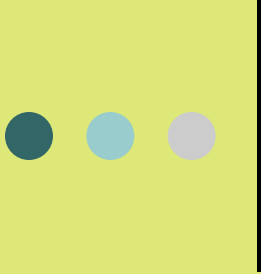


Pressure Measurement



Definition of Pressure

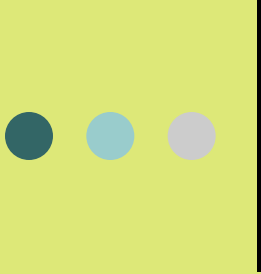
- Pressure is defined as

Force per unit Area

Pounds per square Inch (PSI)

Newtons per square Meter (Pascal)

1000 Newtons per square Meter (KPA)



Other common units of pressure

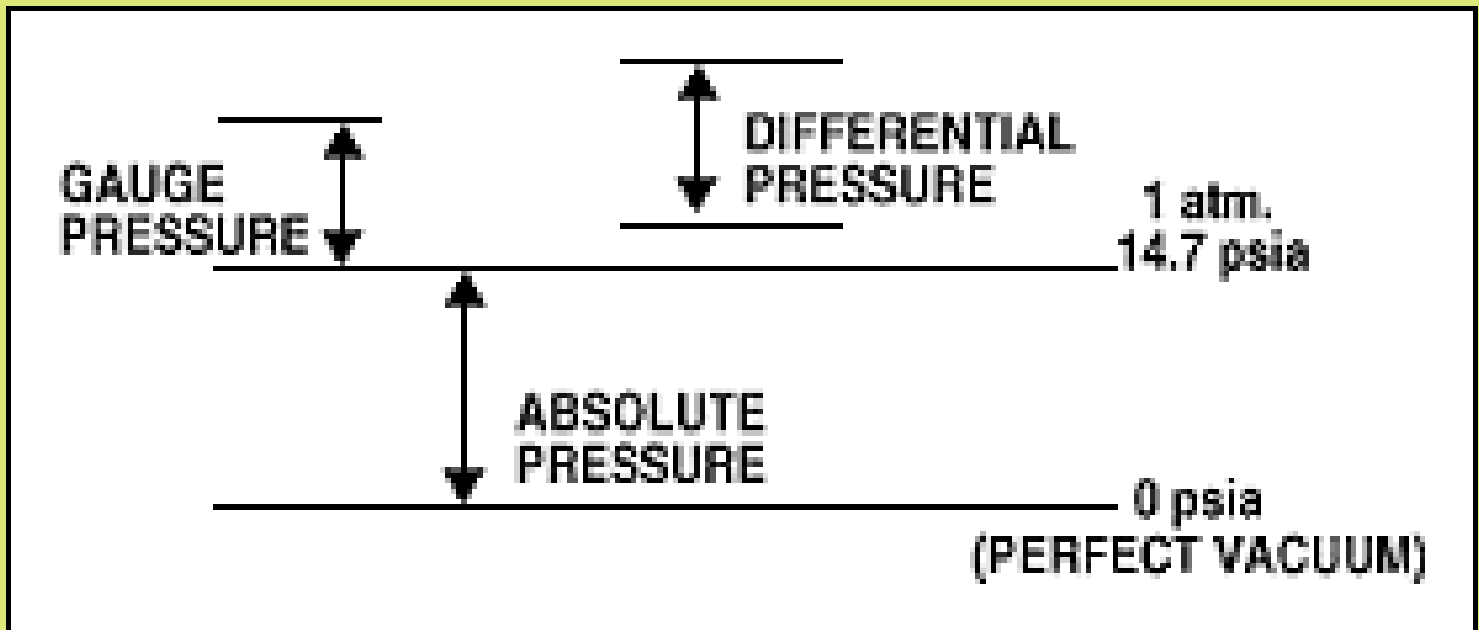
$$\begin{aligned} 1 \text{ psi} &= 51.714 \text{ mmHg} \\ &= 2.0359 \text{ in.Hg} \\ &= 27.680 \text{ in.H}_2\text{O} \\ &= 6.8946 \text{ kPa} \end{aligned}$$

$$1 \text{ bar} = 14.504 \text{ psi}$$

$$1 \text{ atm.} = 14.696 \text{ psi}$$

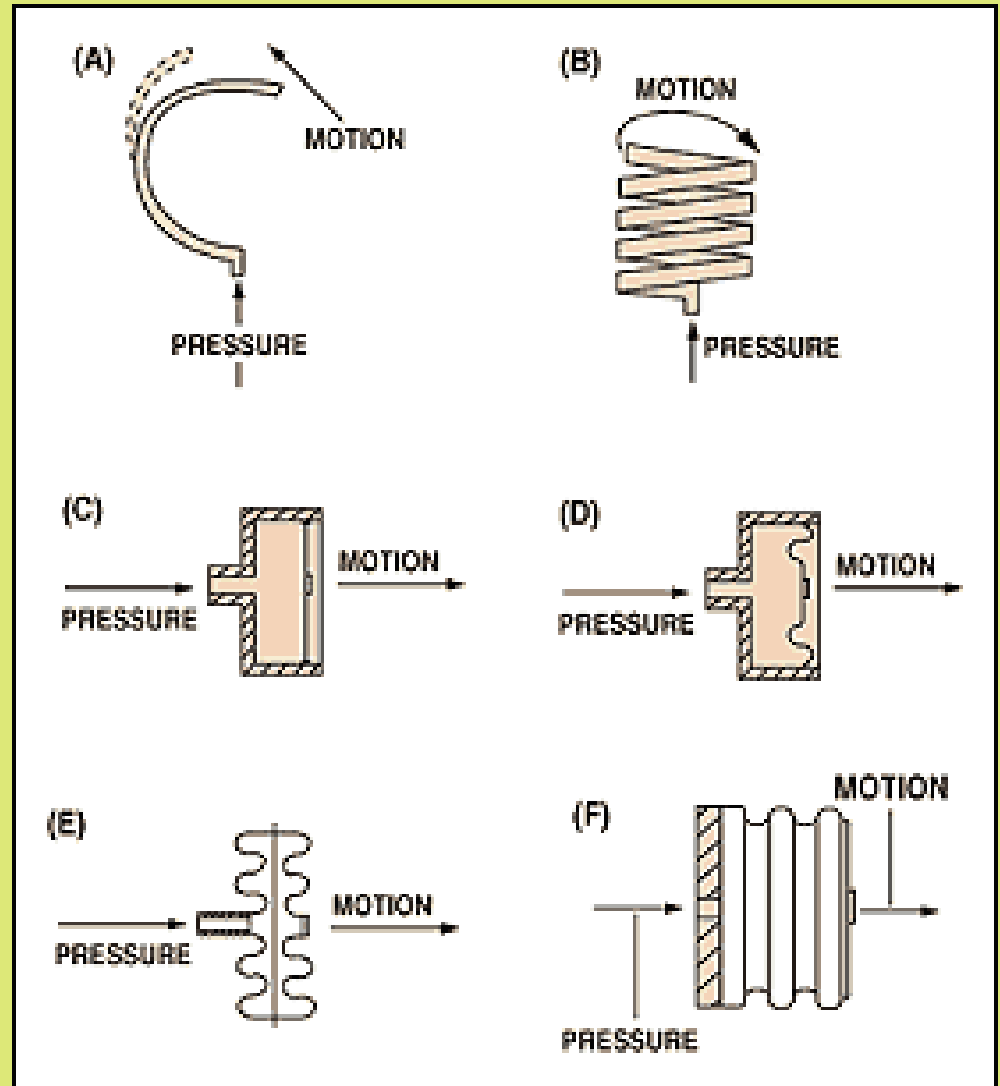
Types of pressure

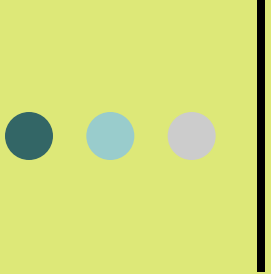
- Gauge (most common)
- Absolute (reference perfect vacuum)
- Differential (Reference some arbitrary pressure)



Pressure sensing elements

- A) “C” Tube
- B) Spiral Tube
- C) Piston in cylinder
- D) Diaphragm capped cylinder
- E) Expandable chamber
- F) Bellows





Indicators

- Use pressure elements to create a visual indication of the pressure.
- These are used for man interface, but not data logging.
- Not all applications require data to be stored!
 - Example: Pressure readings on building HVAC system water pumps and chillers. There for diagnostics purposes.

