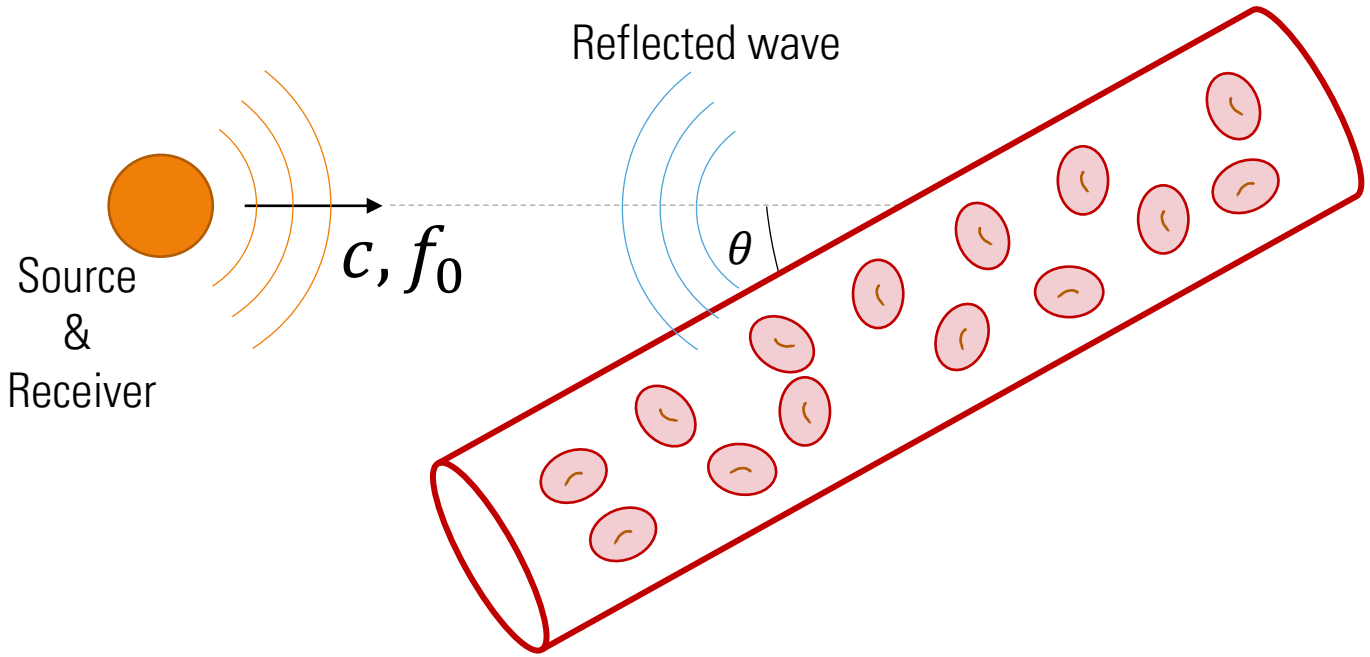


$$\Delta f = \frac{v}{c} f_0$$



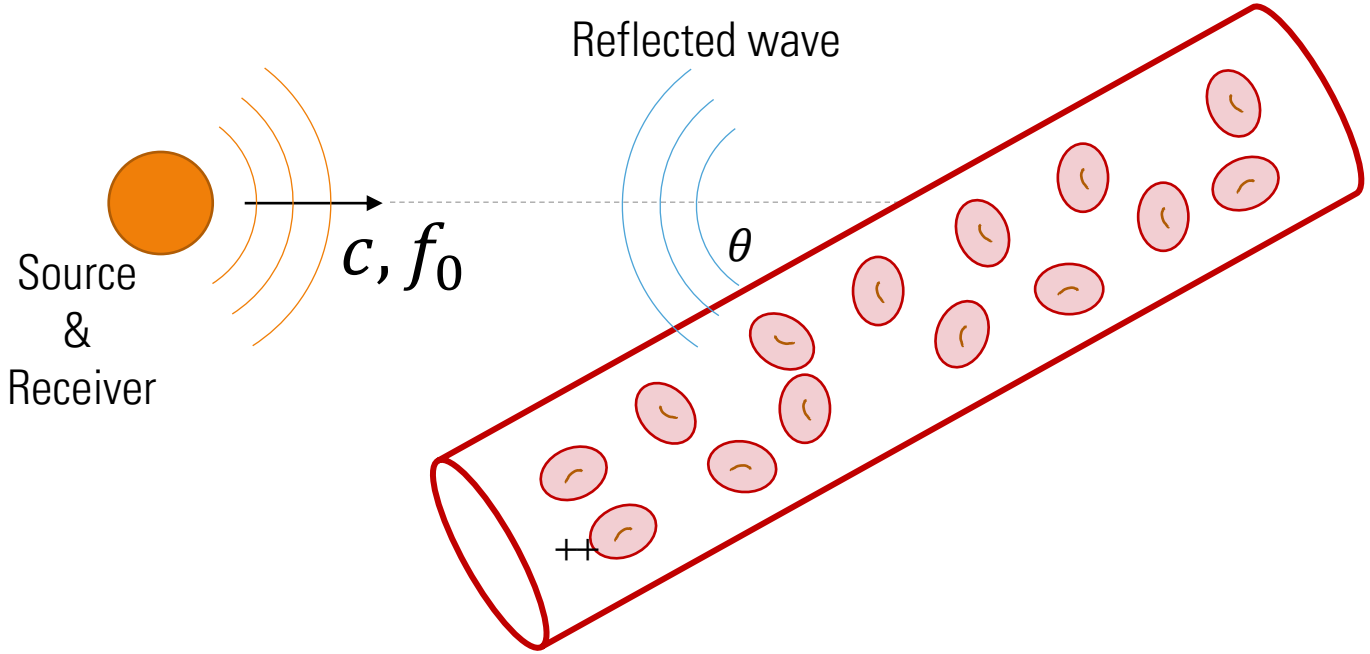
$$\Delta f = \frac{v}{c} f_0 \cos\theta$$

