Instrumentation

Pressure Measurement

Course Instructor: Mohammad Reza Nayeri

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Pressure

Density is defined as the mass per unit volume of a material

$$\rho = \frac{m}{V}$$

mass

volume

Specific weight is defined as the weight per unit volume of a material,

$$\gamma = \rho\, g$$

Specific gravity of a liquid or solid is a dimensionless value since it is a ratio of two measurements in the same unit. It is defined as the density of a material divided by the density of water or it can be defined as the specific weight of the material divided by the specific weight of water at a specified temperature.

$$SG_{\text{true}} = \frac{\rho_{\text{sample}}}{\rho_{\text{H}_2\text{O}}}$$

Pressure

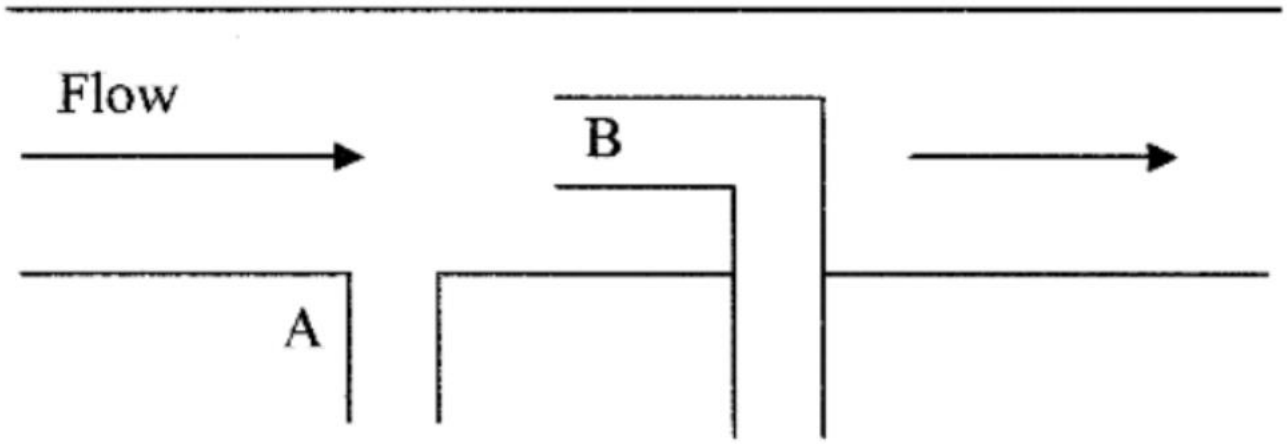
	Temperature, °F	Specific weight		Specific gravity
		lb/ft^3	kN/m^3	
Acetone	60	49.4	7.74	0.79
Alcohol (ethyl)	68	49.4	7.74	0.79
Glycerin	32	78.6	12.4	1.26
Mercury	60	846.3	133	13.55
Steel		490	76.93	7.85
Water	39.2	62.43	9.8	1.0

Pressure

Static pressure is the pressure of fluids or gases that are stationary or not in motion

Dynamic pressure is the pressure exerted by a fluid or gas when it impacts on a surface or an object due to its motion or flow.

Impact pressure (total pressure) is the sum of the static and dynamic pressures on a surface or object.



Pressure

Total vacuum–which is zero pressure or lack of pressure, as would be experienced in outer space.

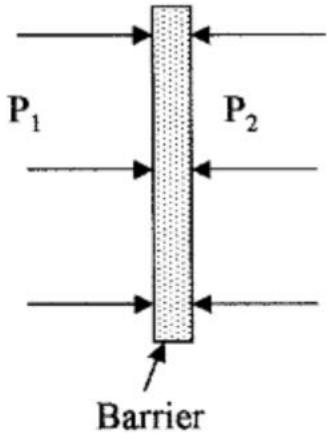
Vacuum is a pressure measurement made between total vacuum and normal atmospheric pressure

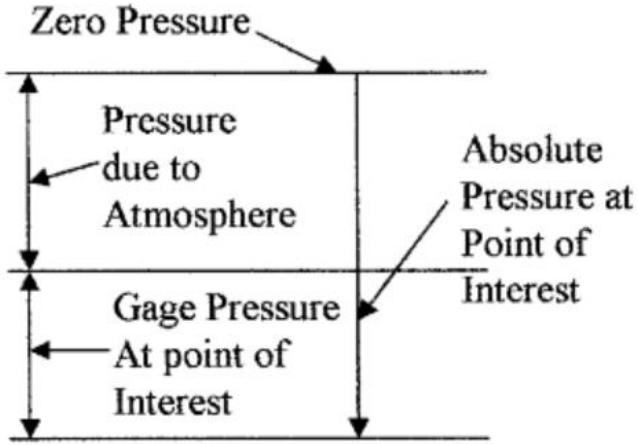
Atmospheric pressure is the pressure on the earth's surface due to the weight of the gases in the earth's atmosphere and is normally expressed at sea level as 14.7 psi or 101.36 kPa.

Absolute pressure is the pressure measured with respect to a vacuum

Gauge pressure is the pressure measured with respect to atmospheric pressure

Differential pressure is the pressure measured with respect to another pressure and is expressed as the difference between the two values.





Buoyancy Force

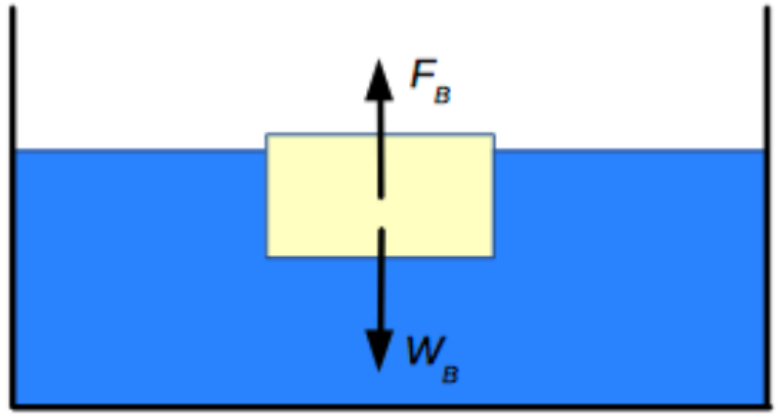
Buoyancy is the *upward force* exerted on an object immersed or floating in a liquid. The weight is less than it is in air due to the weight of the displaced fluid. The upward force on the object causing the weight loss is called the buoyant force and is given by

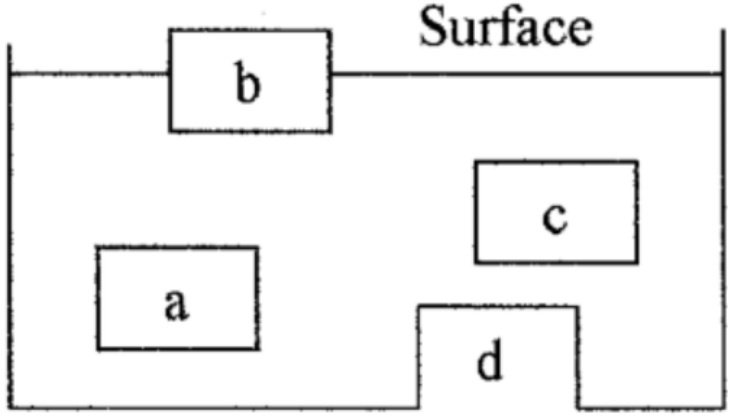
$$B = \gamma V$$

γ = specific weight

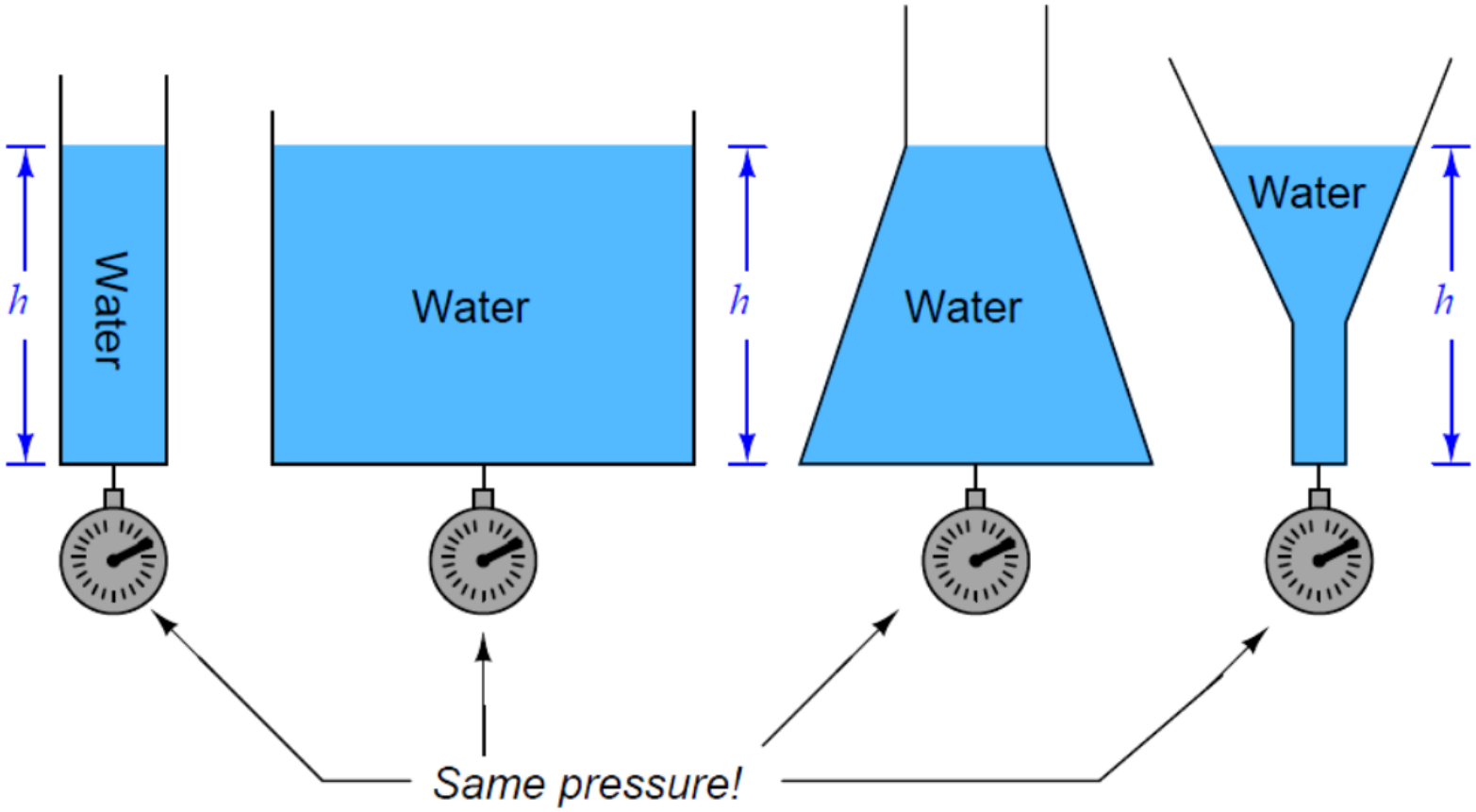
B = buoyant force

V = volume of the liquid displaced





Hydrostatic Pressure

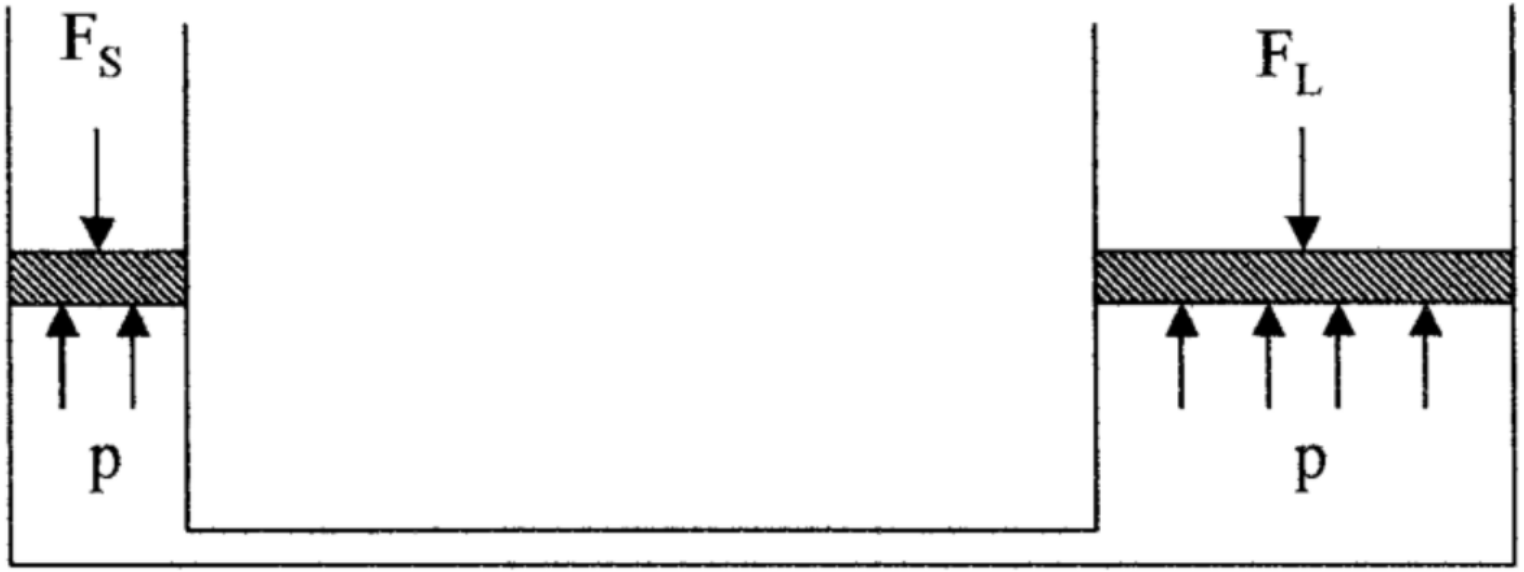


$$P = \rho g h = \gamma h$$

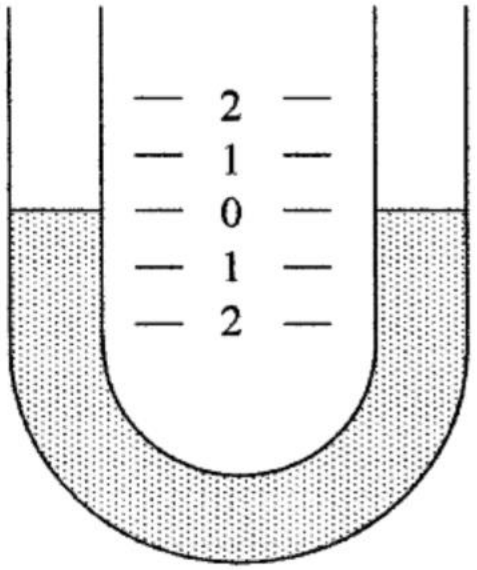
Hydrostatic Pressure

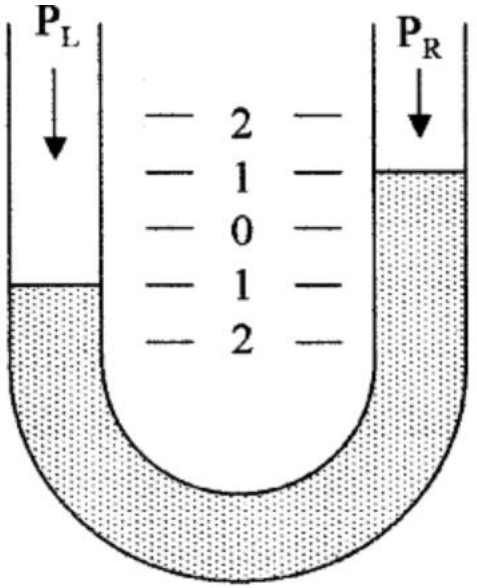
Pascal's law states that the pressure applied to an enclosed liquid (or gas) is transmitted to all parts of the fluid and to the walls of the container.