Indicating Units

- Fall into two main categories

- Gauges
- Manometers



Manometers

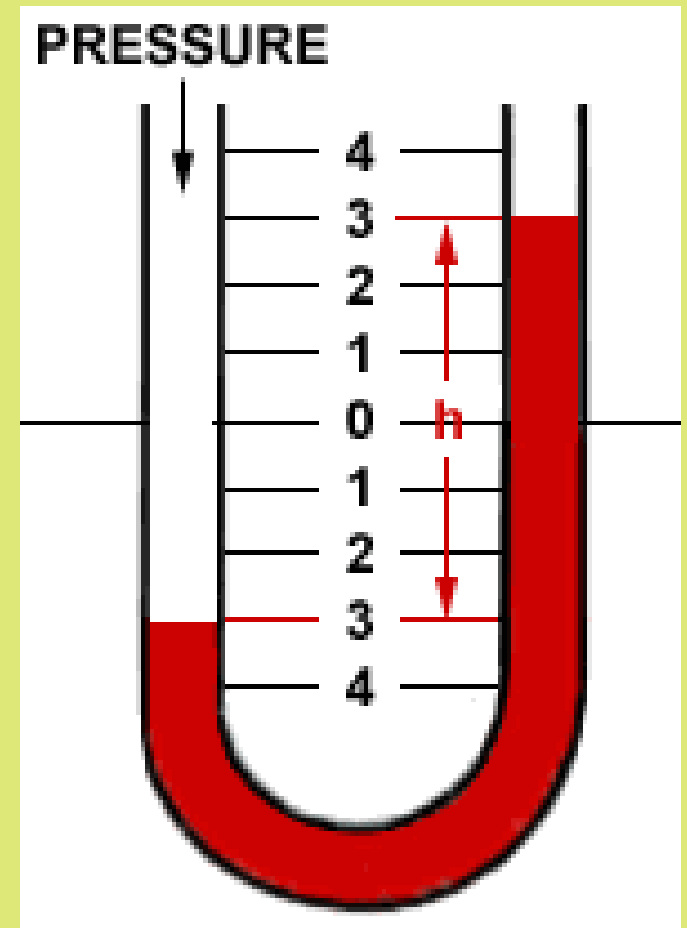


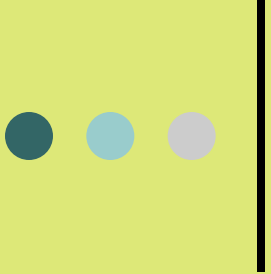
- Are a variation on the piston/cylinder device
- Are by definition differential devices
- Can be used as gauge device by leaving one tube at atmospheric
- Low pressure
 - Limited by density of fluid and height