Ultrasound continuous Doppler flow sensing



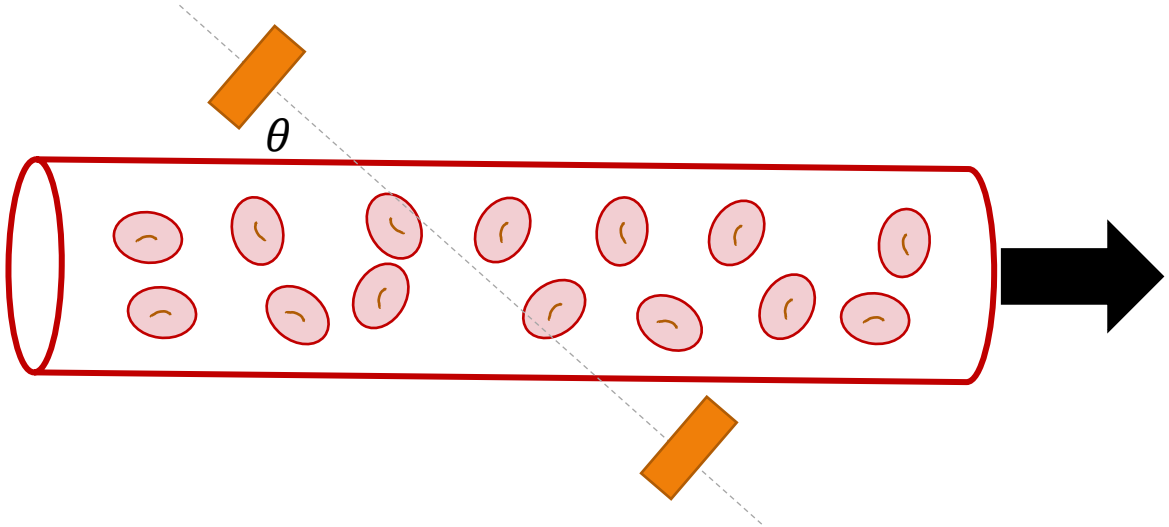
$$\Delta f = \frac{2v}{c} f_0 \cos\theta$$