$$p = \frac{F_S}{A_S} \qquad F_L = pA_L \qquad F_L = \frac{A_L F_S}{A_S}$$



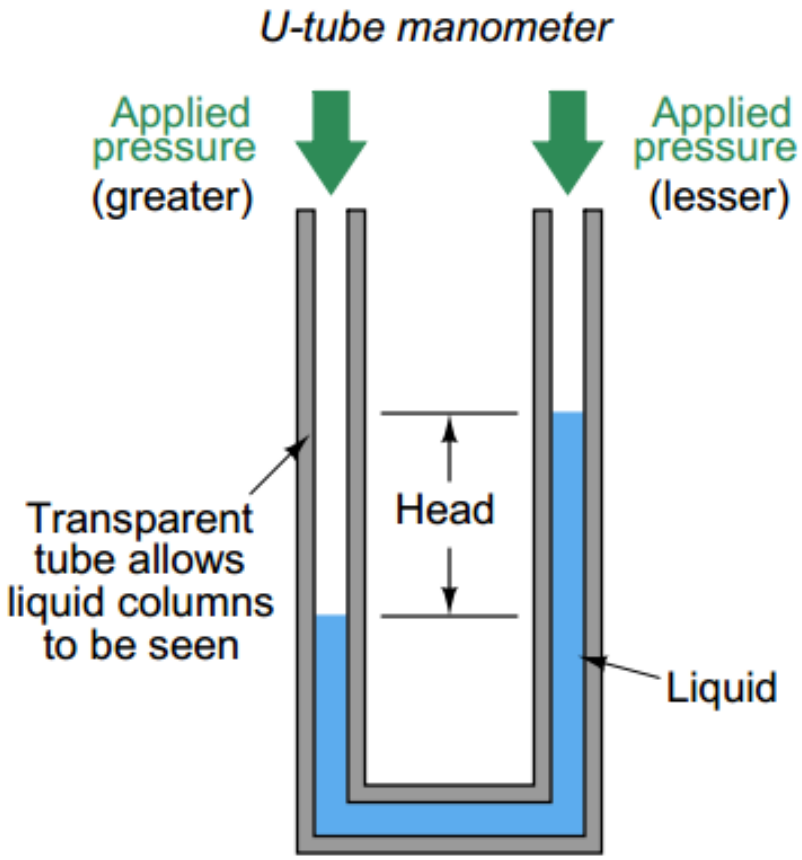
Manometer

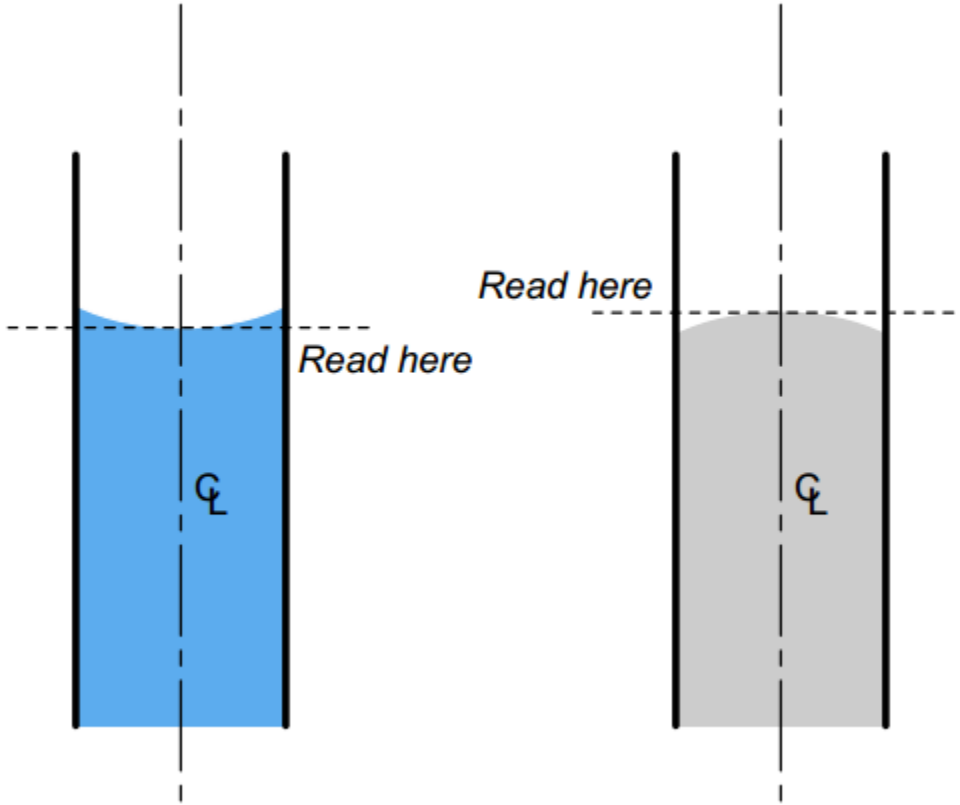




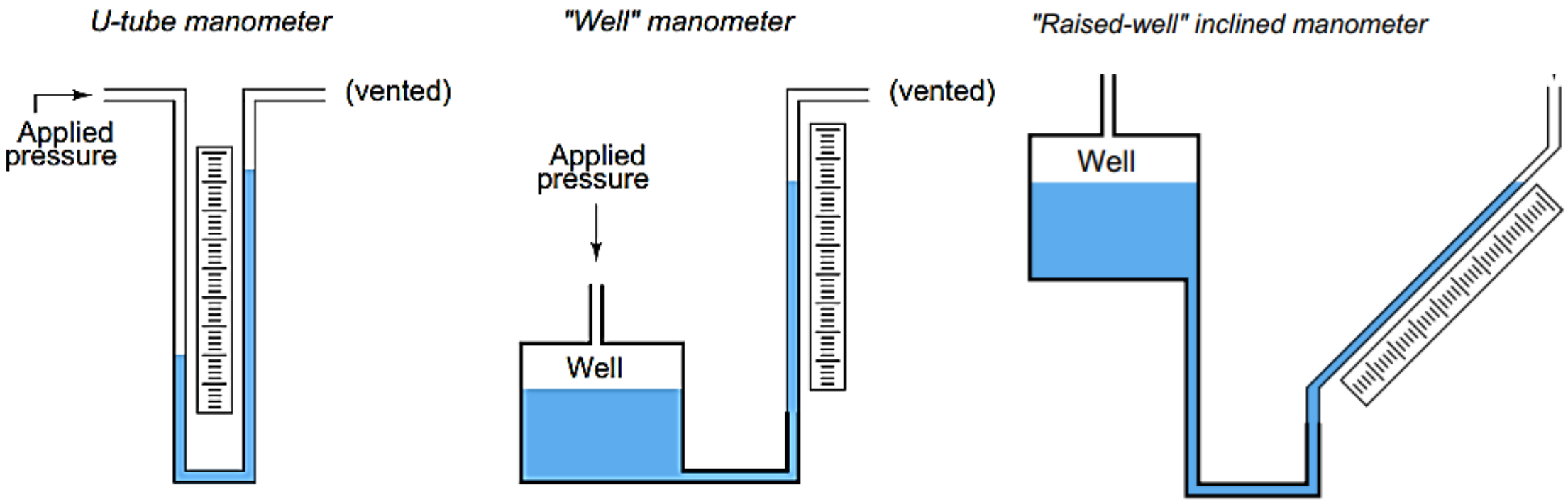
$$P_L - P_R = \gamma \times \text{difference in height of the liquid in the columns}$$

Manometer


U-tube manometer
Applied pressure (greater)
Applied pressure (lesser)
Transparent tube allows liquid columns to be seen
Head
Liquid


Read here
Read here
℄
℄

Manometer


U-tube manometer
Applied pressure
(vented)
"Well" manometer
Applied pressure
Well
(vented)
"Raised-well" inclined manometer
Well

Manometer

Barometer

A barometer is a scientific instrument used in meteorology to measure *atmospheric pressure*

- **Water-based barometers**
- **Mercury barometers**
- **Aneroid barometers**
- **MEMS Barometers**

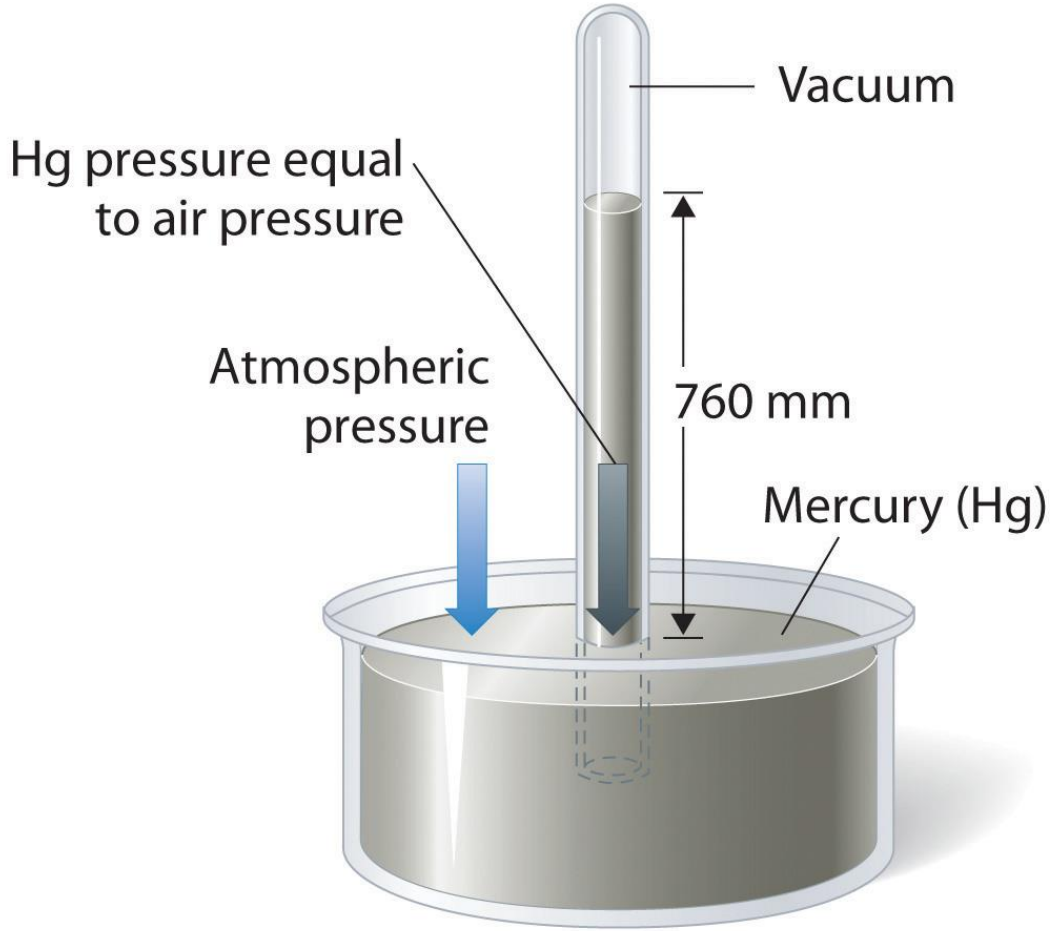
Barometer

- **Water-based barometers**

Decreasing atmospheric pressure predicts stormy weather.
Weather prediction device called a "weather glass" or a "Goethe barometer“.

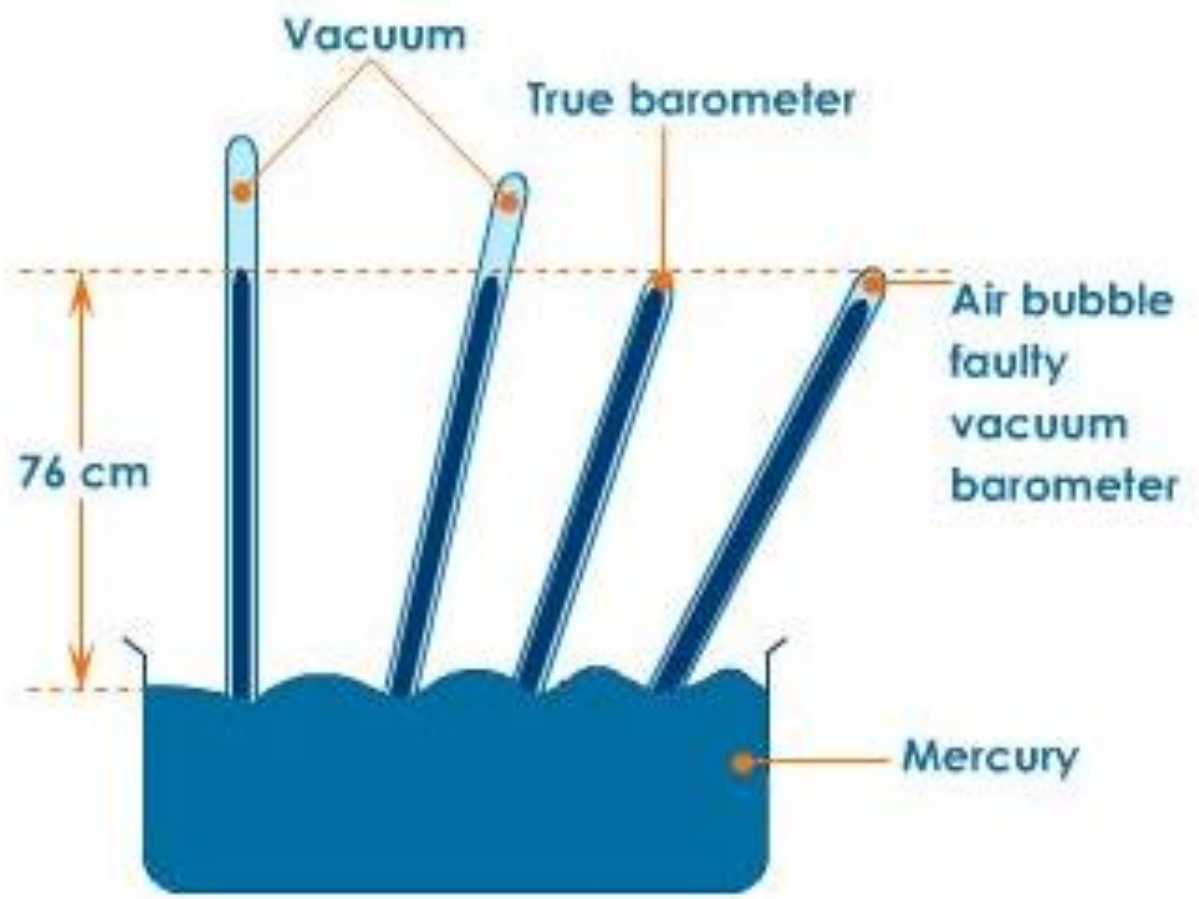
Barometer

- **Mercury barometers**



Barometer

- **Mercury barometers**



Barometer

- **Aneroid barometers**

An aneroid barometer is an instrument for measuring pressure as a method that does not involve liquid.

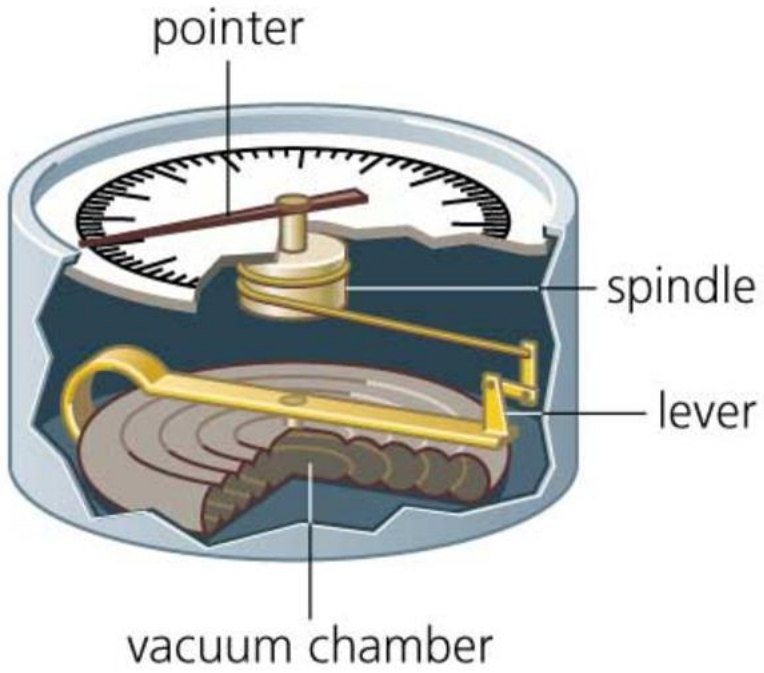
The aneroid barometer uses a small, flexible metal box called an aneroid cell (capsule) , which is made from an alloy of beryllium and copper.