Manometers

Pressure measured
by differential height
of fluid

1 PSI = $27\frac{1}{2}$ " water
 2.036" Hg



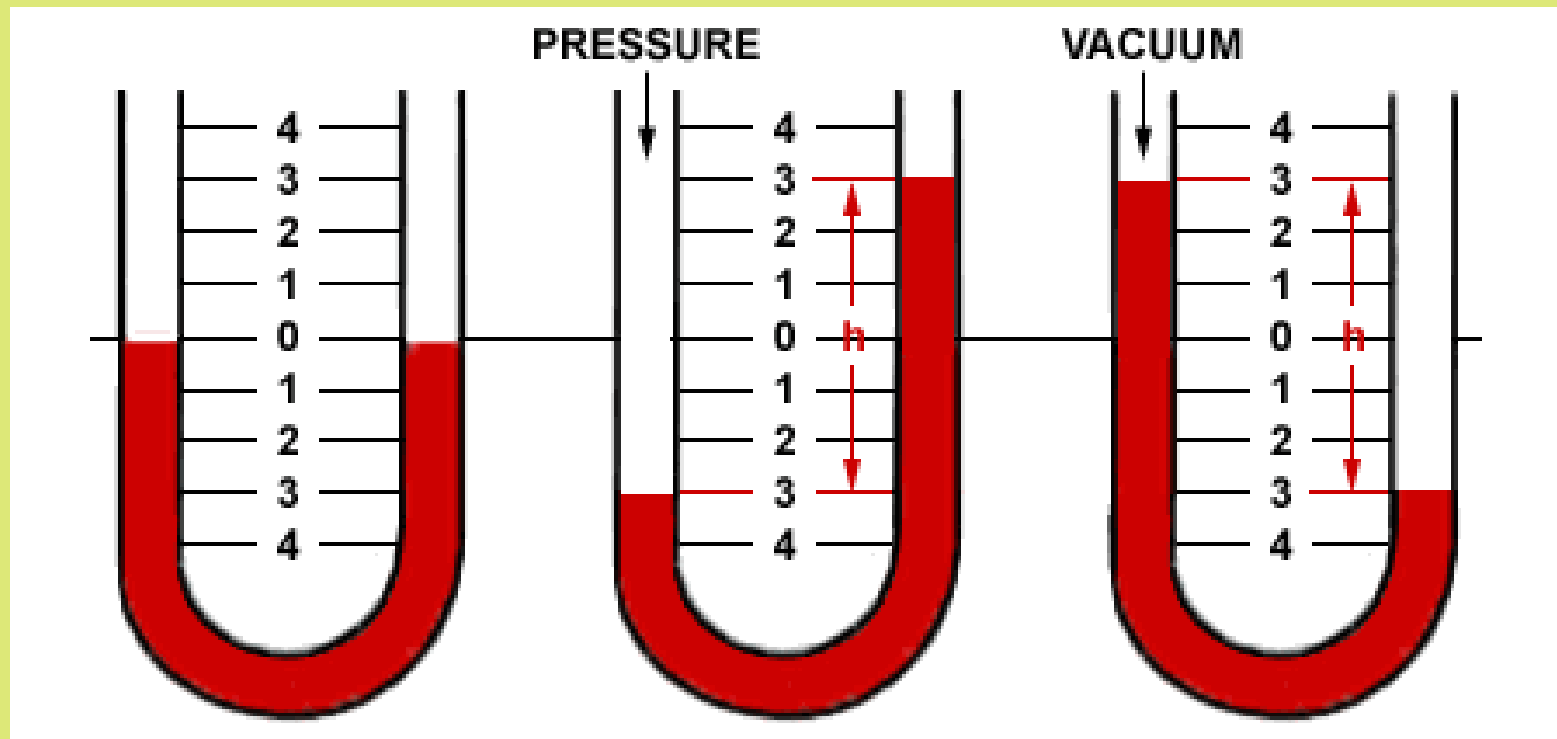


Variations

- U Tube
- Reservoir type
- Inclined

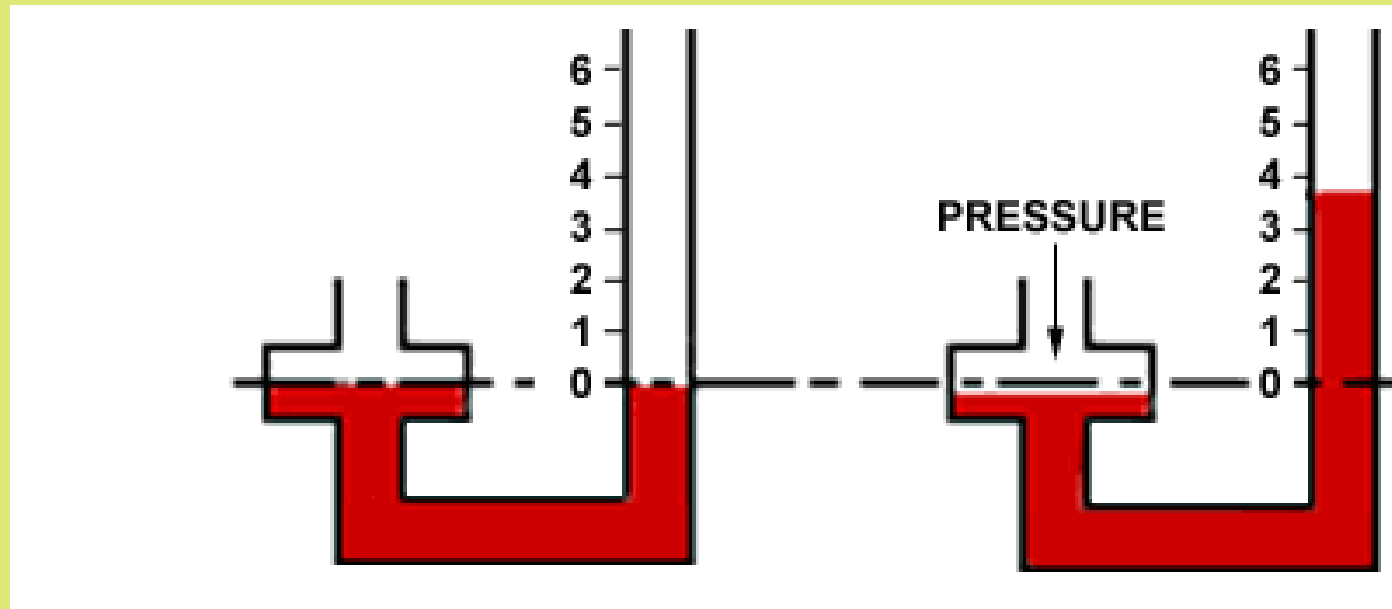
U-Tube

- Reading is always the difference in height of the fluid in both sides



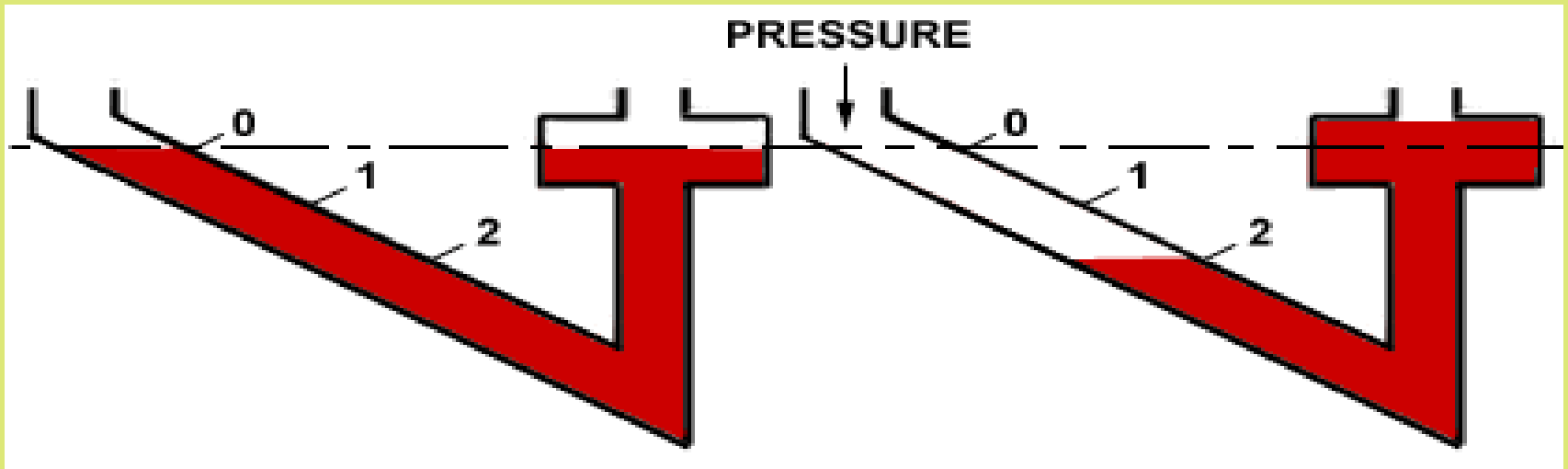
Reservoir type

- Uses a reservoir on one side so that there is a single scale.
- Volume of the reservoir MUST be significantly larger than the volume in the tube so that it's height change is negligible!



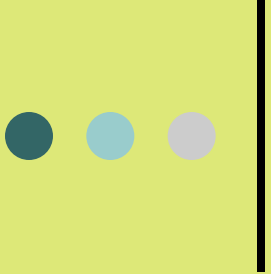
Inclined

- Similar to Reservoir type
- Designed to read smaller changes by expanding the scale
- There are also combinations with “portions” of the scale inclined



Examples



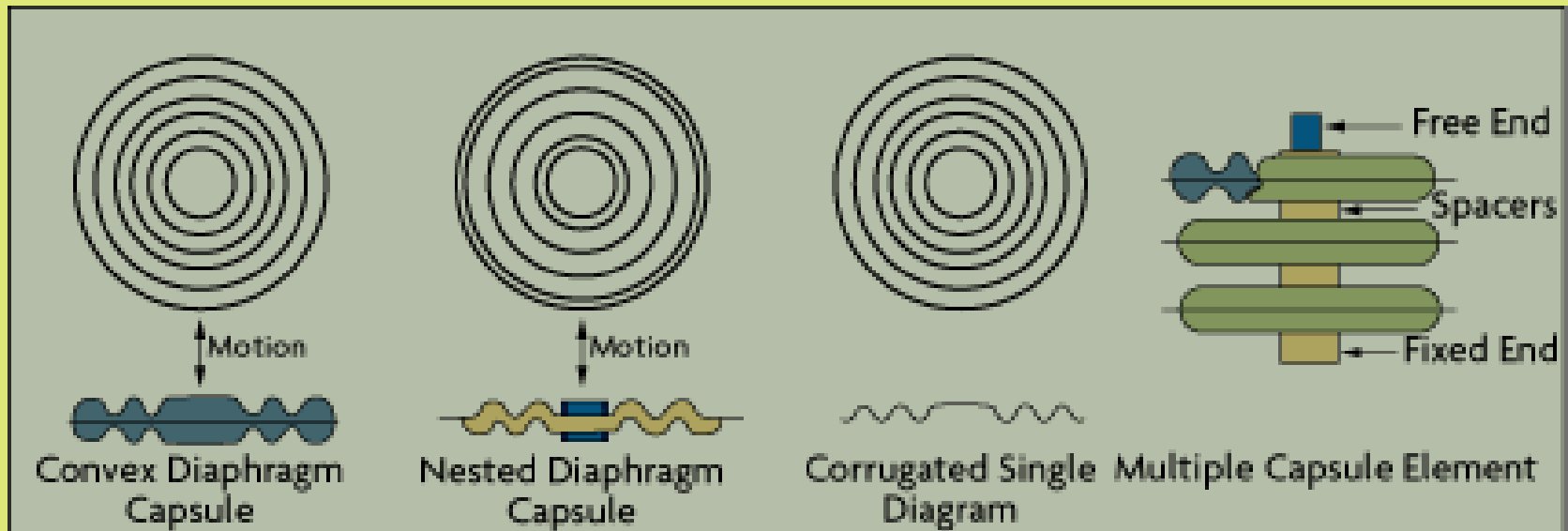


Gauges

- Fall into three basic categories
 - Diaphragm
 - Bellows
 - Bourdon Tube

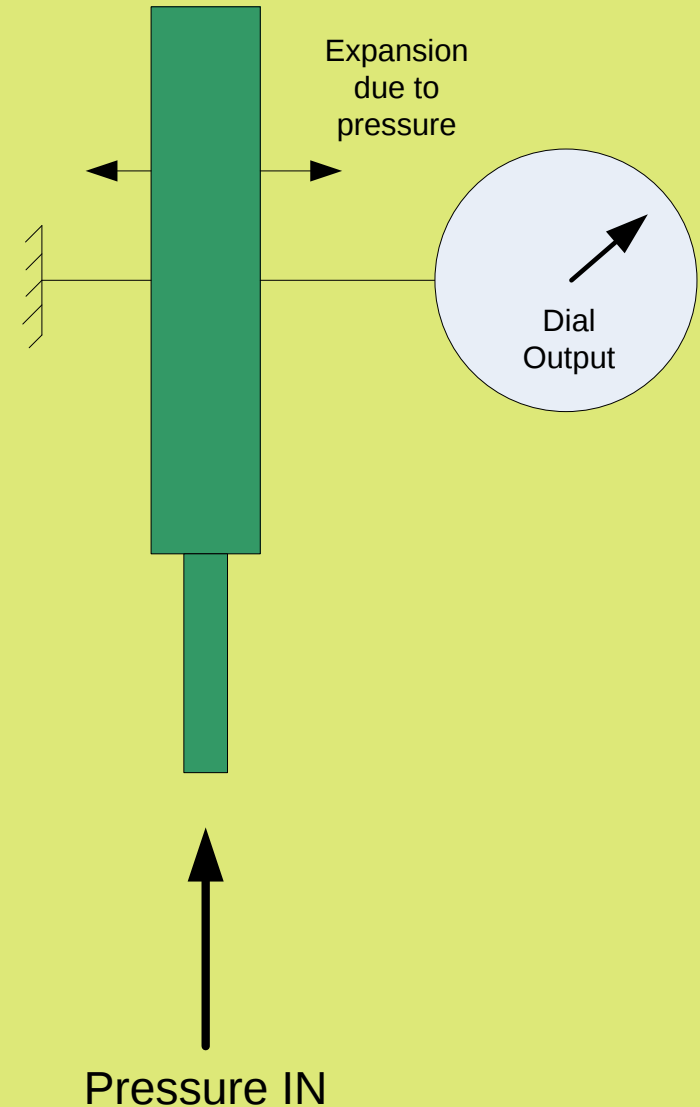
Diaphragm Gauges

- Measure the pressure across a diaphragm



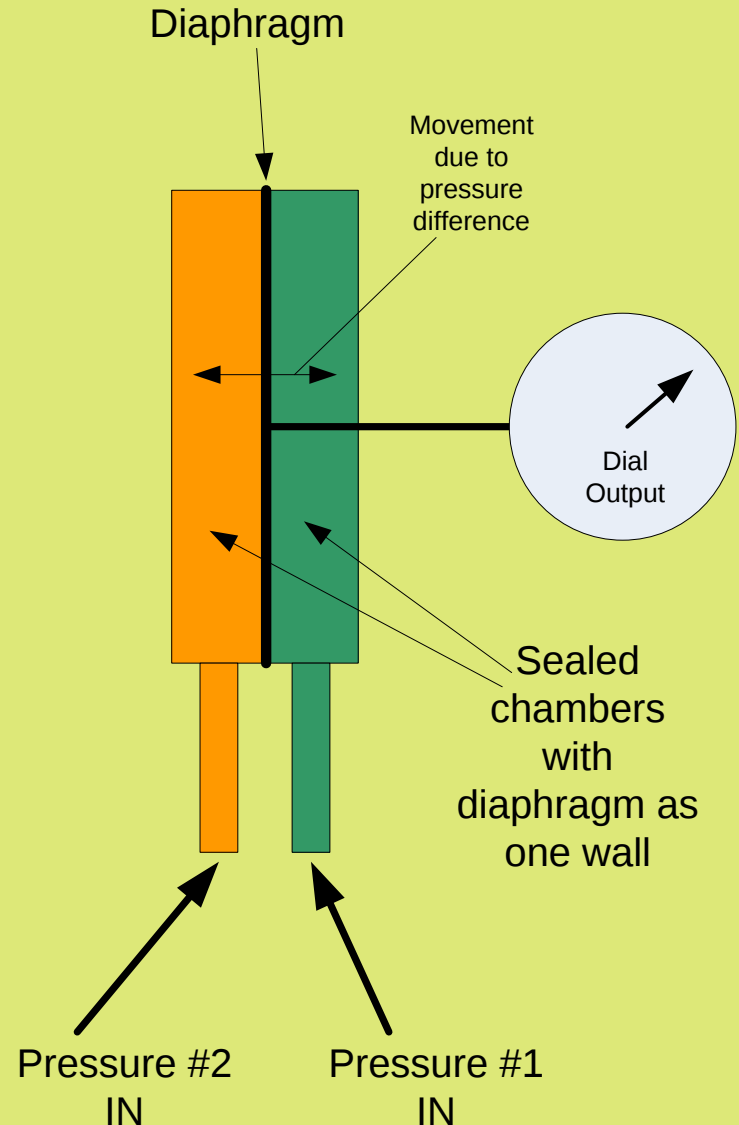
Diaphragm Gauge

- In its simplest form:
- Pressure in the capsule expands it
- Force to expand is calibrated
- Moving a needle
- Gauge pressure