Ultrasound continuous Doppler flow sensing



$$\Delta f = \frac{2v}{c} f_0 \cos\theta$$

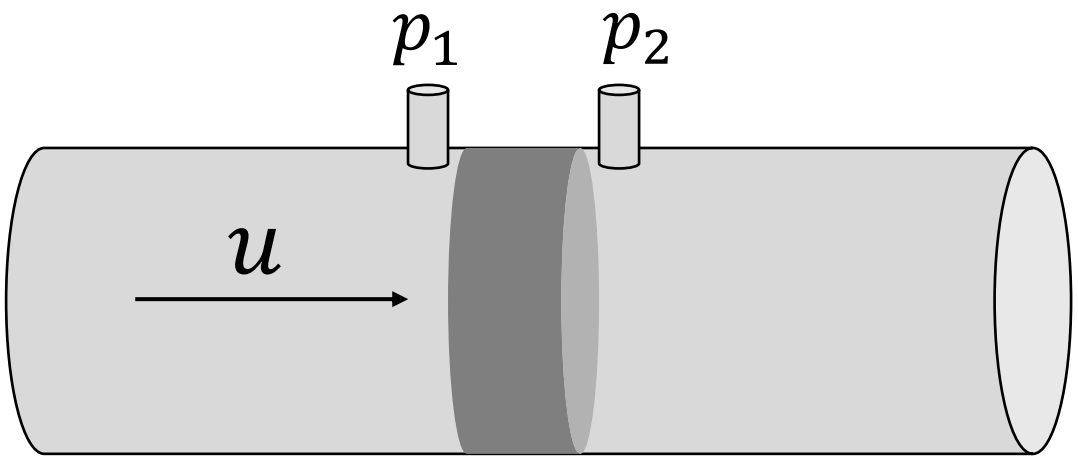
Ultrasound transit time flow sensing



$$\Delta T = \frac{D}{c \pm u \cos\theta}$$

Pressure drop method – Pneumotachometer

- There is a pressure drop when air flows through a path offering resistance to air flow.



Laminar Flow (through a set of capillaries)

$$\Delta p = p_1 - p_2 = \frac{128\mu L}{N\pi D^4} u$$

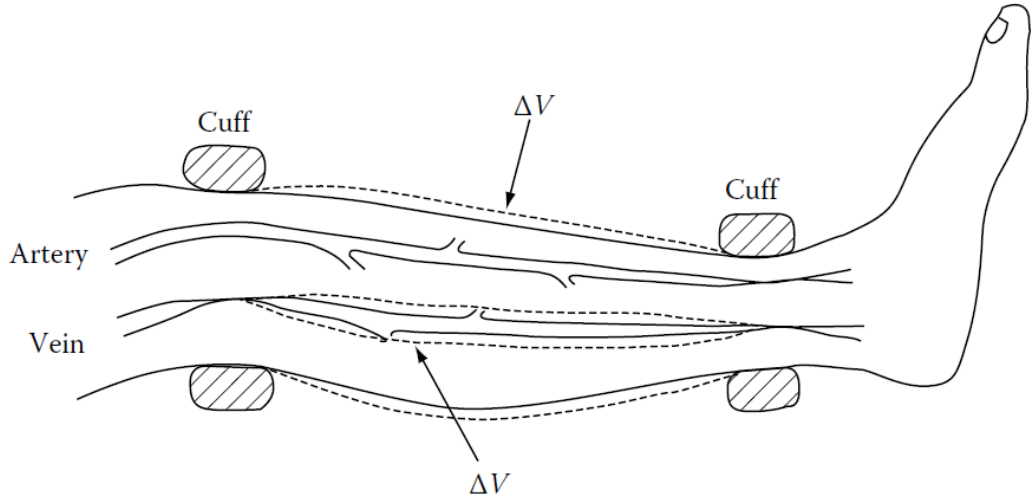
Turbulent Flow (with square edge orifice)

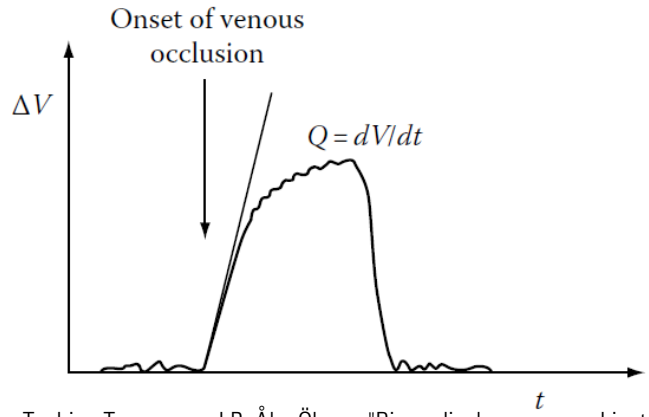
$$\Delta p = \frac{\rho}{2C_D A^4} |u| u$$

$$\Delta p = Ru + k|u|u$$

Venous occlusion plethysmography

- Plethysmography is a technique of measuring volume change in a tissue.