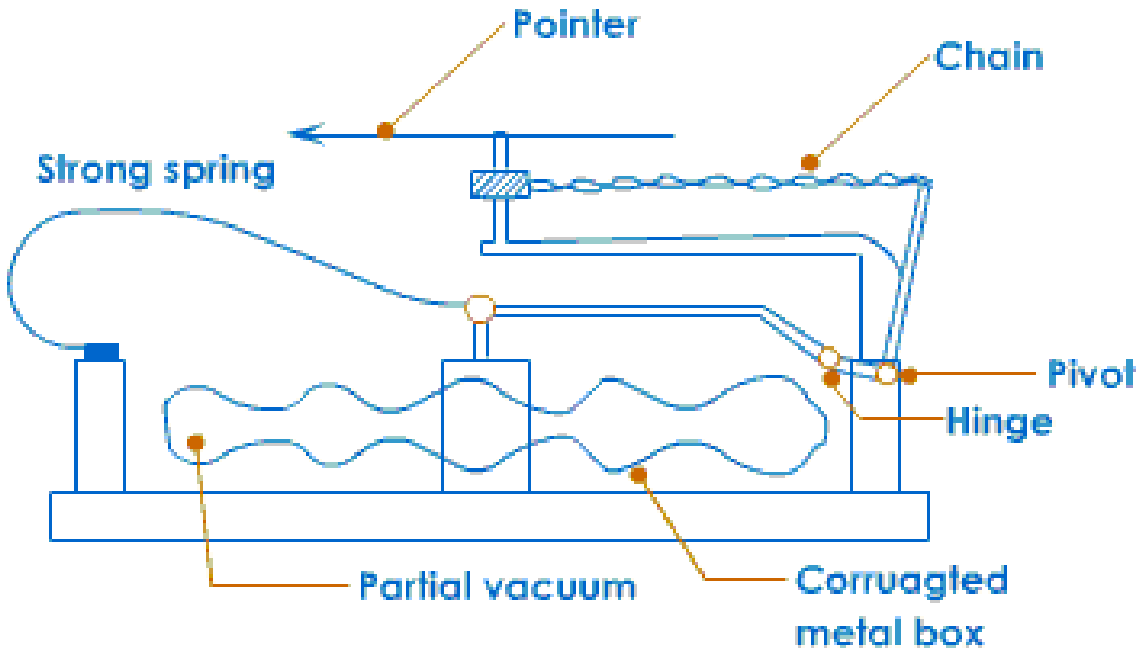
Small changes in external air pressure cause the cell to expand or contract

This expansion and contraction drives mechanical levers such that the tiny movements of the capsule are amplified and displayed on the face of the aneroid barometer.

Barometer

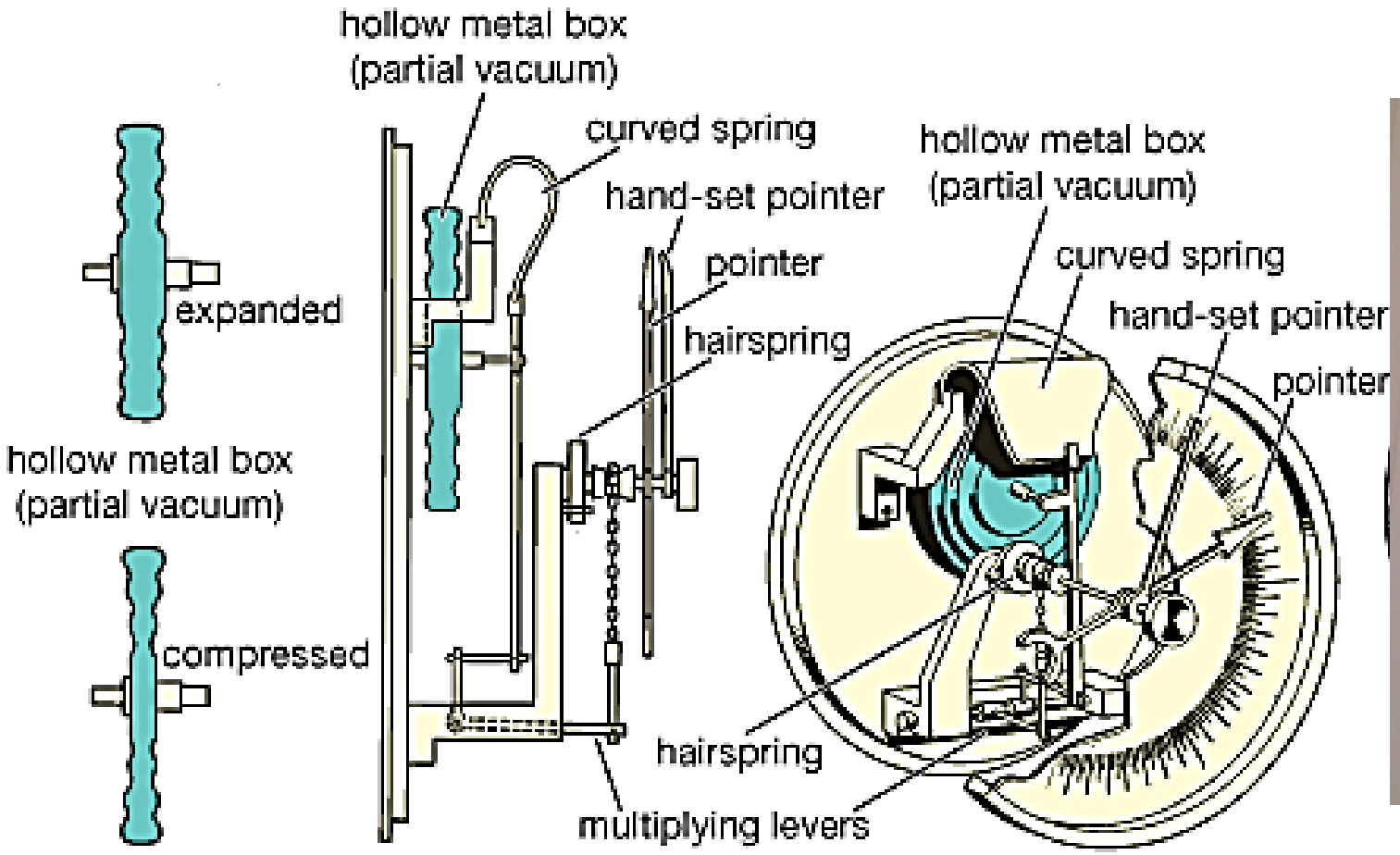
- **Aneroid barometers**

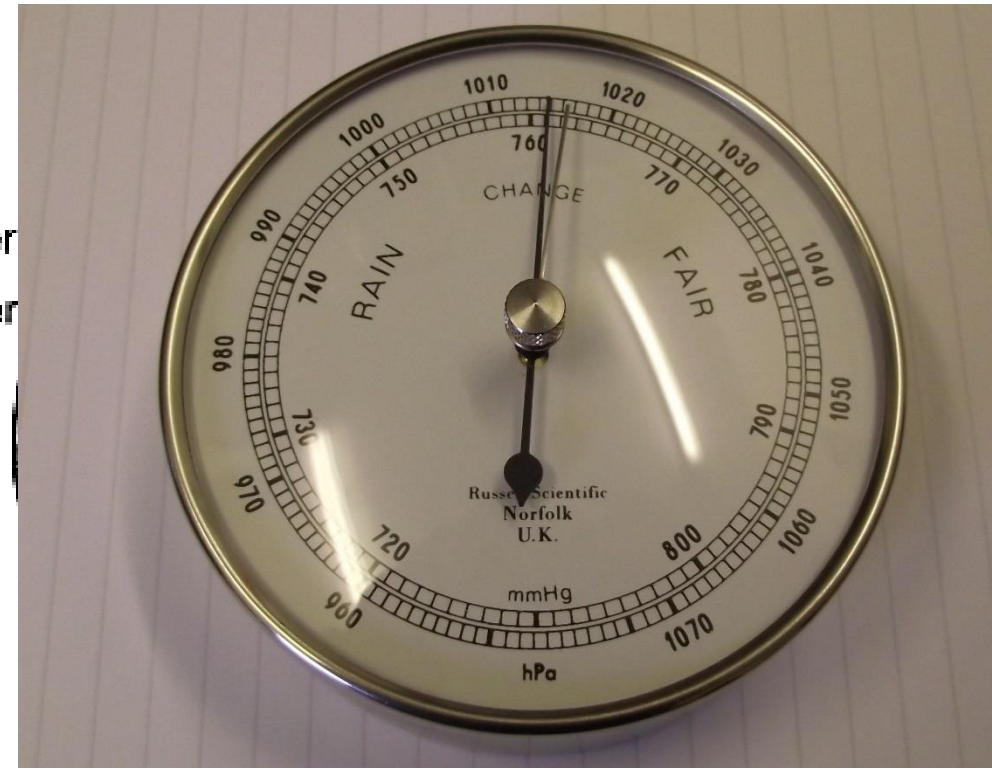




Barometer

- **Aneroid barometers**





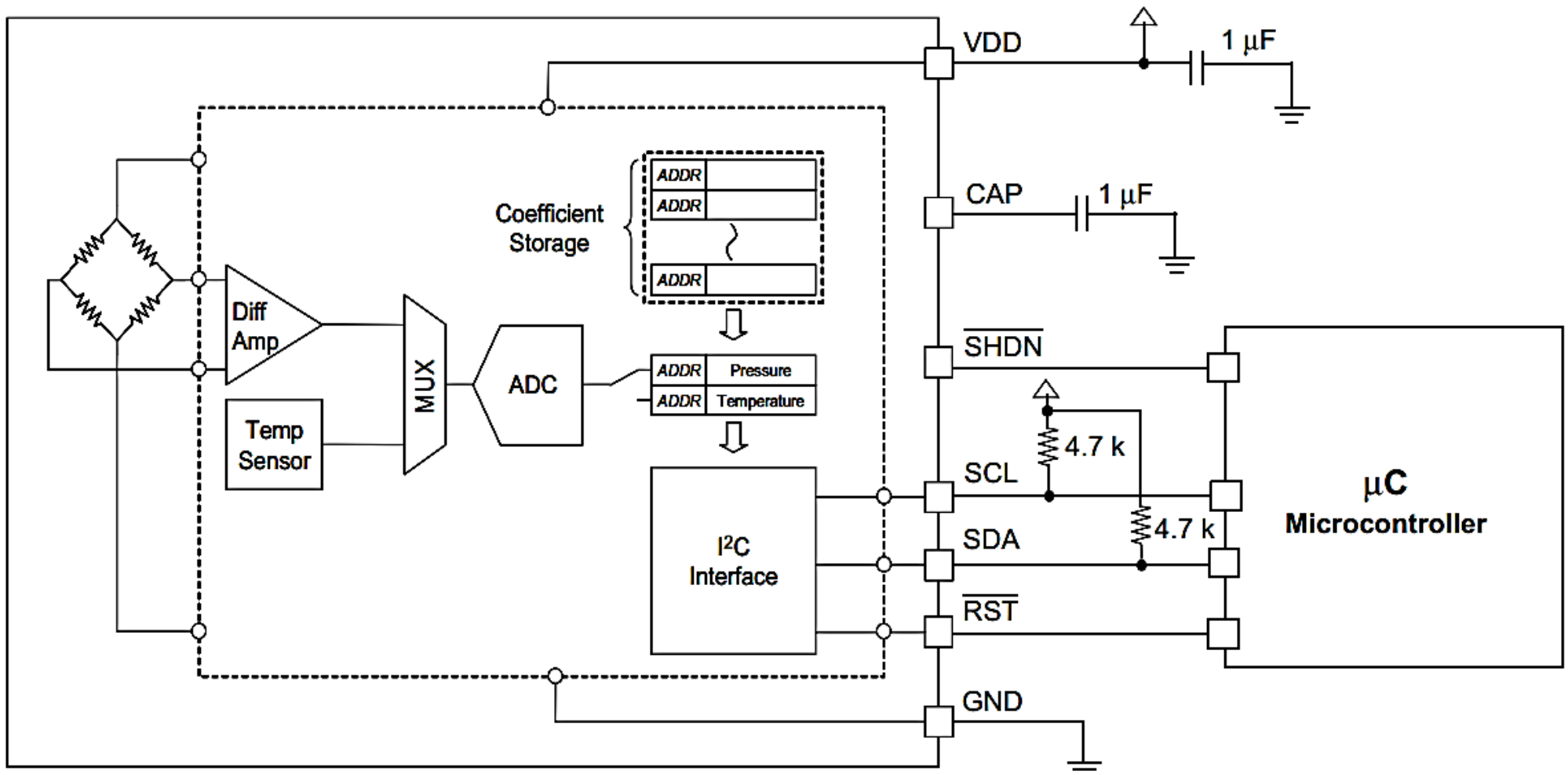
Barometer

- **MEMS Barometers**

- Digitized pressure and temperature information together with programm calibration coefficients for host micro use.
- Factory calibrated
- 50 kPa to 115 kPa absolute pressure
- ±1 kPa accuracy
- 2.375V to 5.5V supply
- Integrated ADC
- I^2C Interface (operates up to 400 kHz)
- 7-bit I^2C address = 0x60
- Monotonic pressure and temperature data outputs
- Surface mount RoHS compliant package