Differential Diaphragm gauge

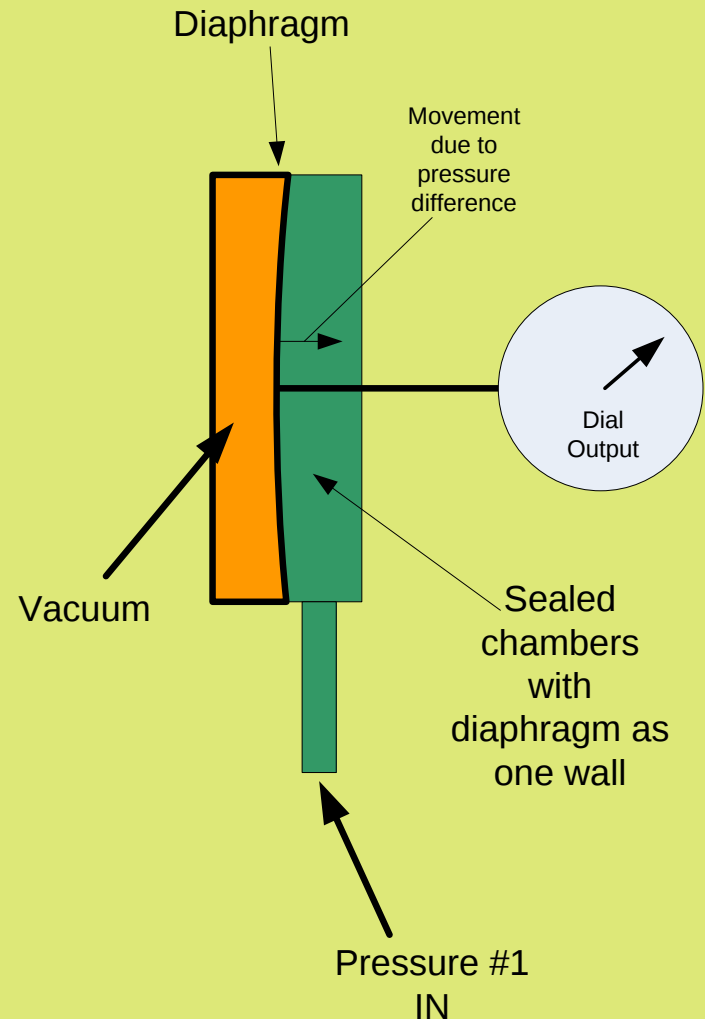
- Two pressures balance on the diaphragm to show differential pressure



Absolute Diaphragm gauge

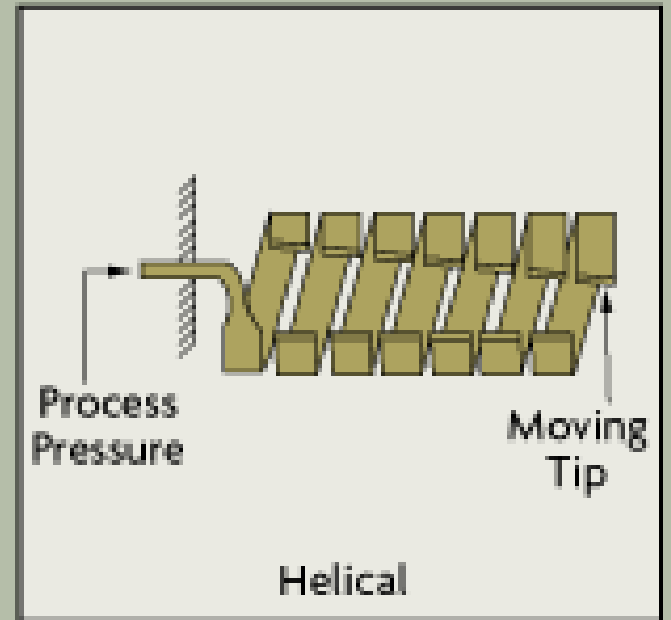
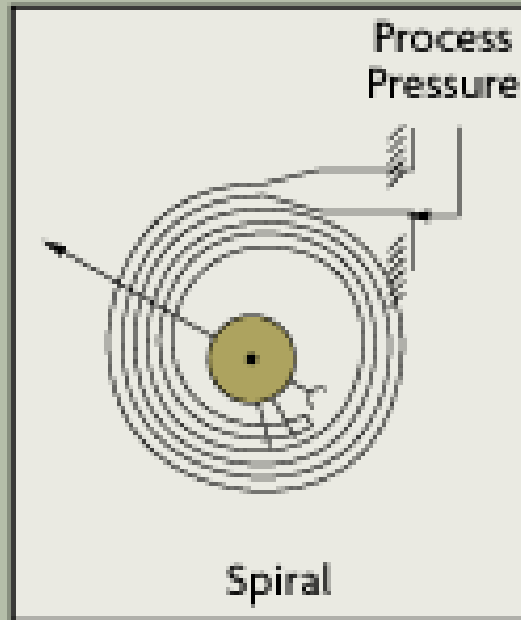
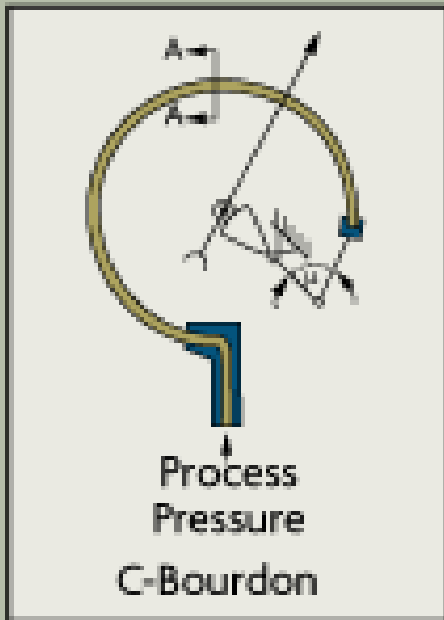
- Uses vacuum as reference pressure

- NOTE: This is NOT an accurate physical depiction!



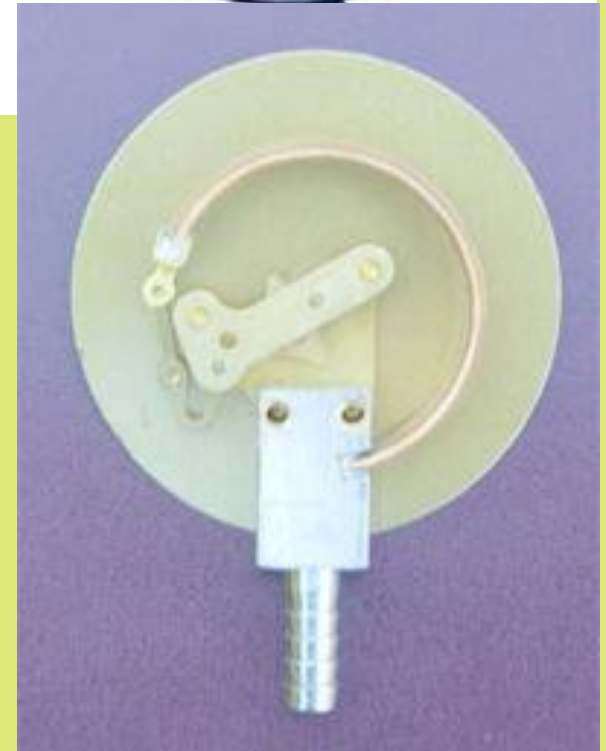
Bourdon Tube Gauge

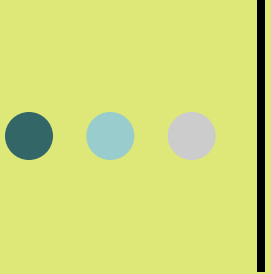
- Three basic physical types



C Type Bourdon Tube

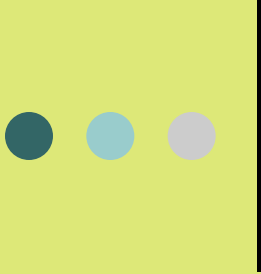
- Most common type of gauge out there
- Expansion causes the end of the tube to move, moving the needle with gear system





Ruggedness?

- All of these designs are VERY susceptible to damage from:
 - Pressure impulses
 - High rate fluctuations
 - Vibration



Solutions:

- Liquid filled gauges
 - Usually filled with mineral oil or something similar
- Snubbers
 - Small orifice or sintered brass piece inserted before the gauge
- Both have the same effect, Slow down the response time of the gauge to give it a chance.
- Liquid filled does a better job at mechanical vibrations!

Why spend so much time on simple gauges?