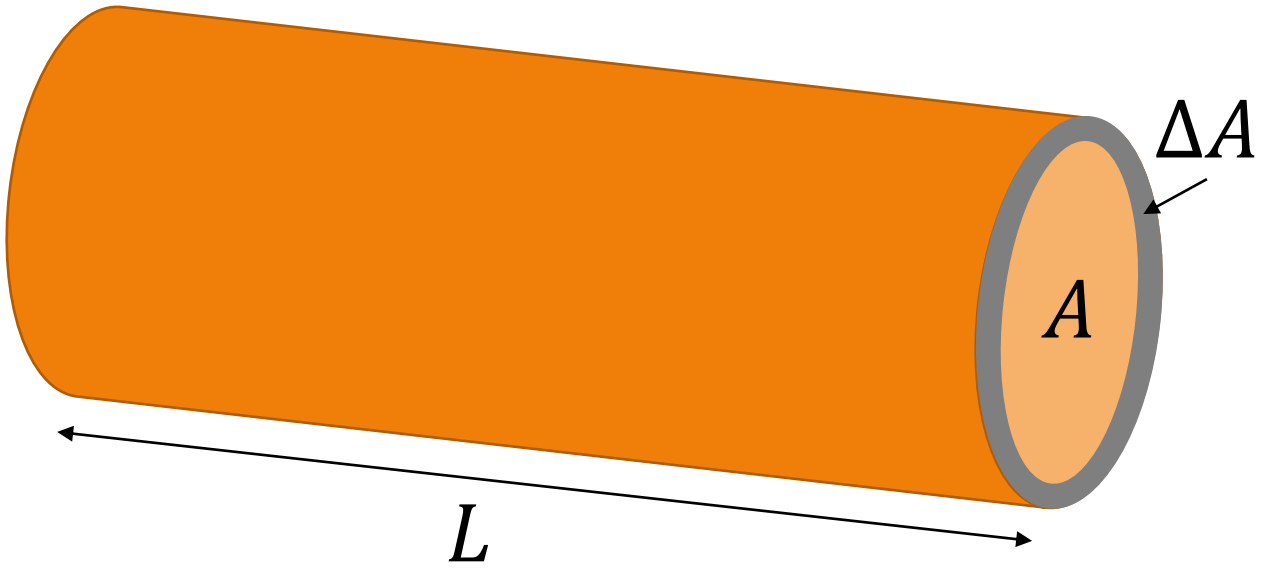




From: Togawa, Tatsuo, Toshiyo Tamura, and P. Åke Öberg. "Biomedical sensors and instruments." (2011).

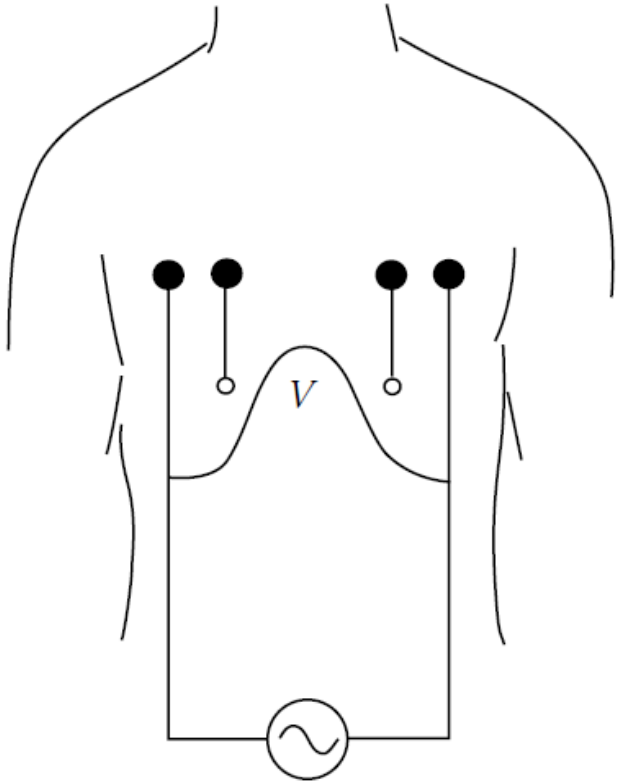
Impedance plethysmograph

- Change in impedance due to a change in volume of a body segment.



Two vs. Four electrodes plethysmograph

Thoracic pneumography



$$\frac{\Delta Z}{\Delta V} = 453.23W^{-1.084}$$