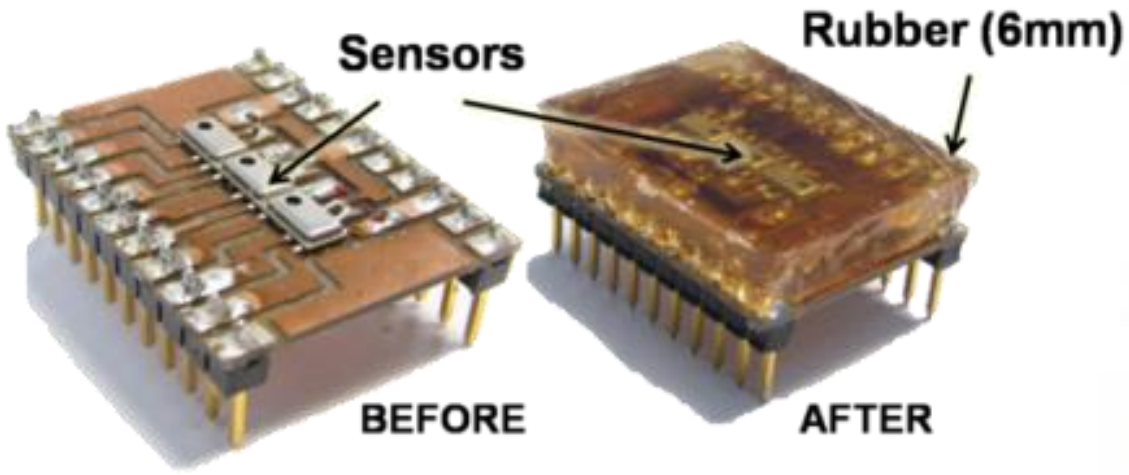
Barometer

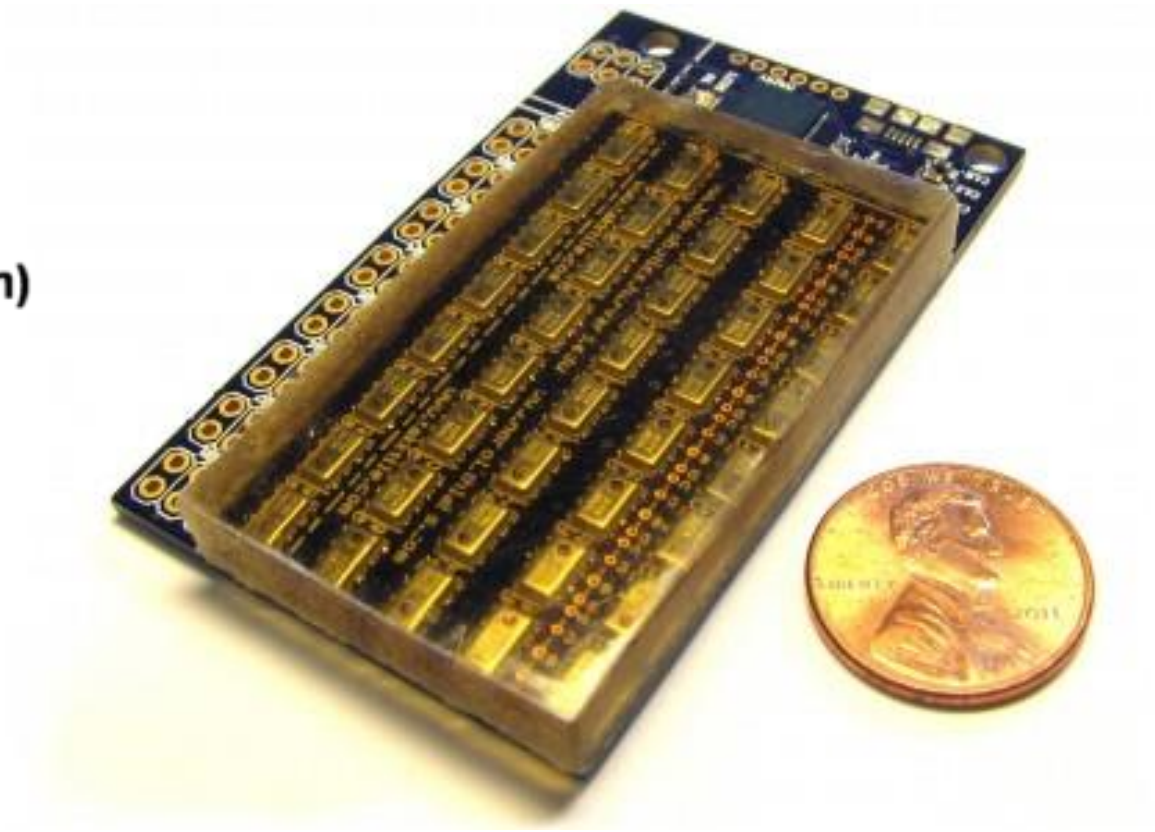
- **MEMS Barometers**



Barometer

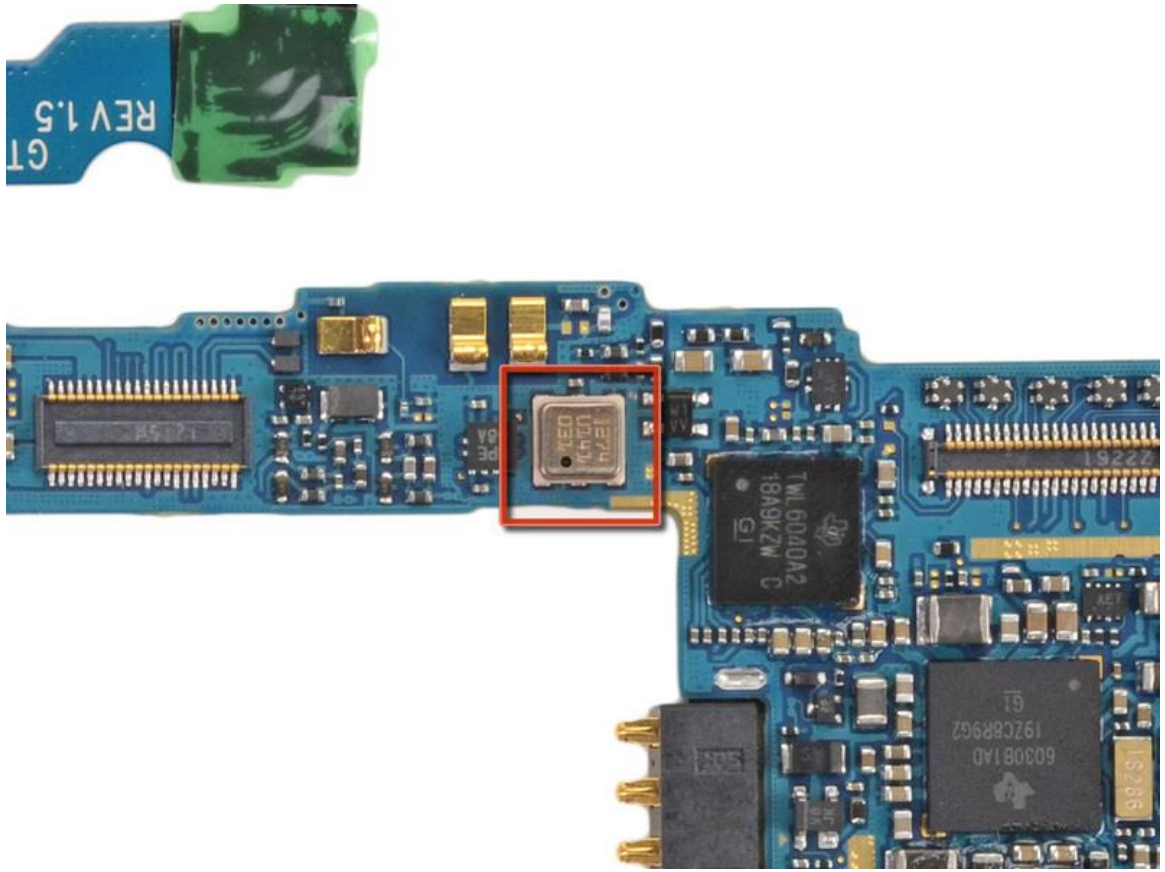
- **MEMS Barometers**

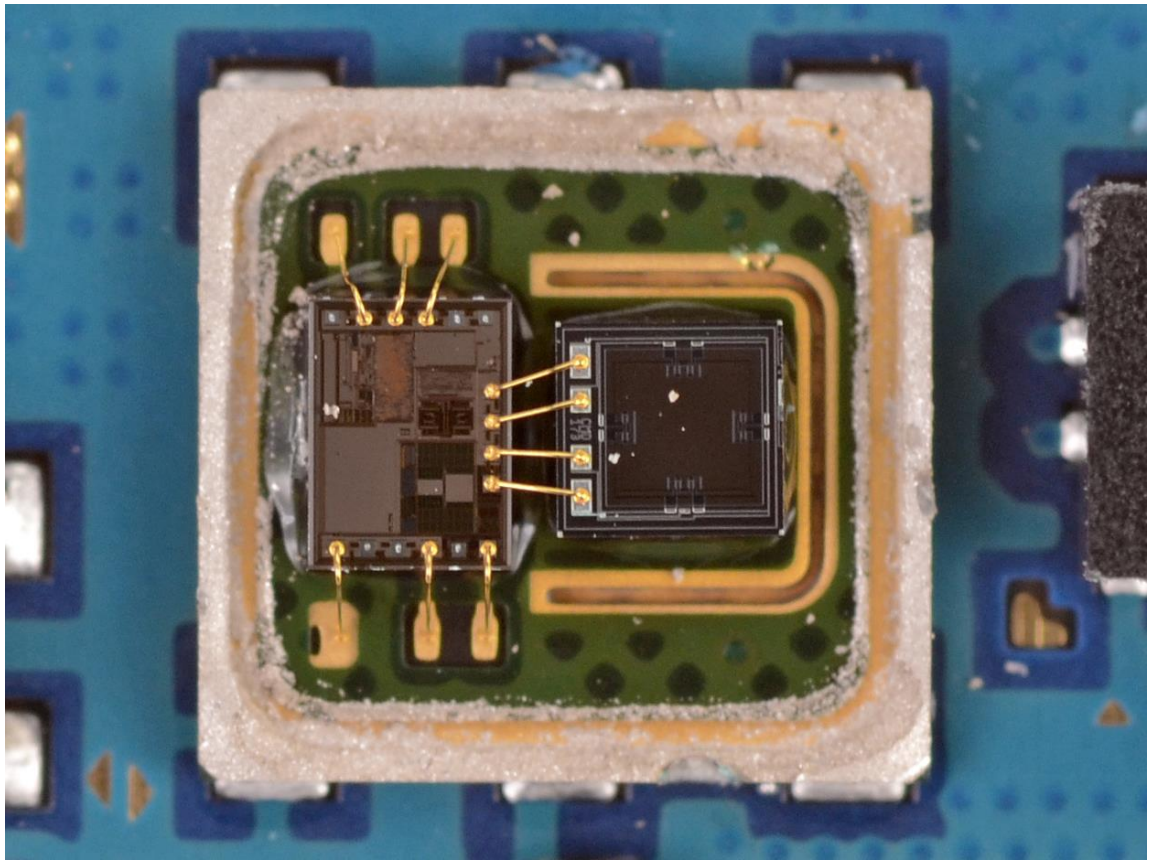




Barometer

- **MEMS Barometers**





Barometer

- **Altimeter (Altitude Meter)**

Altitude can be determined based on the measurement of atmospheric pressure

Application Examples: aircraft ,hikers, skydivers

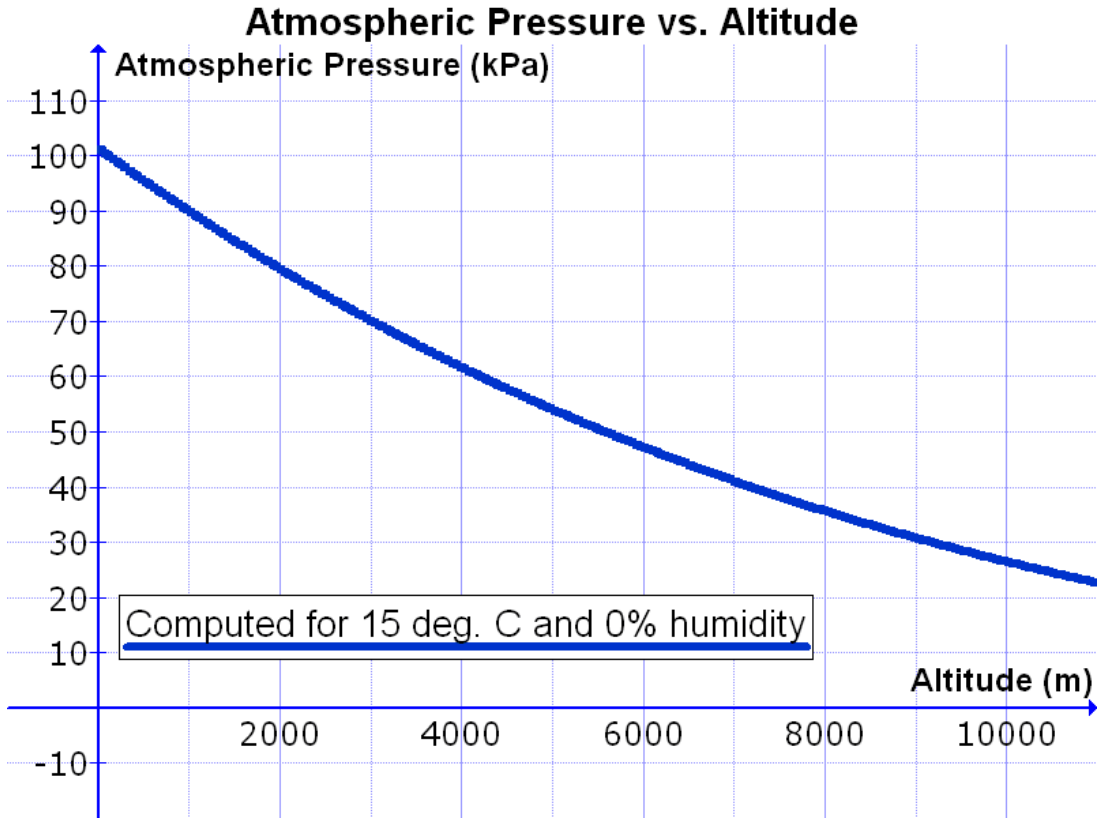
$$z = c\,T\,\log(P_o/P)$$

P is the pressure at altitude z

P_o is the pressure at sea level

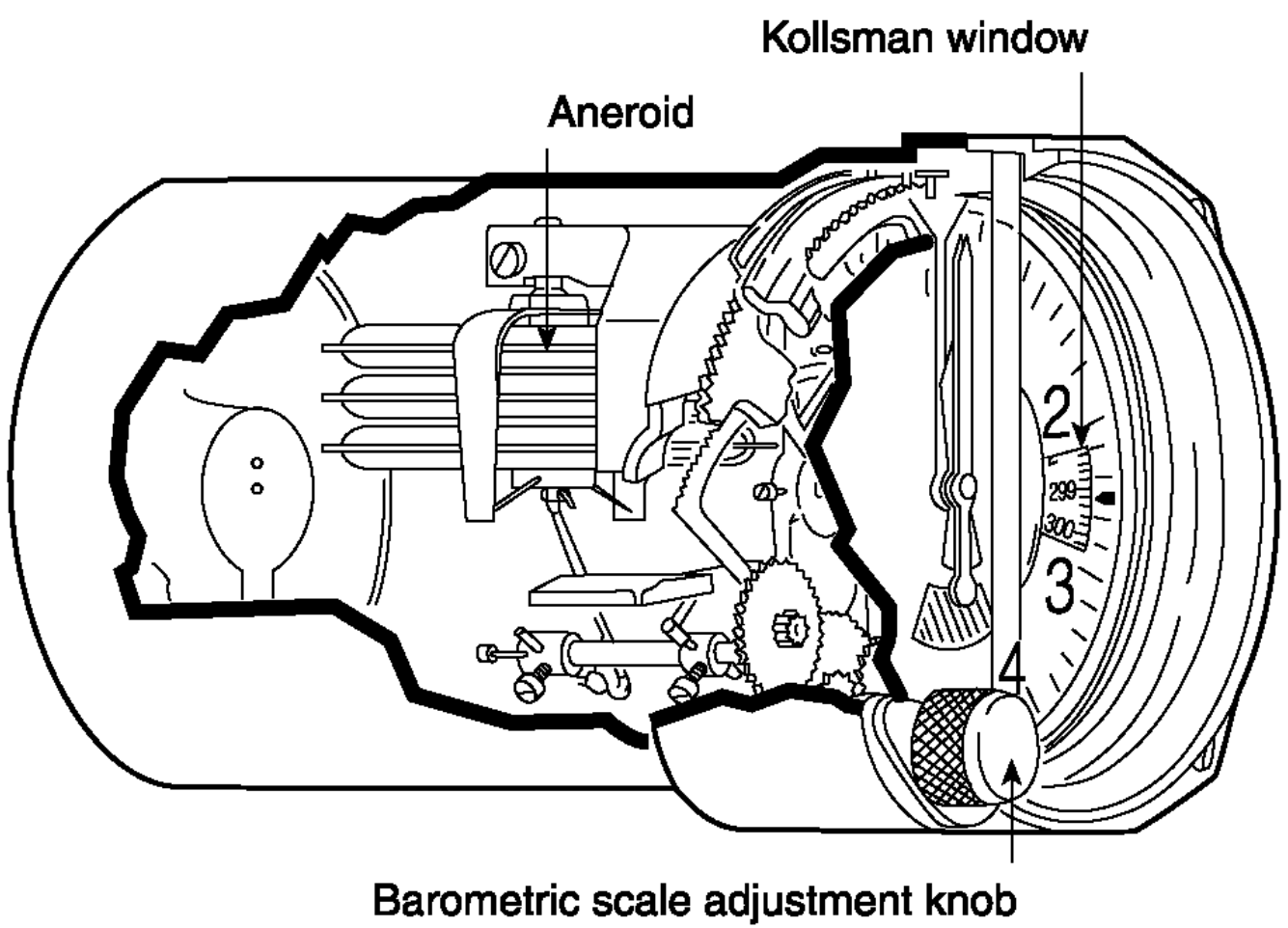
T is the absolute temperature

c is a constant