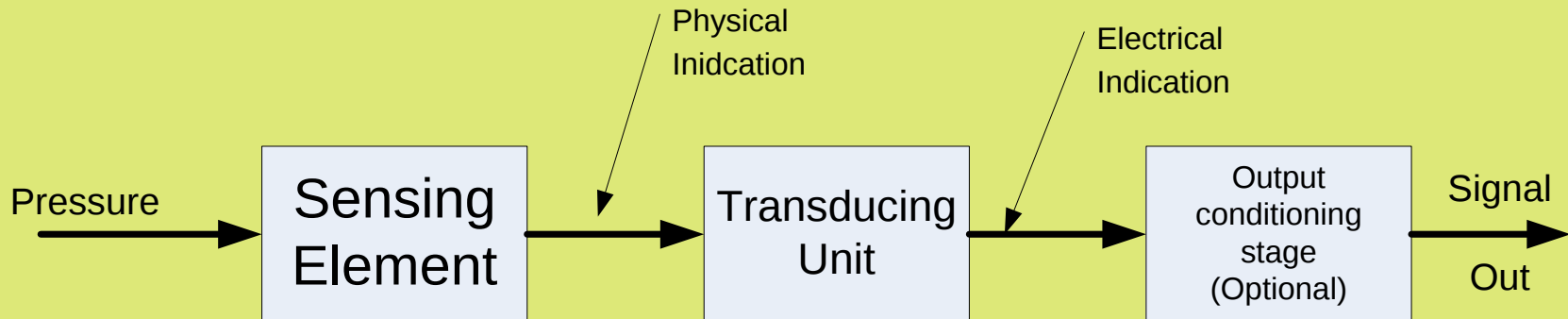
- Answer:

Nearly all electronic transducers use these same basic mechanical sensing elements as the basis for the transducer



Transducers

- Designed to allow data logging and acquisition by remote systems
- Consist of 3 parts



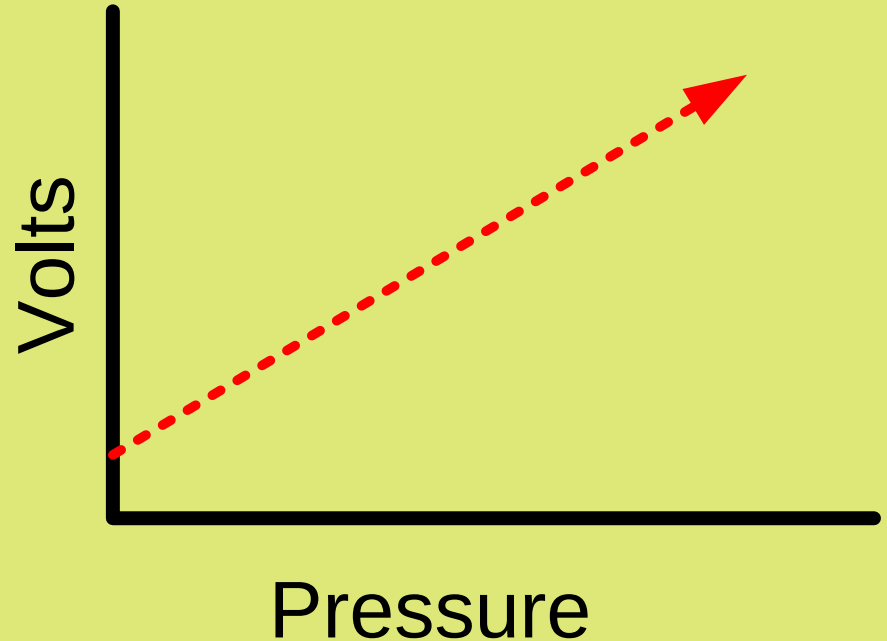
Simple Model

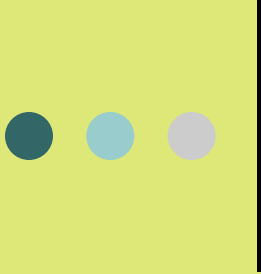
$$V_{\text{out}} = K_0 + K_1 P$$

Where

K_0 = some offset

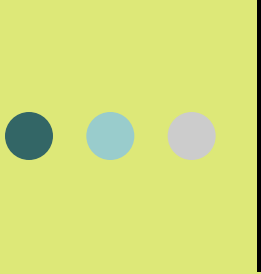
K_1 = some sensitivity
Volts / pressure unit





Life is ***NEVER*** simple!

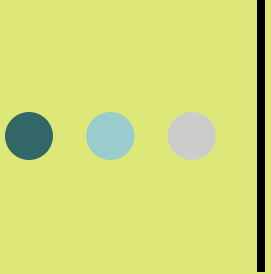
- Transducer output is effected by:
 - Temperature
 - Linearity
 - Repeatability
 - Hysteresis



Temperature

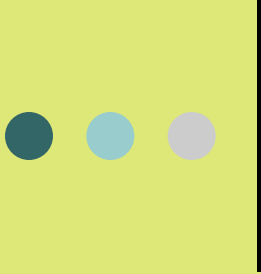
- The sensing element is a mechanical system
- What do we know about ALL mechanical systems?

Temperature changes everything!



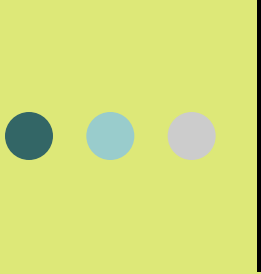
Two classes of transducers

- Static and low speed transducers
 - Slower than 100ms impulse
- Dynamic transducers
 - Faster than 100ms impulse



Technologies that work for static transducers

- Resistive
- Variable reluctance
- Inductive
- Capacitive
- Strain Gage
- Piezo-Resistive (Semiconductor)

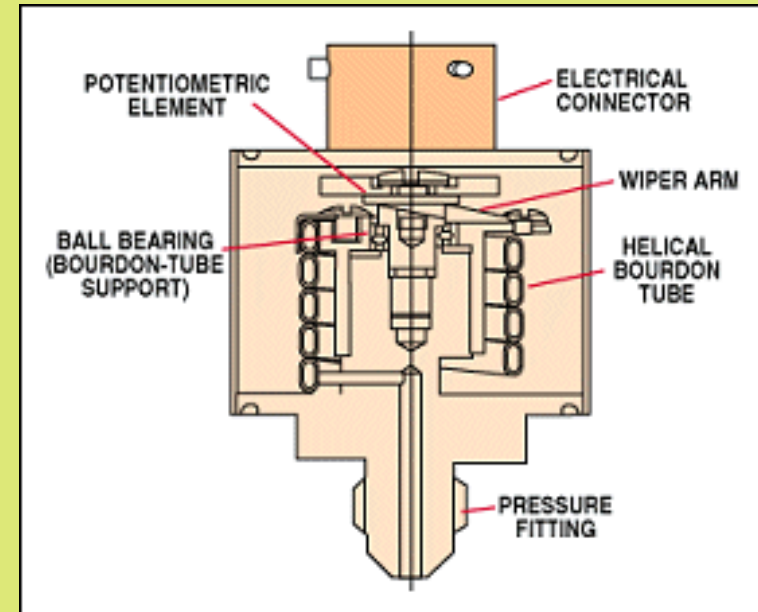


Technologies that require dynamic signals

- Piezo Electric

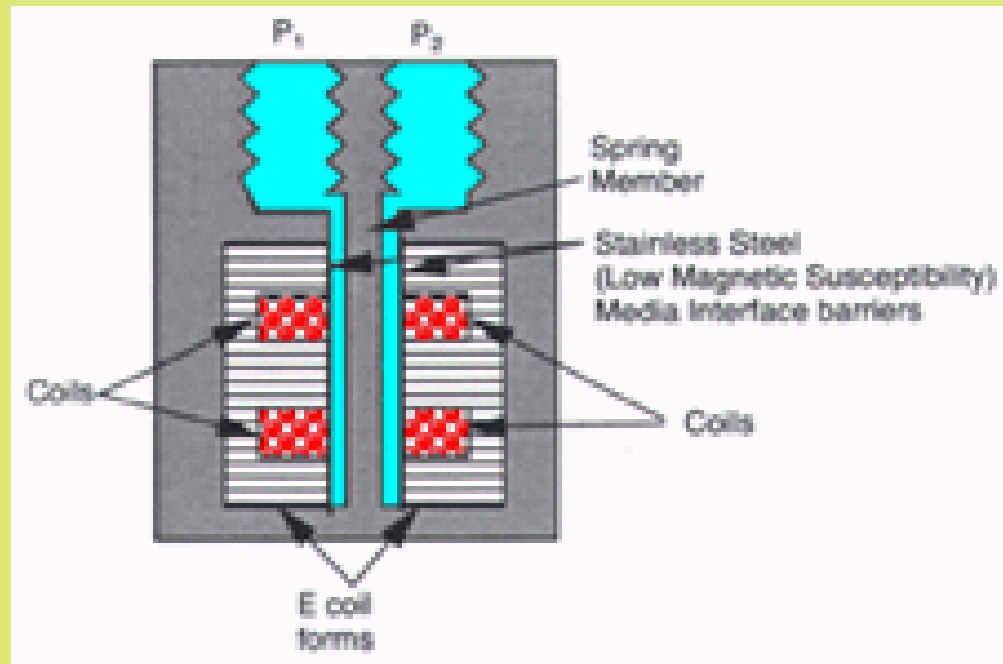
Resistive

- Use a bourdon tube element to rotate the wiper on a resistance element.
- Not seen a lot any more.
This is an older technology
- Had poor Hysteresis
- Good linearity
- This had all the faults of a bourdon tube gage.



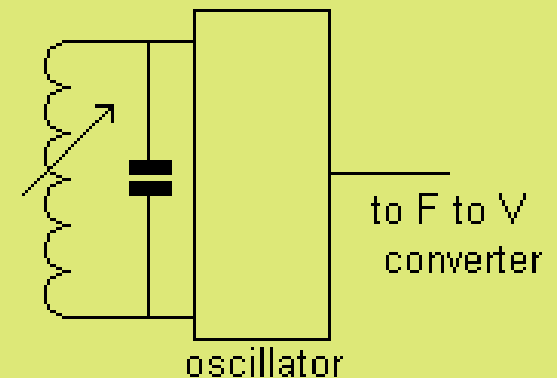
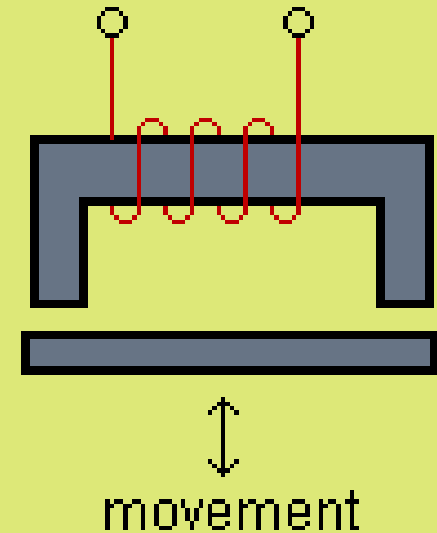
Variable Reluctance

- The pressure moves a flexible member closer or farther from a coil, which changes the reluctance (Magnetic resistance) of the circuit.



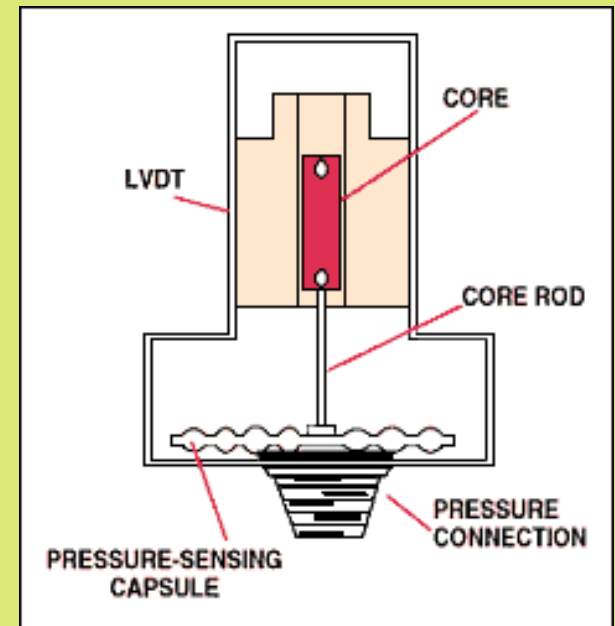
Variable reluctance

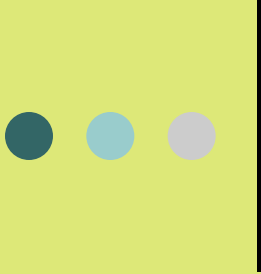
- Output drives an LC oscillator.
- These transducers are good for either static or moderate speed dynamics (< 50 hz)
- Have become fairly special purpose and not widely used
- Electronics need to be close to the transducer and are expensive.
- Require a lot of conditioning to be linear.
- Very good Hysteresis and very low temperature effects.



Inductive

- Uses the effects of moving a core through a transformer set to vary the magnetic coupling, and hence the output.



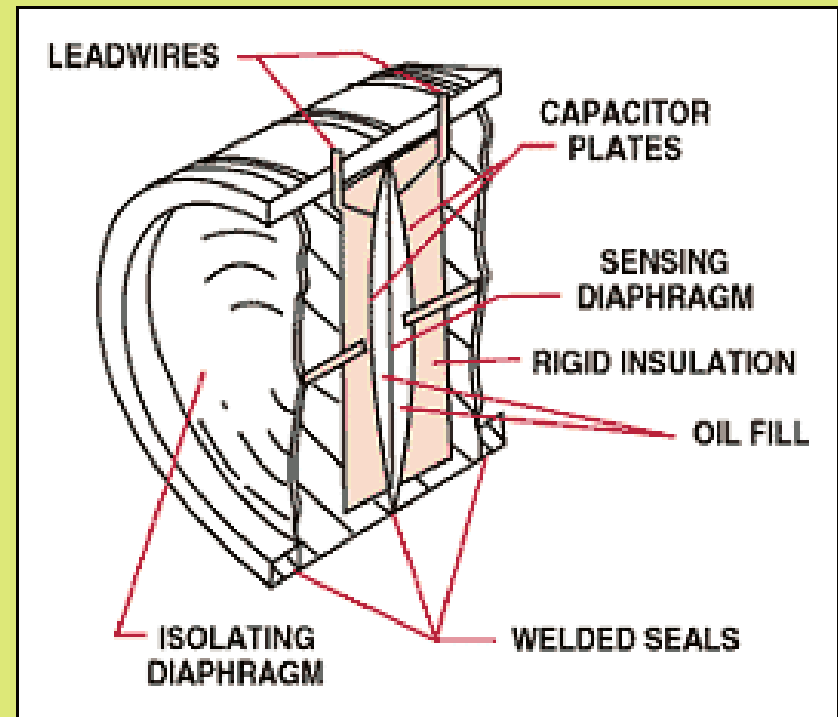


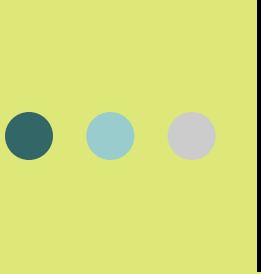
Inductive

- These require an AC voltage supply and return two AC signals, the amplitude difference of which determines the value.
- Generally fairly expensive and the electronics are expensive
- Very good linearity
- Very good on Hysteresis
- Good for signals $< 20\text{Hz}$ (limiting factor is the electronics, not the transducer)

Capacitive

- Usually incorporate a thin diaphragm as one plate of a capacitor.
- Applied pressure deforms the diaphragm, changing the capacitance.



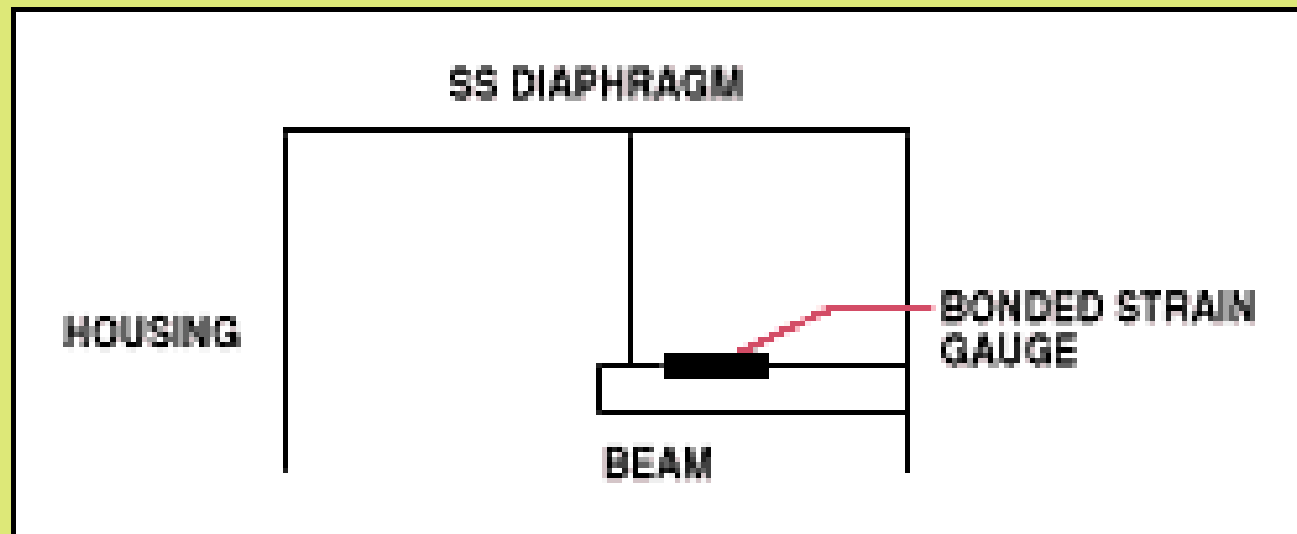


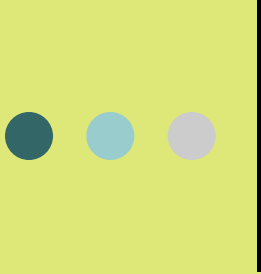
Capacitance

- The capacitance can be used to vary the coupling of an ac signal source or to control the frequency of an oscillator circuit.
- Very non-linear
- Signal conditioning must be VERY close to the transducer to minimize external and cable capacitance effects.
- Transducers are inexpensive, but electronics are expensive.
- Good for moderately high speed measurements <100 Hz. Limiting factor is the electronics.

Strain gage transducer

- Uses a thin diaphragm and measures the deformation of the diaphragm due to pressure.