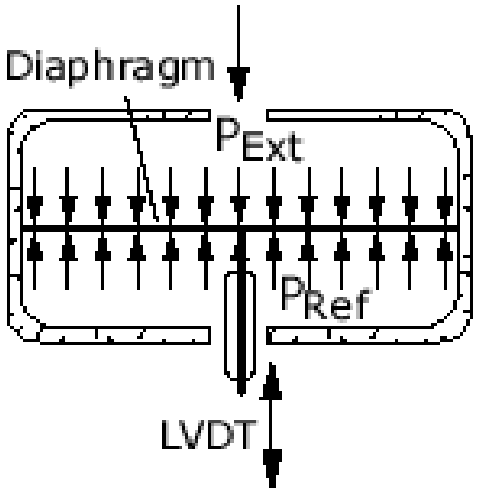


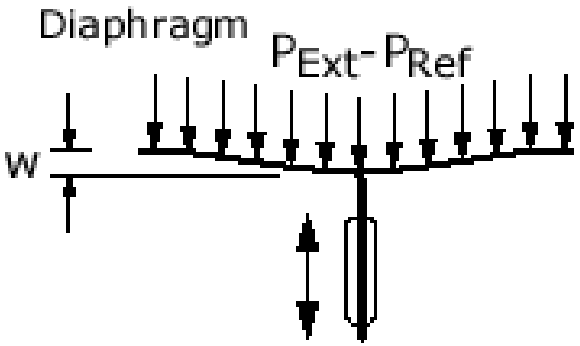
Barometer

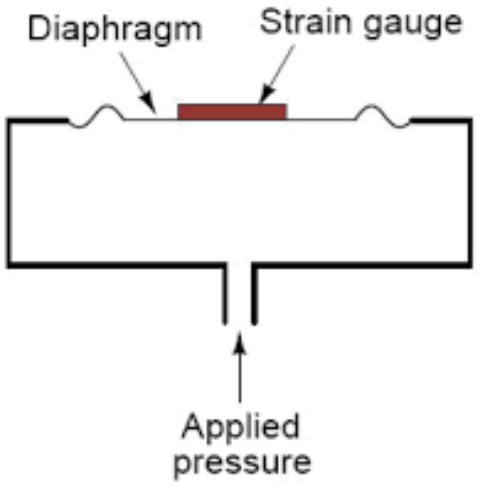
- **Altimeter (Altitude Meter)**

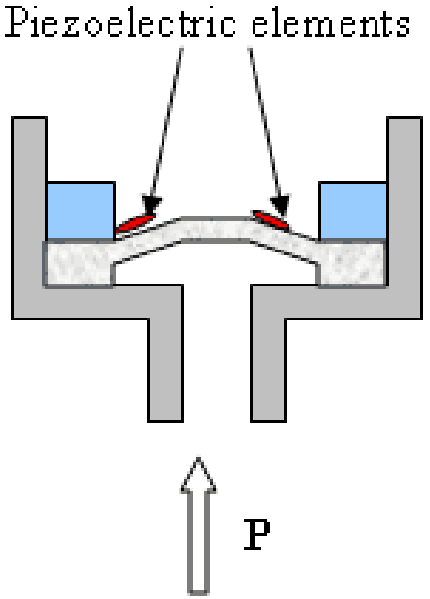


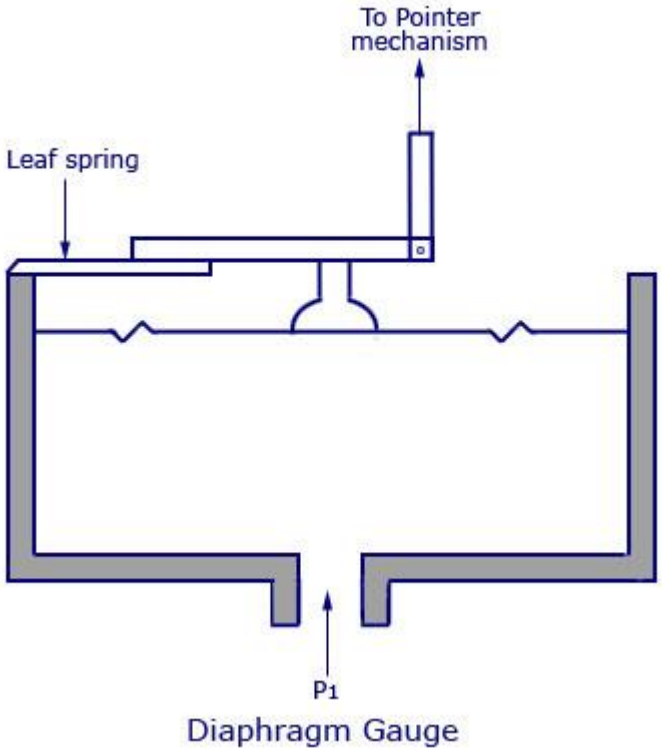
Diaphragm


Diaphragm
P_{Ext}
P_{Ref}
LVDT


Diaphragm
P_{Ext}- P_{Ref}
w


Diaphragm
Strain gauge
Applied pressure


Piezoelectric elements
P

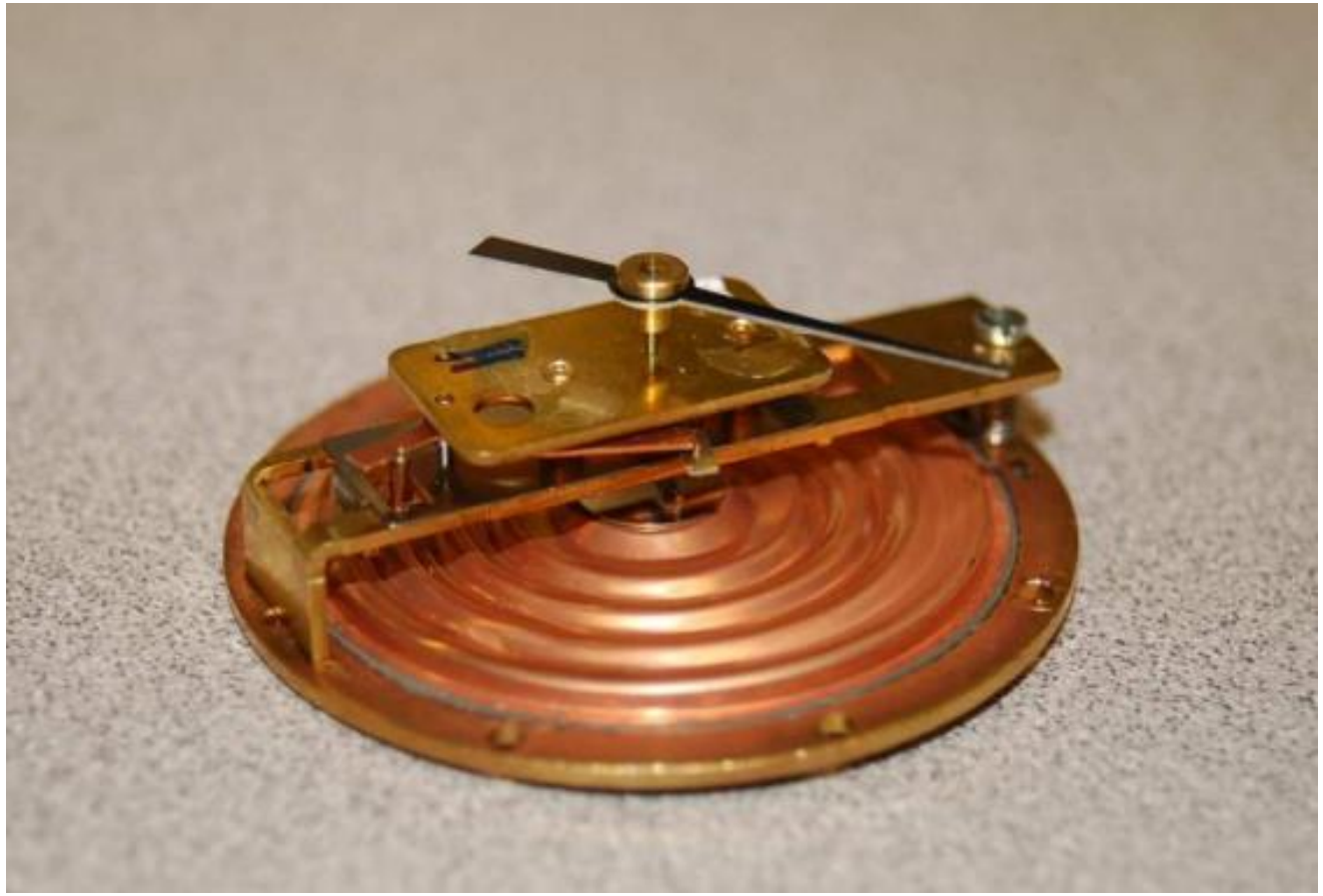

To Pointer mechanism
Leaf spring
P_1
Diaphragm Gauge

Diaphragm

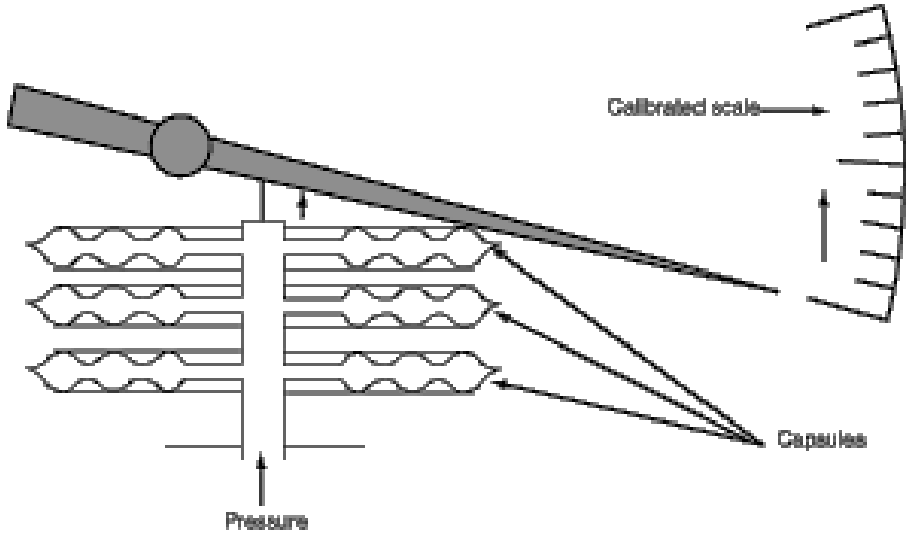
damaged
stainless steel diaphragm

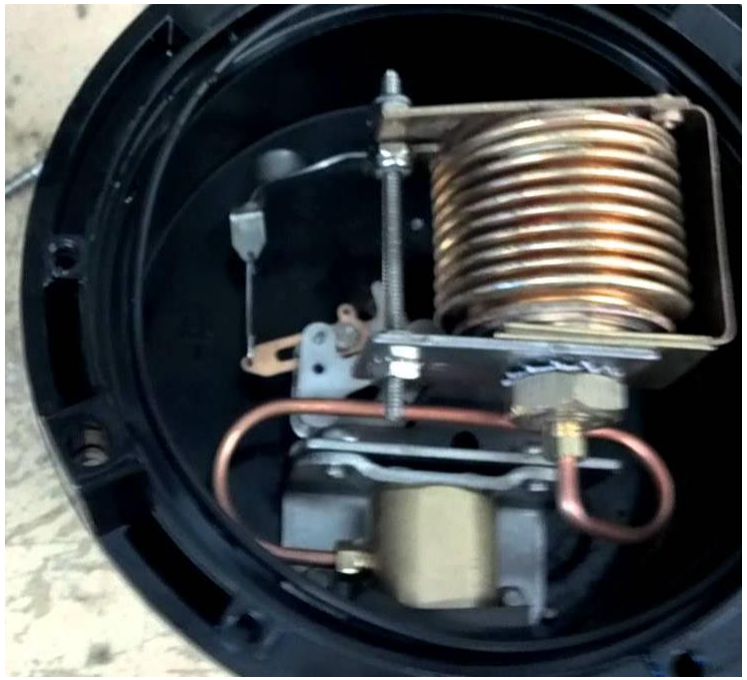
undamaged
stainless steel diaphragm

Diaphragm