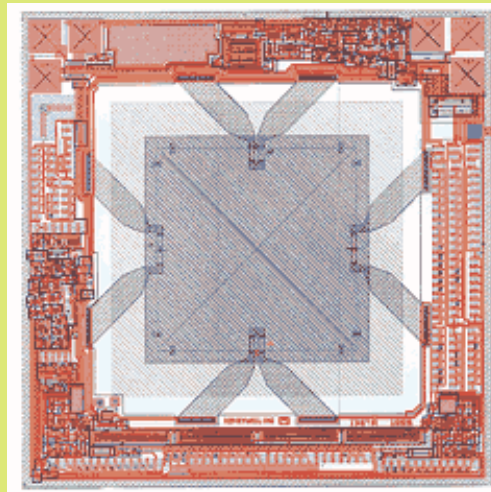


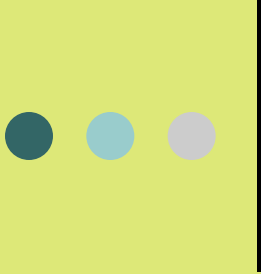
Strain Gage

- Can have a lot of different internal configurations
- Very good accuracy, linearity and Hysteresis.
- Electronics are more expensive
- Originals were 120 ohm resistance bridges
- Very small outputs meant expensive electronics
- Now use gages up into the 5K range to boost the output ratio (mv / v)
- can be read with low voltage meters directly and don't require bridge circuits.
- Accuracy is VERY dependent on the stability of the power supply

Piezoresistive

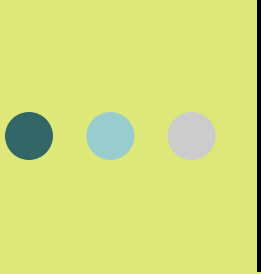
- Uses a piezoresistive strain bridge formed on a silicon wafer.
- The silicon MAY be the actual diaphragm, but does not have to be.





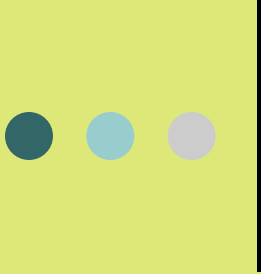
Piezoresistive

- Frequently these have the amplifier built into the circuit to generate a voltage output.
- Very inexpensive
- Very small
- Built in electronics mean less susceptible to power supply issues than standard gage types.



Dynamic Transducer

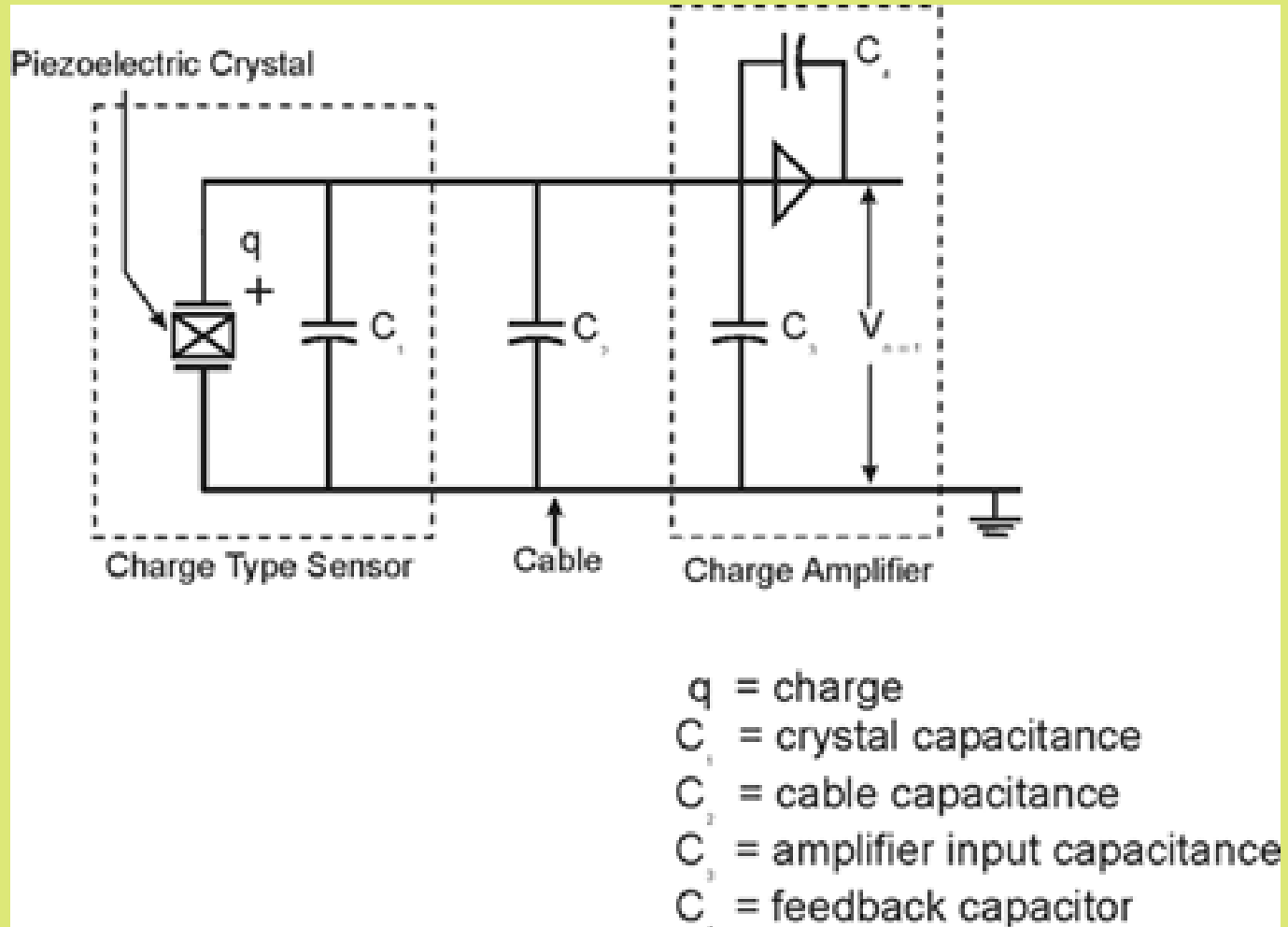
- Currently only one technology that requires a dynamic signal
- Piezoelectric
- Its unique advantage is that it can be extremely fast!
 - Blast studies
 - Engine combustion
 - Shock wave measurements



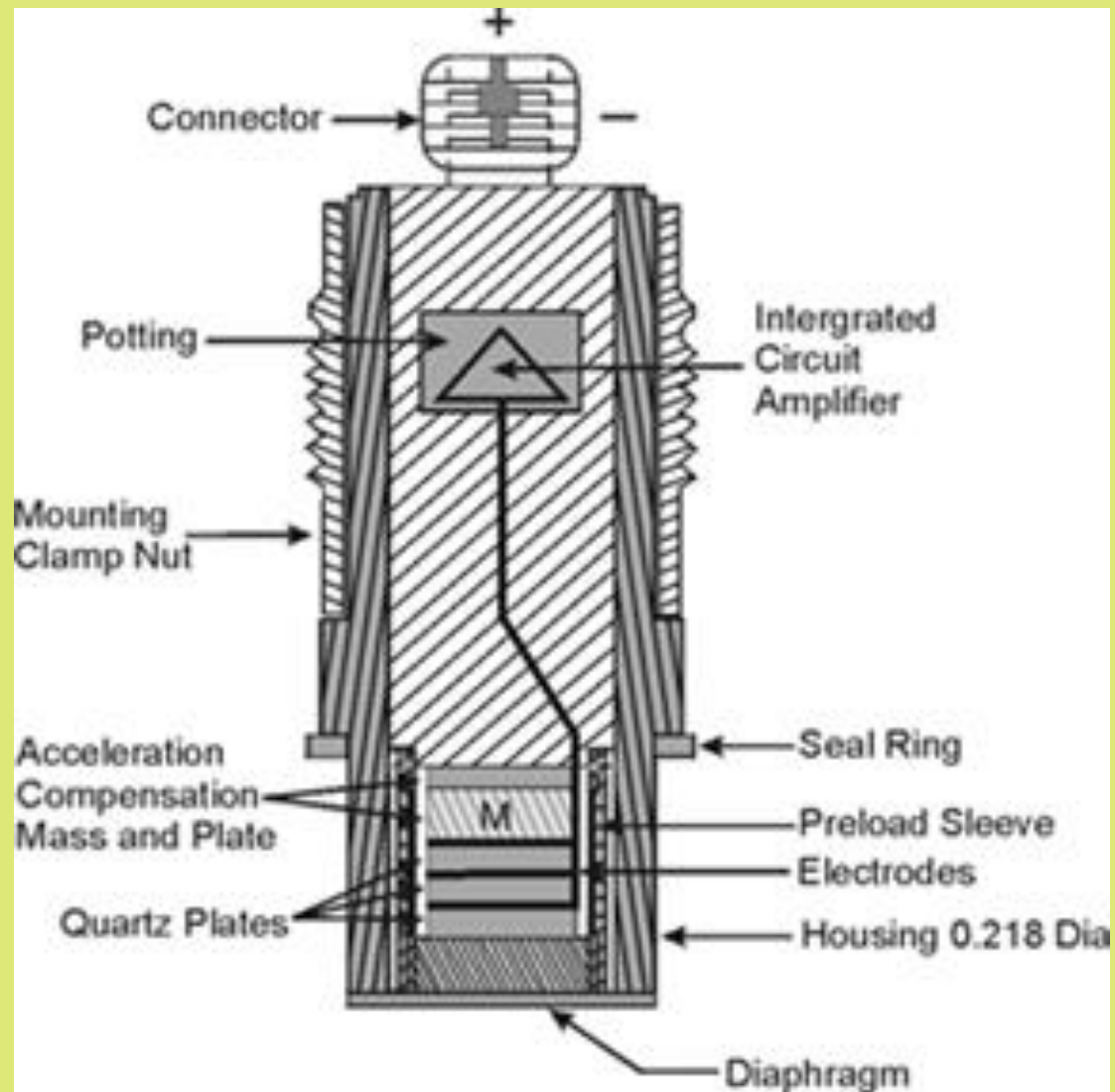
Piezoelectric

- Consist of a quartz element attached to a diaphragm
- Pressure on the quartz element changes the amount of charge it generates.
- Charge bleeds off quickly, so a static reading changes back to zero quickly.
- Good for high speed pressure fluctuations
- Minimum speed based on specific transducer “bleed off time”.
- Maximum speeds as fast as 1 microsecond
- Responds to any “stress” on the crystal
- High speed temperature changes cause a temperature differential across the crystal,