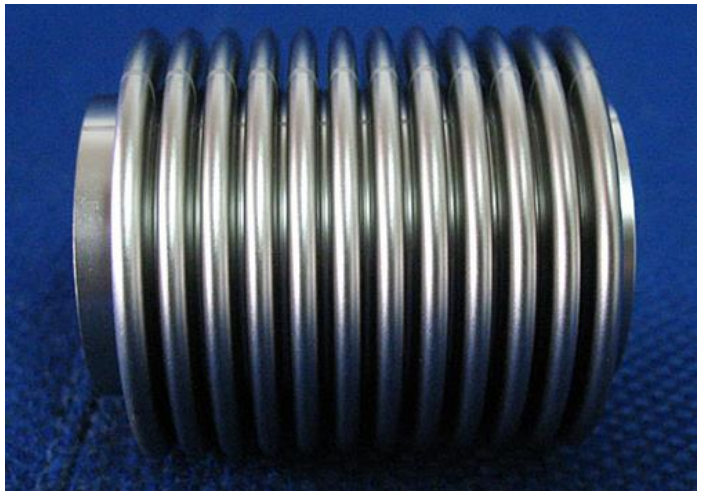


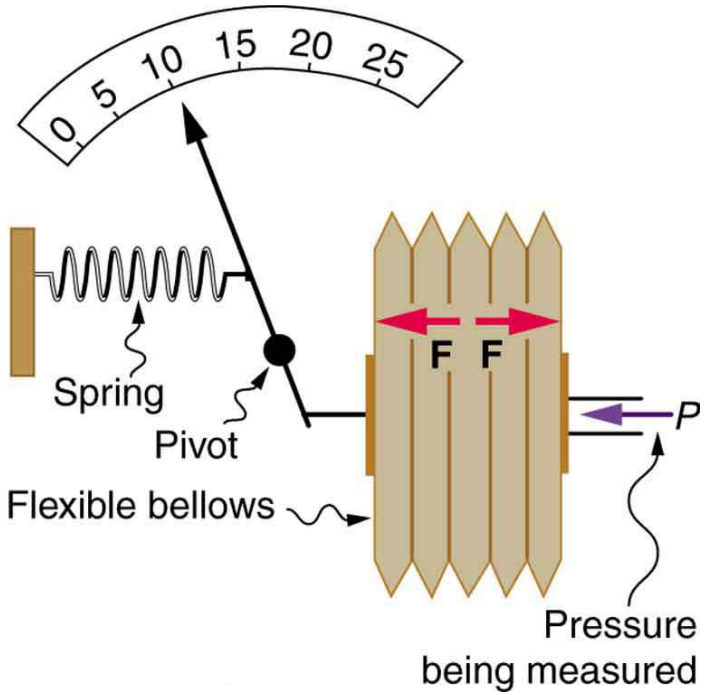
Capsule

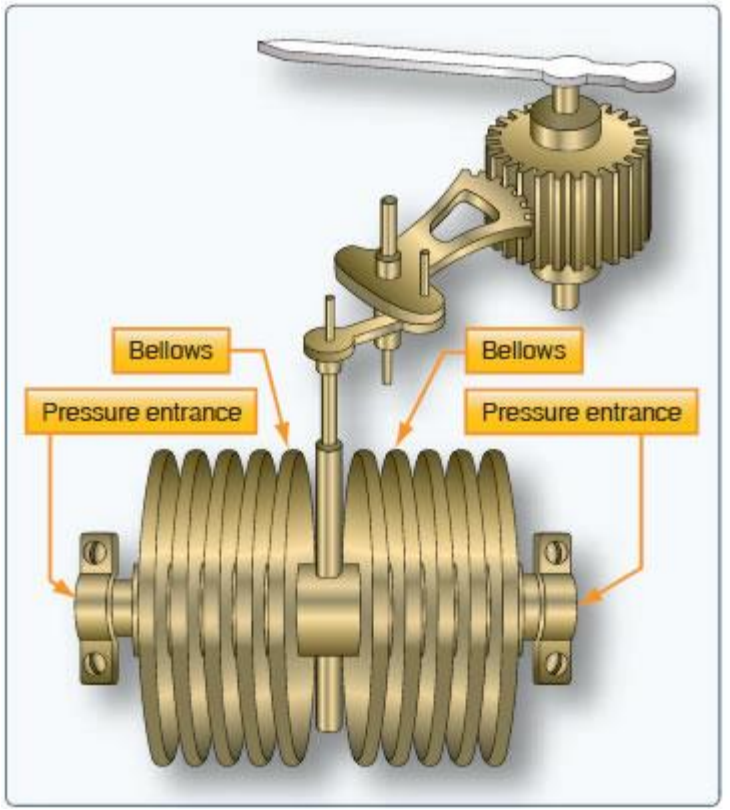


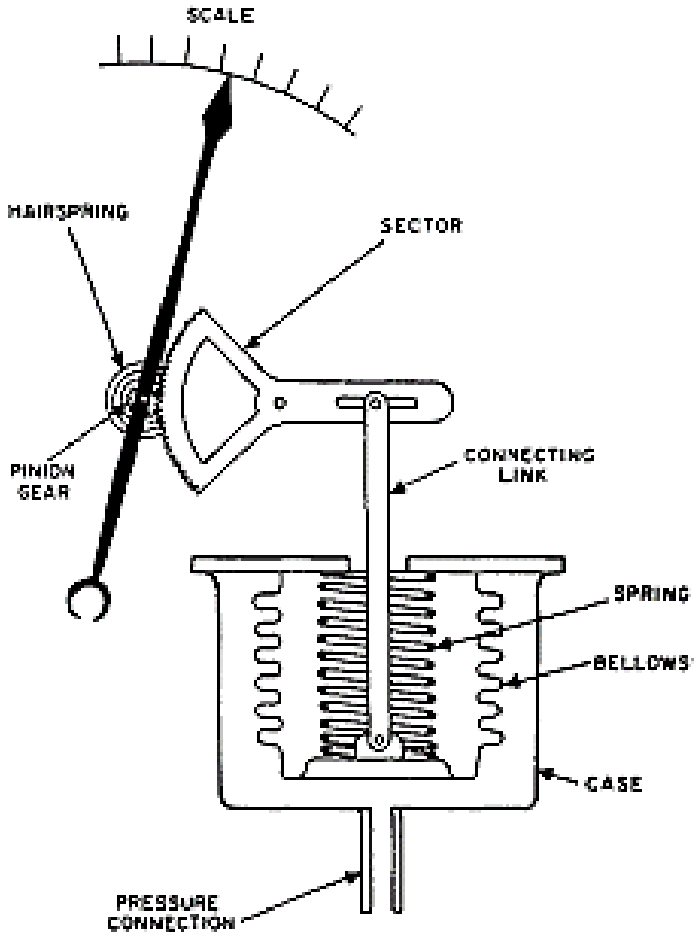


Bellows

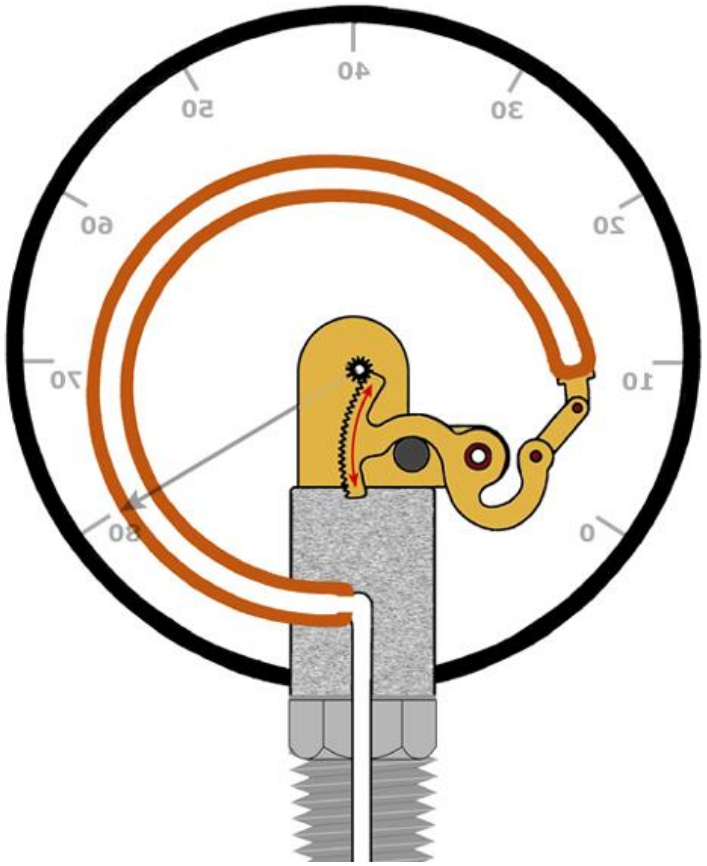



0 5 10 15 20 25
Spring
Pivot
Flexible bellows
F F
P
Pressure
being measured


Bellows
Pressure entrance
Bellows
Pressure entrance

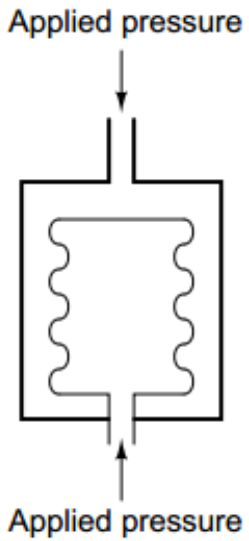

SCALE
HAIRSPRING
SECTOR
PINION GEAR
CONNECTING LINK
SPRING
BELLOWS
CASE
PRESSURE CONNECTION

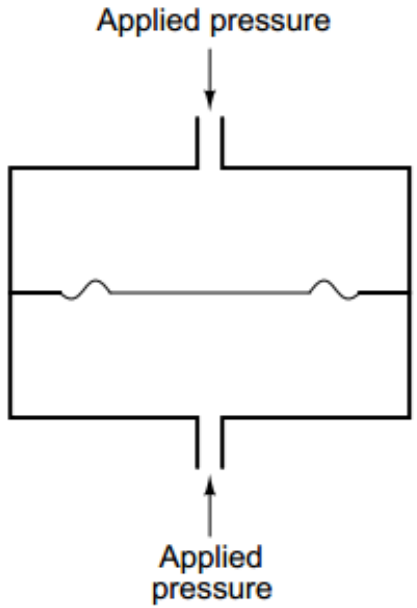
Bourdon Tube

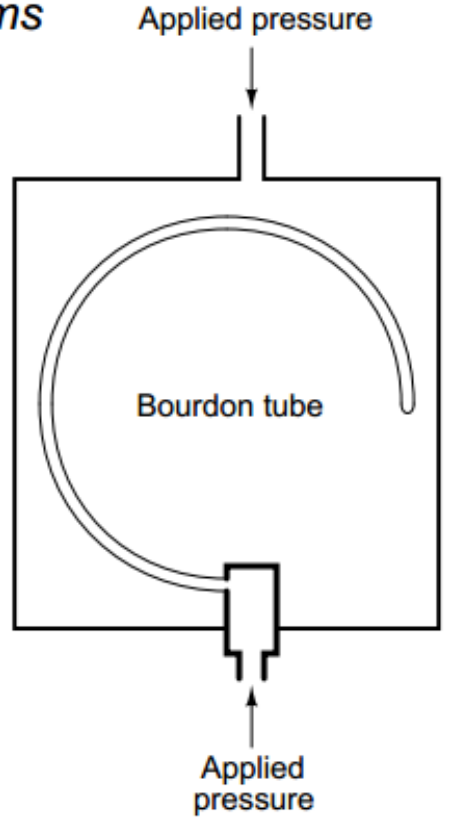


Bourdon Tube

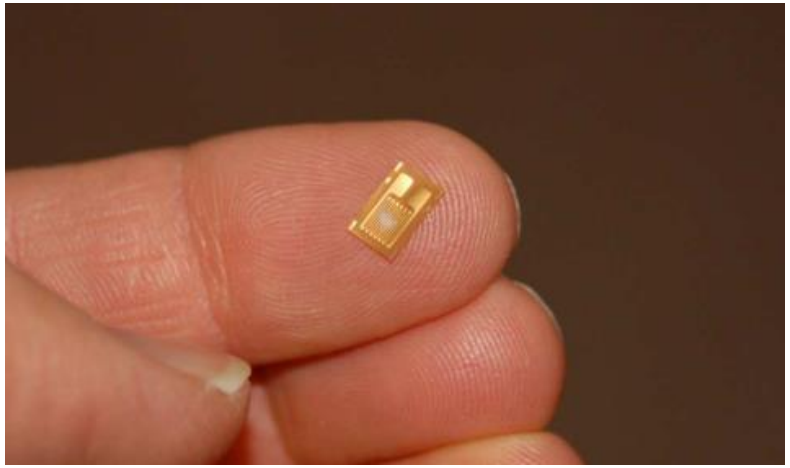
Differential pressure sensing mechanisms

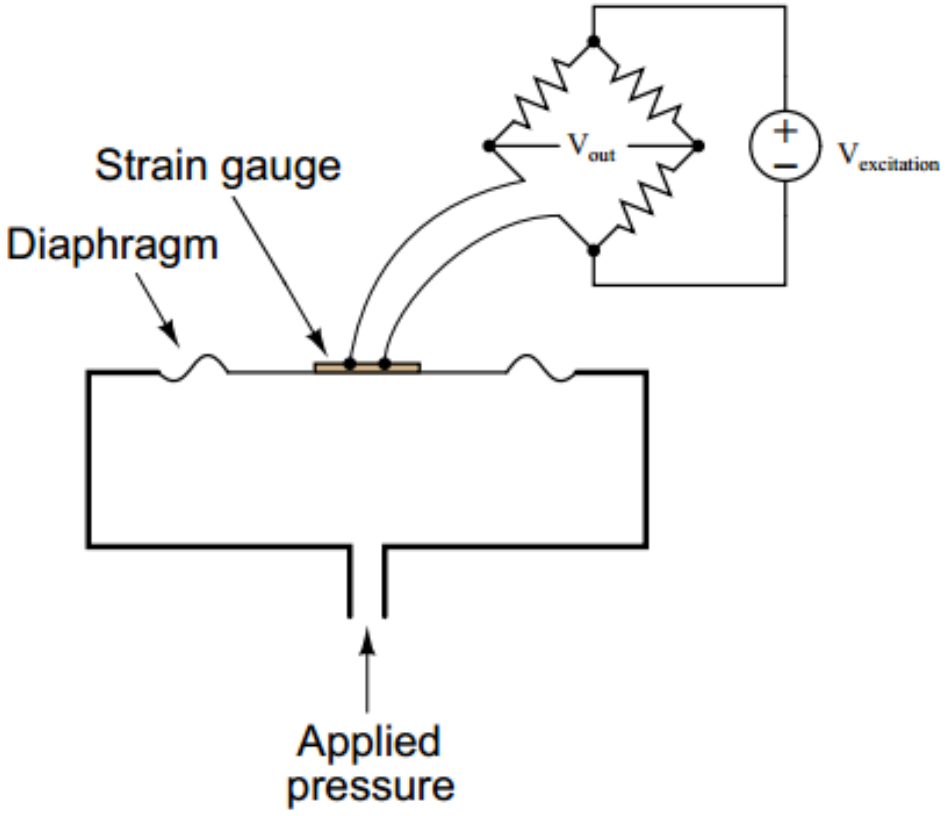




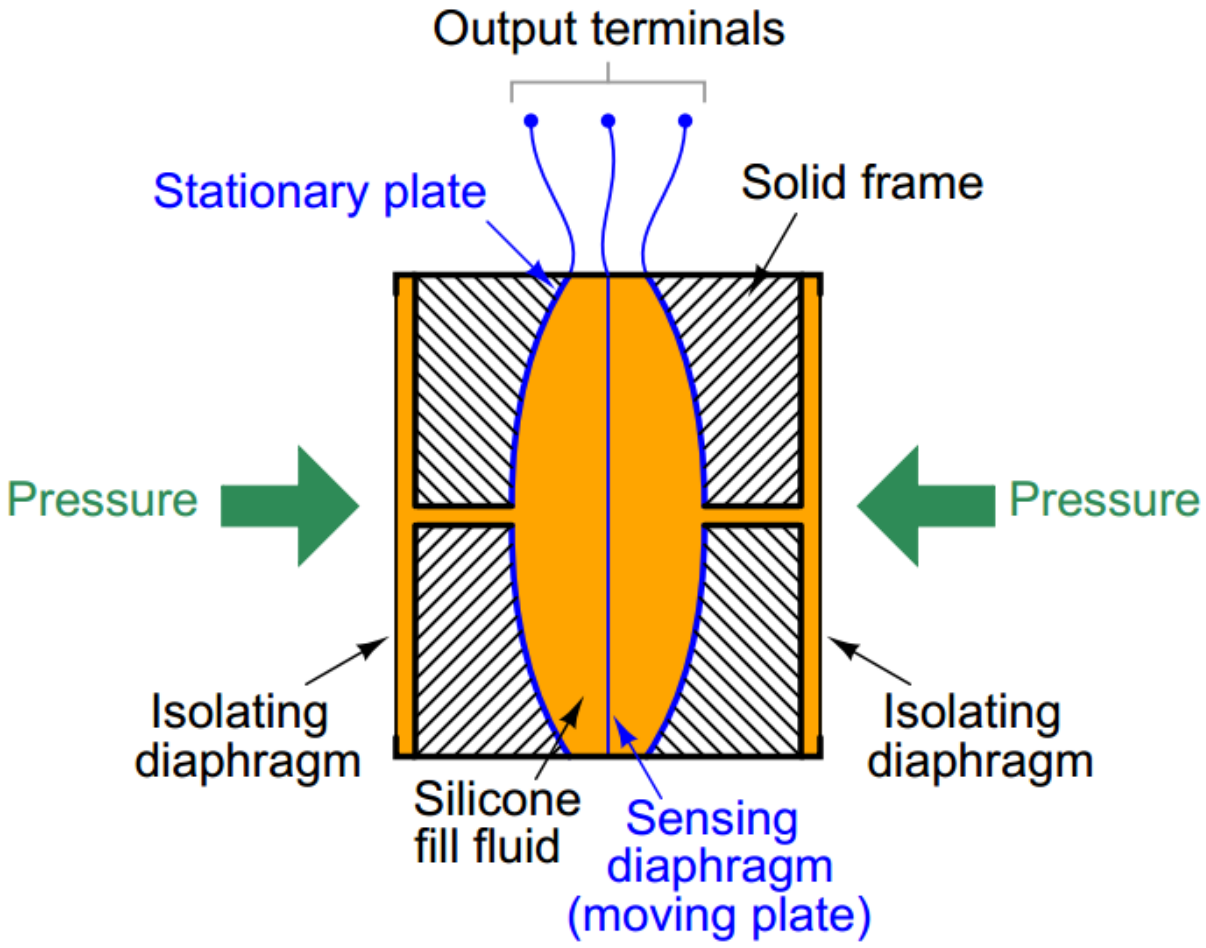


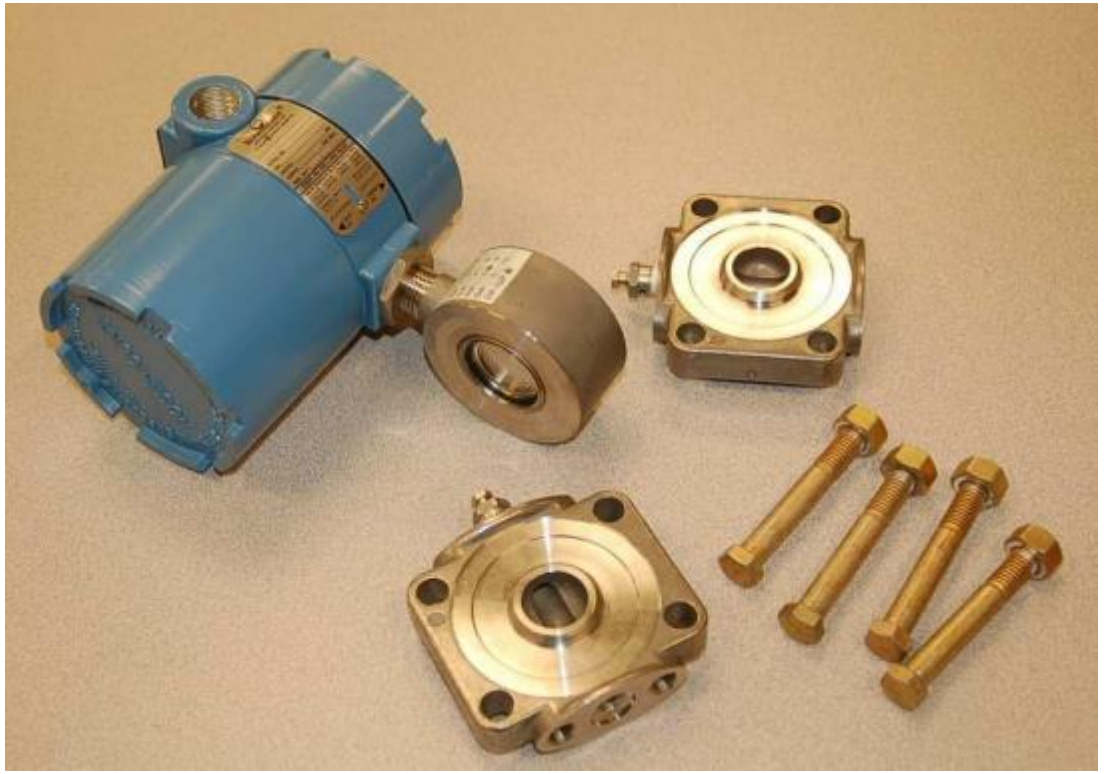
Piezoresistive (strain gauge) sensors





Differential capacitance sensors

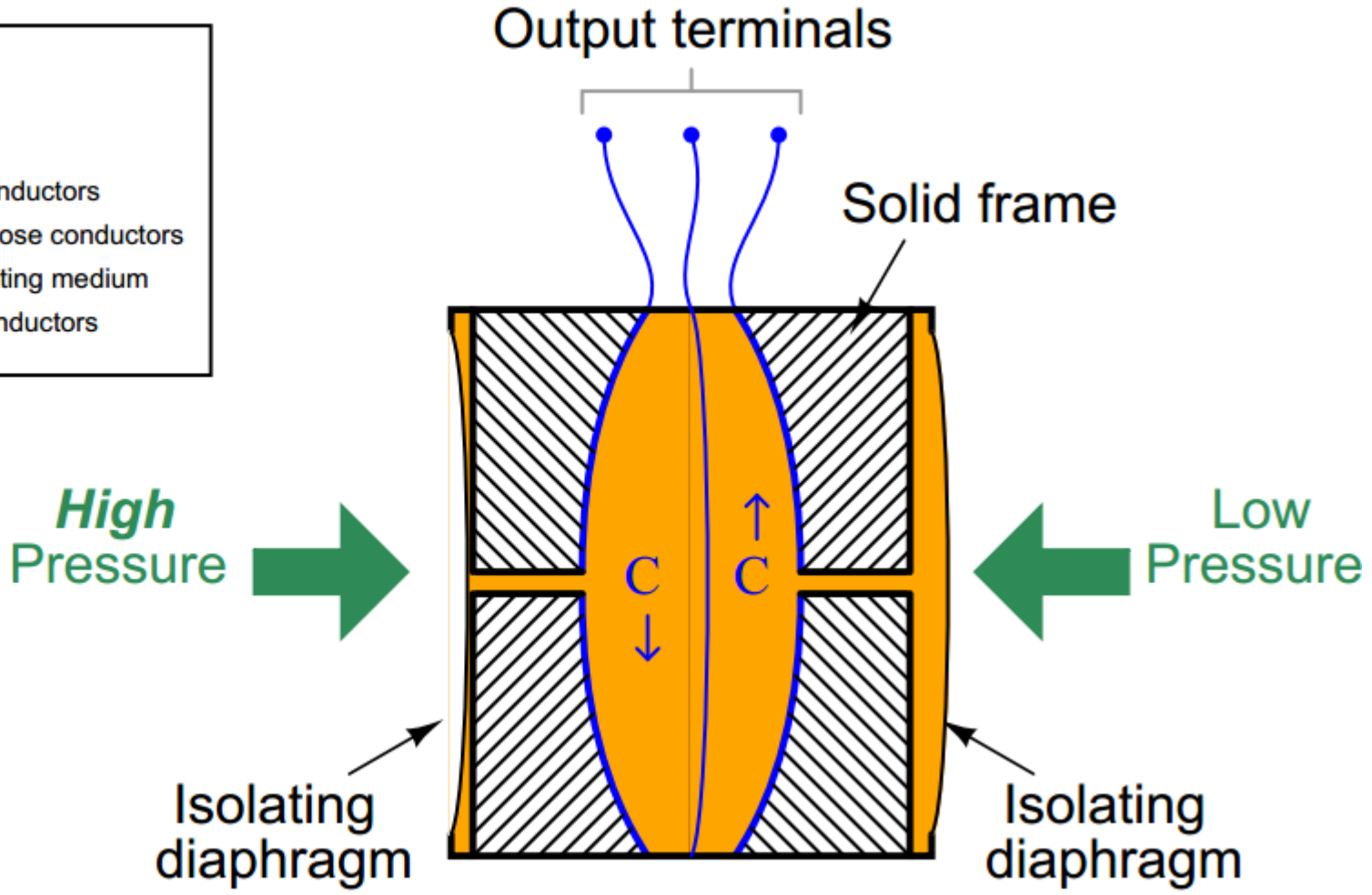




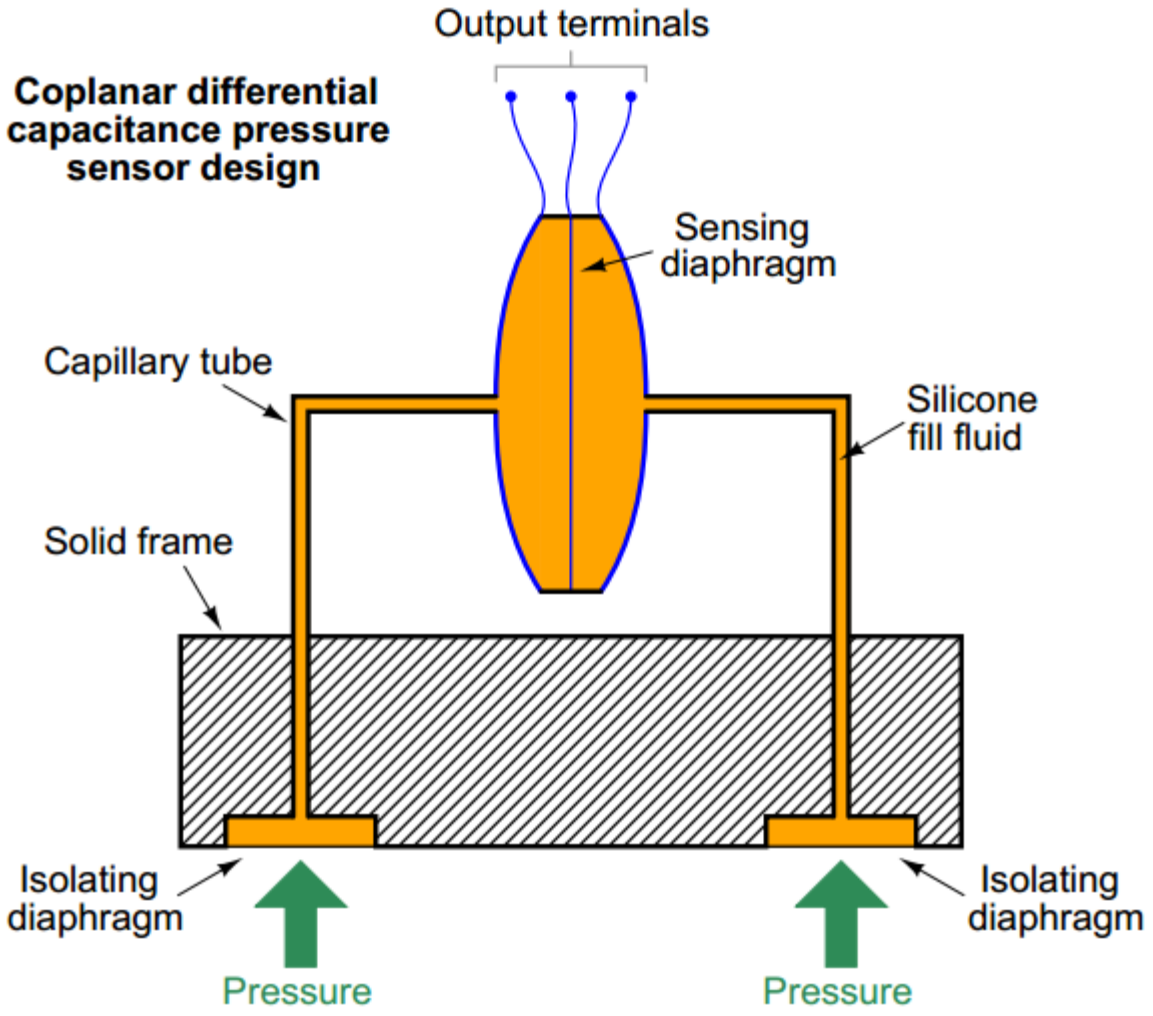
Differential capacitance sensors

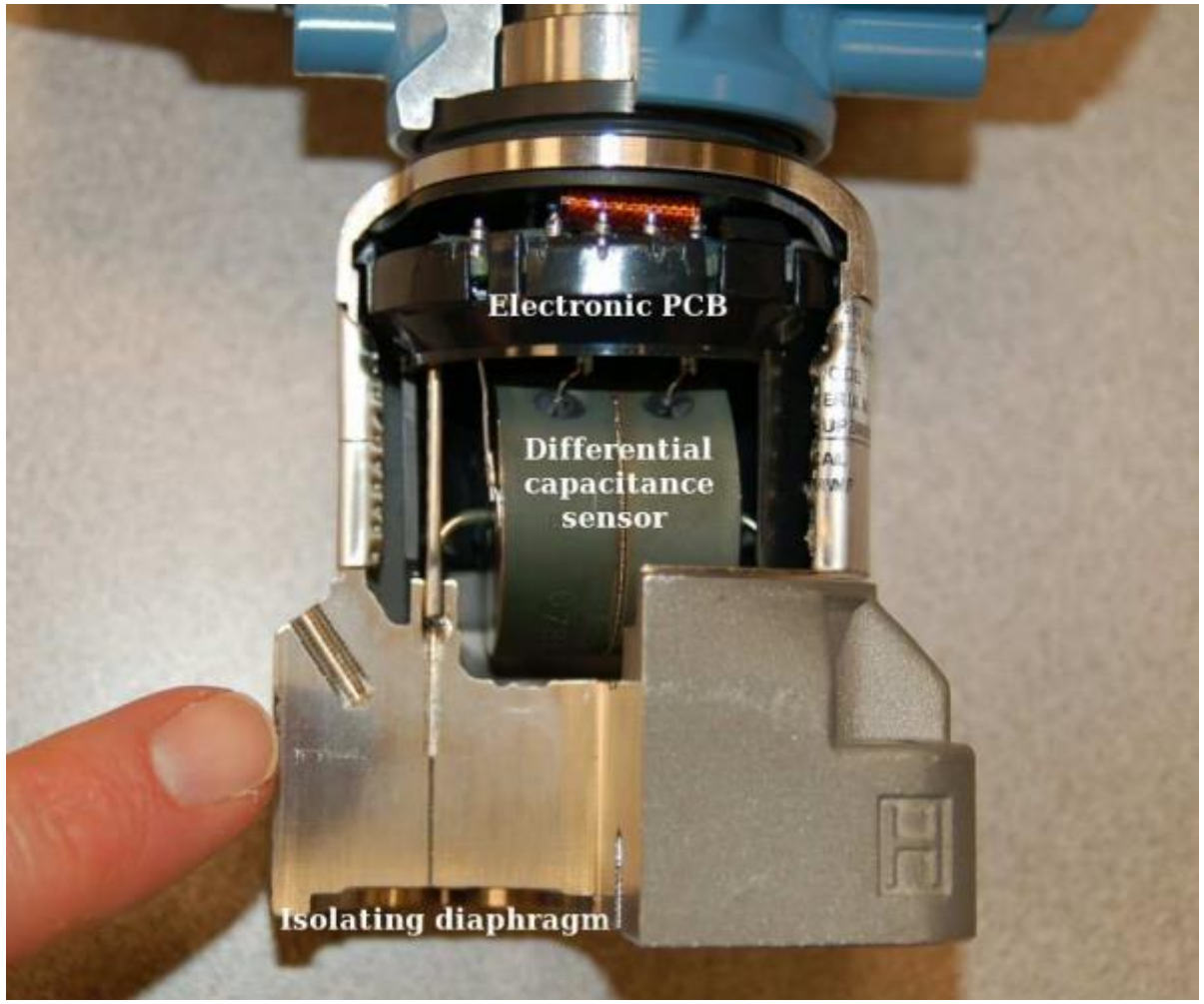
$$C = \frac{A\varepsilon}{d}$$

C = Capacitance between two conductors
A = Overlapping area between those conductors
ε = Dielectric permittivity of insulating medium
d = Distance separating those conductors



Differential capacitance sensors





Resonant element sensors

$$f = \frac{1}{2L}\sqrt{\frac{F_T}{\mu}}$$

Where,

f = Fundamental resonant frequency of string (Hertz)
L = String length (meters)
F_T = String tension (newtons)
μ = Unit mass of string (kilograms per meter)

Resonant element sensors

$$f = \frac{1}{2L}\sqrt{\frac{F_T}{\mu}}$$

Where,

f = Fundamental resonant frequency of string (Hertz)
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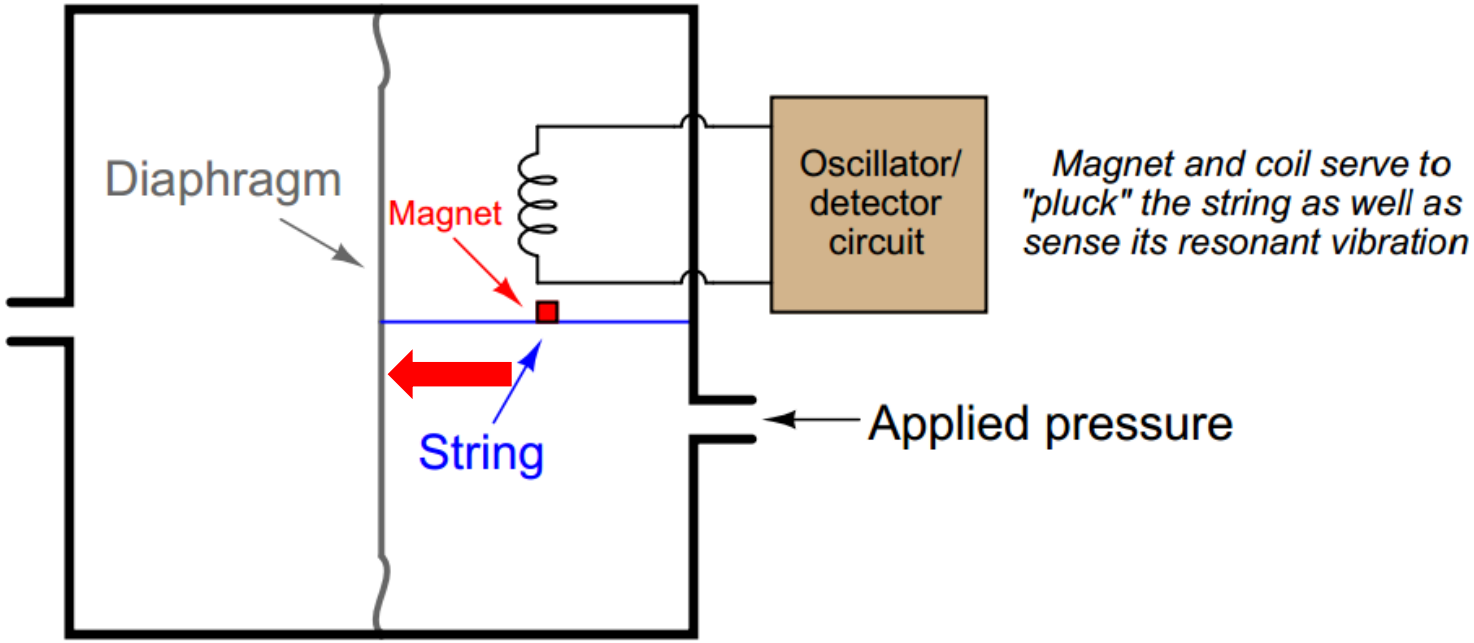
F_T = String tension (newtons)
μ = Unit mass of string (kilograms per meter)

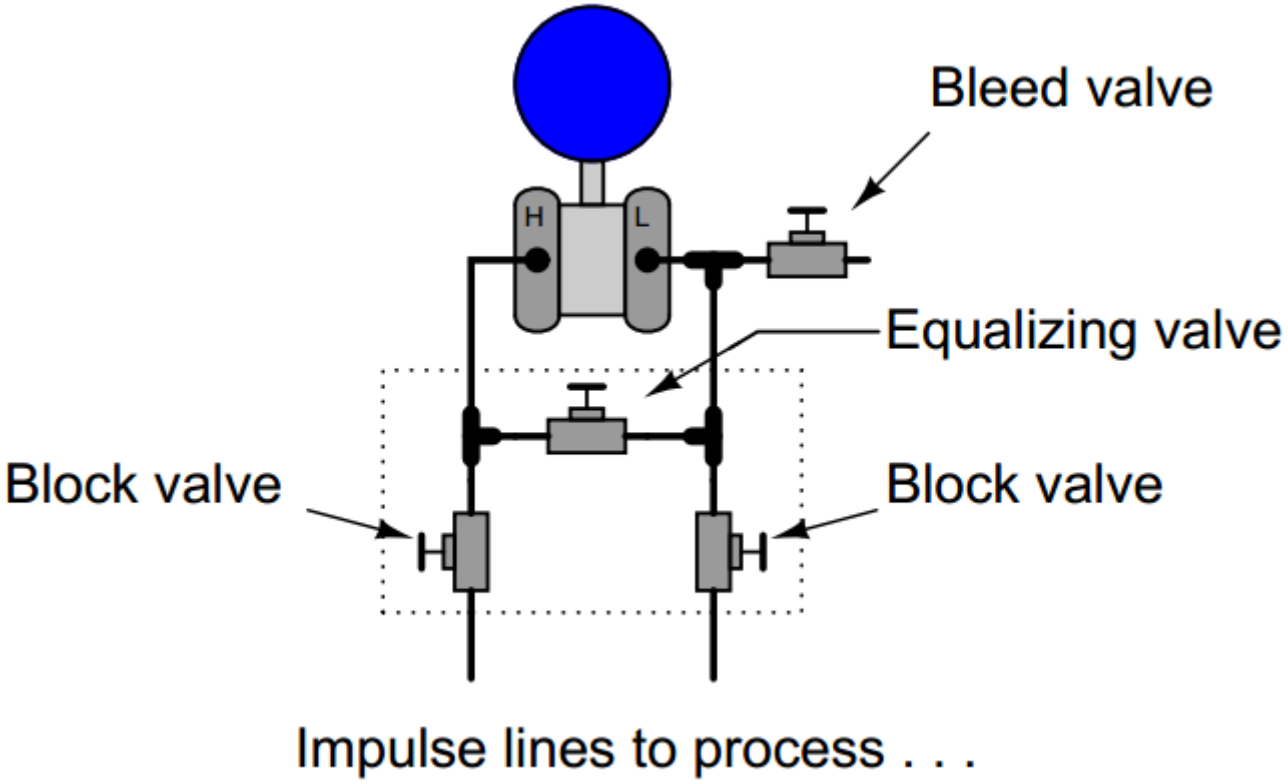


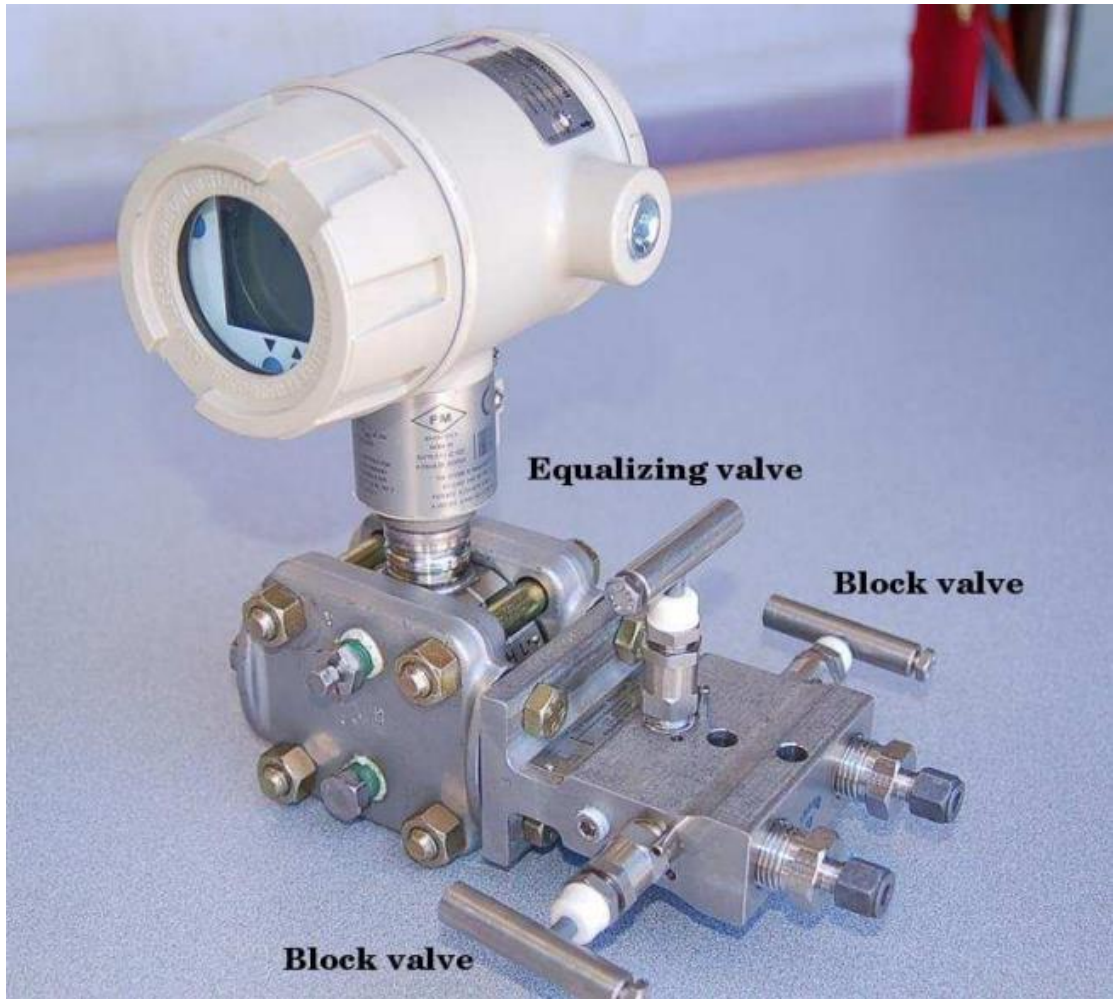
Electrical pressure elements

Manufacturer	Model	Pressure sensor technology
ABB/Bailey	PTSD	Differential reluctance
ABB/Bailey	PTSP	Piezoresistive (strain gauge)
Foxboro	IDP10	Piezoresistive (strain gauge)
Honeywell	ST3000	Piezoresistive (strain gauge)
Rosemount	1151	Differential capacitance
Rosemount	3051	Differential capacitance
Rosemount	3095	Differential capacitance
Yokogawa	EJX series	Mechanical resonance

Pressure sensor accessories

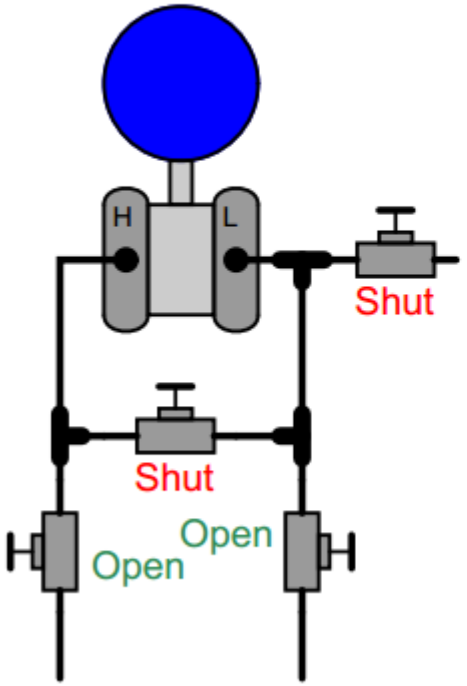
Valve manifolds



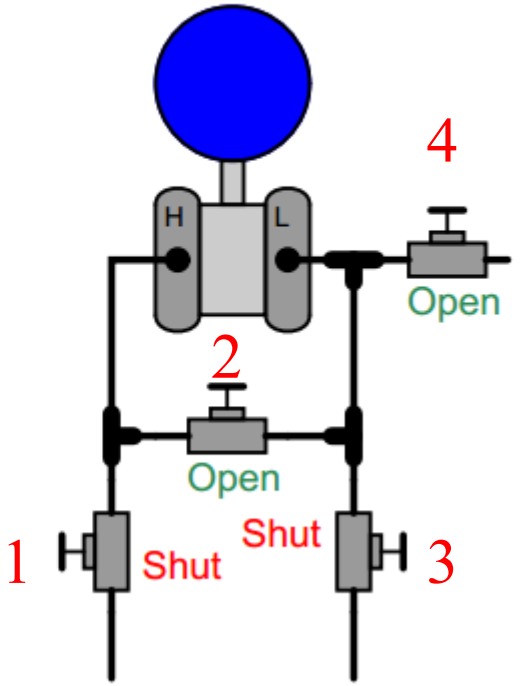


Pressure sensor accessories

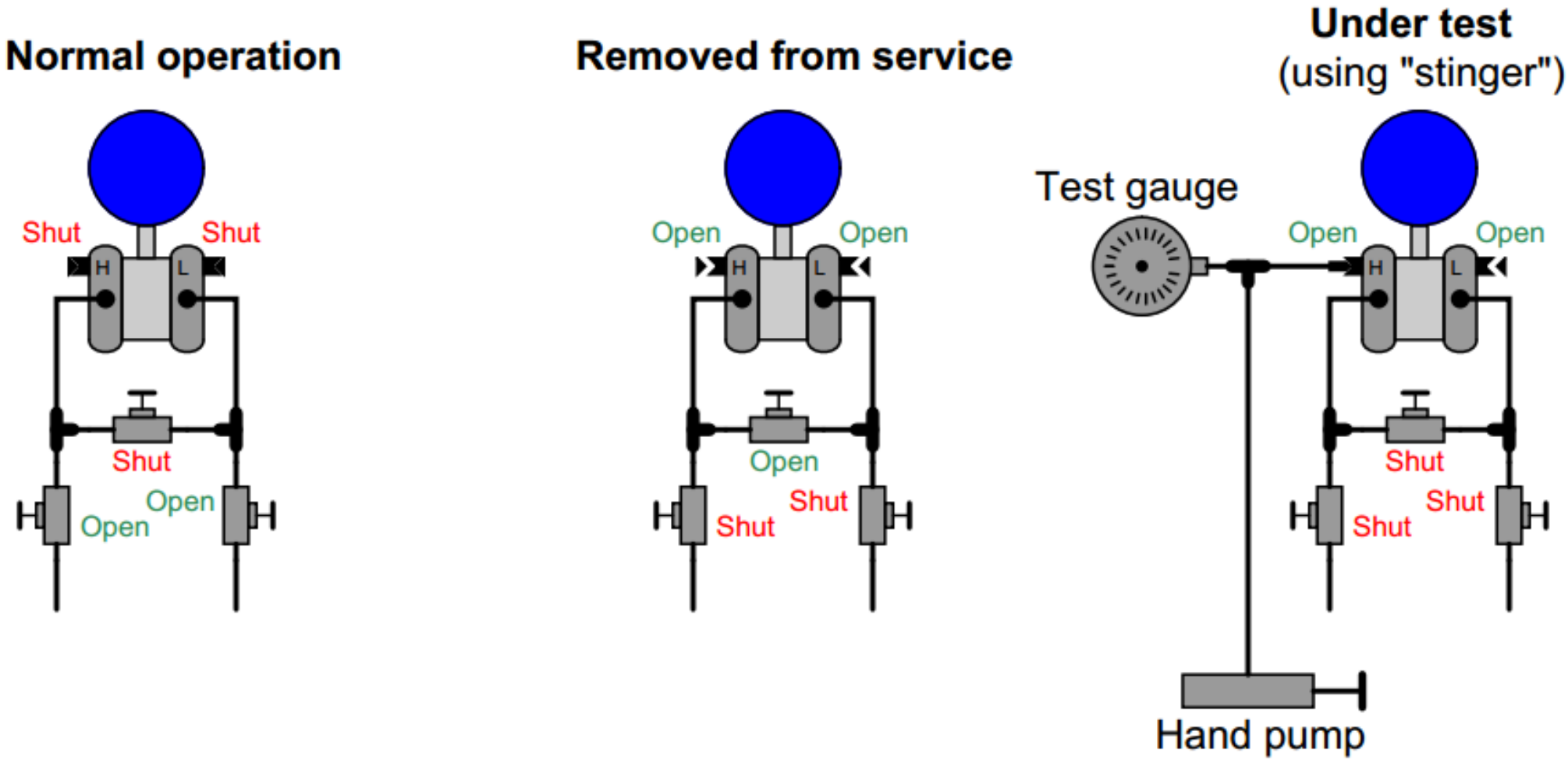
Normal operation



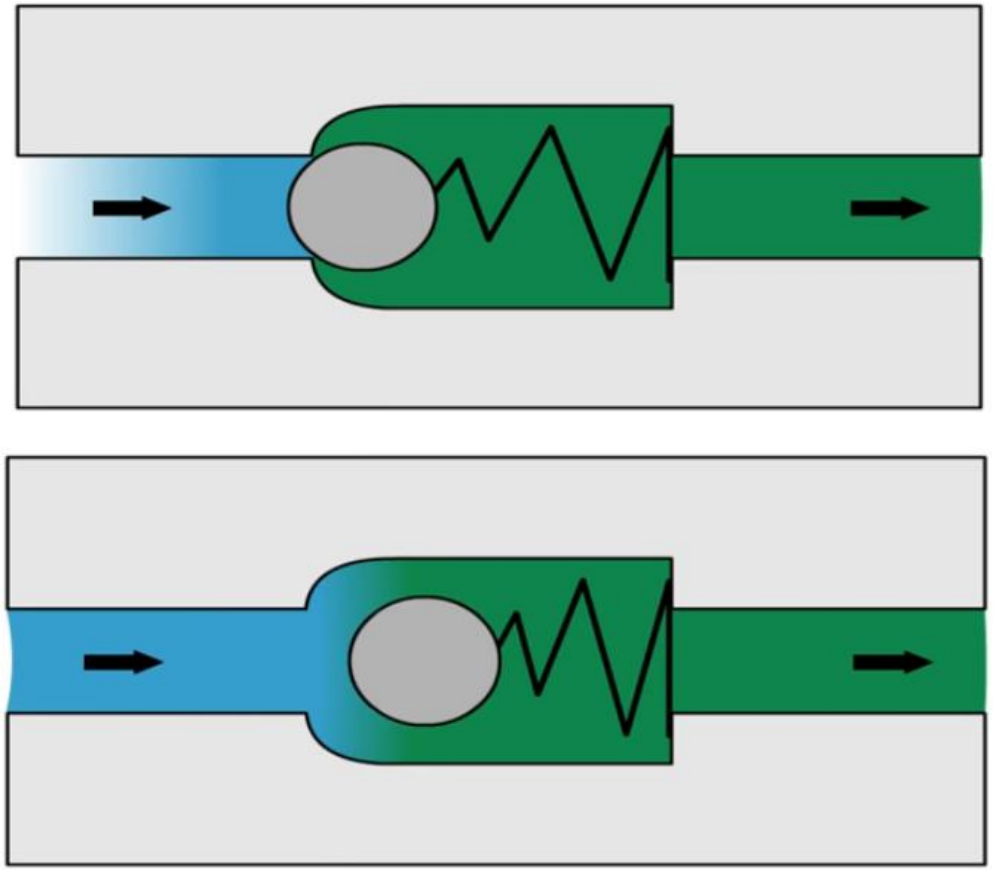
Removed from service



Pressure sensor accessories



Pressure sensor accessories



Pressure Units

Unit	Abbreviation	Equivalent number of pascals
Atmosphere	atm	1 atm = 101,325 Pa
Bar	bar	1 bar = 100,025 Pa
Millimeter of mercury	mmHg	1 mmHg = 133.322 Pa
Inches of mercury	inHg	1 inHg = 3386 Pa
Pascal	Pa	1
Kilopascal	kPa	1 kPa=1000 Pa
Pounds per square inch	psi	1 psi = 6,893 Pa
Torr	torr	1 torr = 133.322 Pa