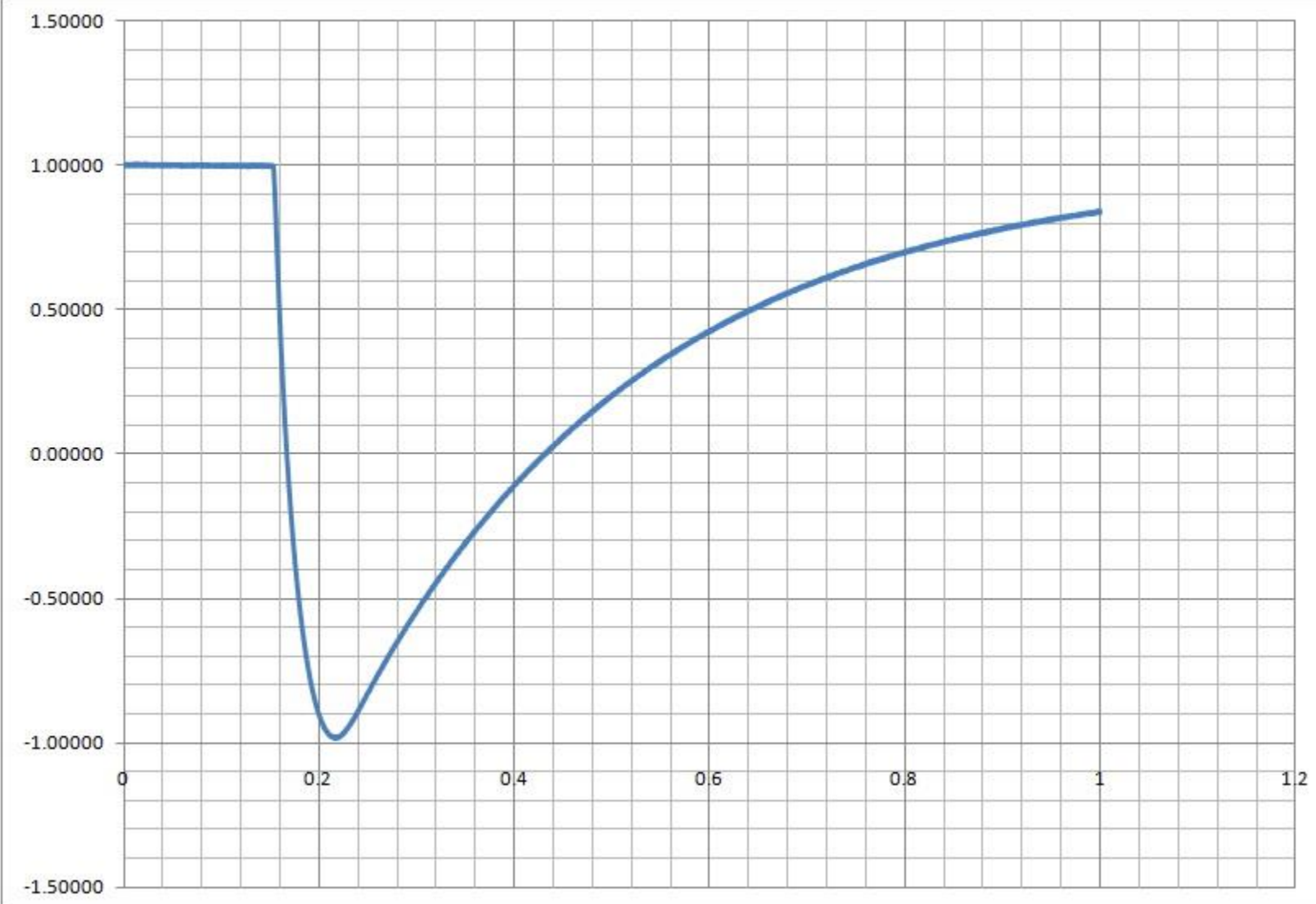
Piezoelectric

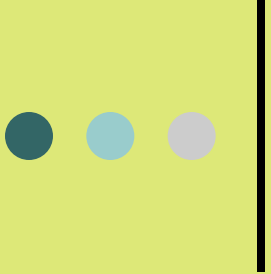


Piezoelectric



Typical transducer output.





Special Purpose transducers

- Acoustic

- Measure the pressure of sound waves
 - Dynamic
 - Carbon
 - Ribbon
 - Condenser
 - Quartz

Special purpose transducers

- Blast wave transducers

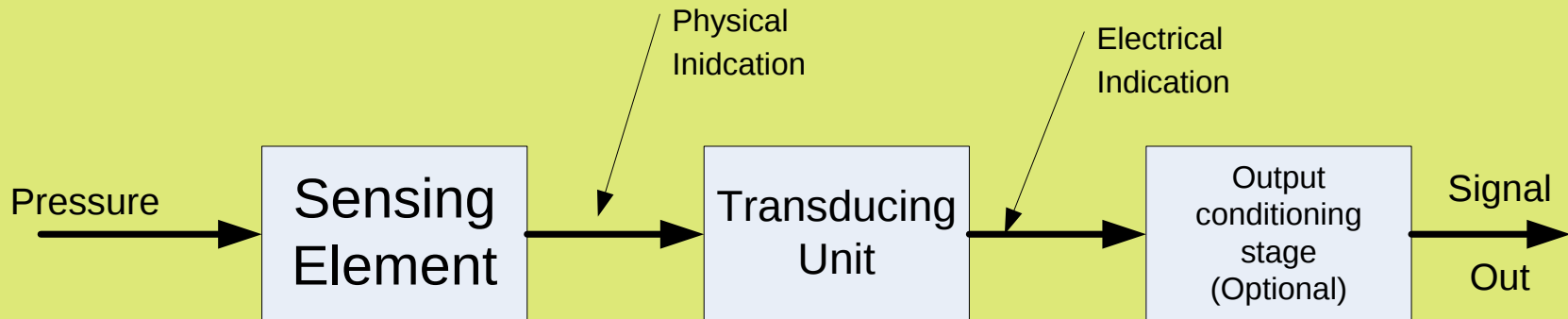
- Barometric Pressure

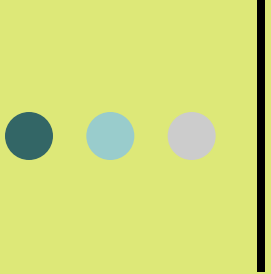
- Altimeters
- Barometers



Transducers

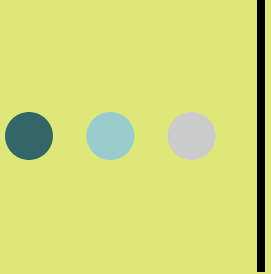
- Now for the third part!
- Conditions the output of the transducing unit into some appropriate signal





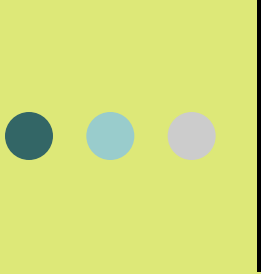
Output types

- Voltage
- Millivolts
- Current
 - 0-20 ma
 - 4-20 ma
- Frequency
 - Square wave
 - Sine wave
- Charge



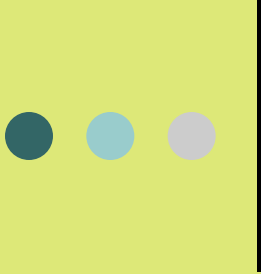
Voltage output

- Typically low voltage
 - +/- 5, +/- 10, 0-5 or 0-10
- True analog moves the granularity of the resolution to the acquisition system
- Digital to analog conversion retains granularity at the transducer
- Poor in noisy environments
- Easy to use, directly plugs into most DAQ systems



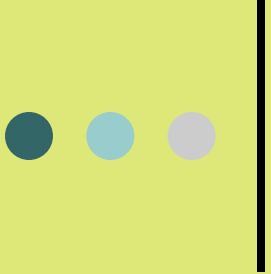
Millivolts

- Typically only good for short distances to the DAQ system
- Requires higher end DAQ
- Generally requires less internal electronics in the transducer
- **NOISE** is an issue!!!



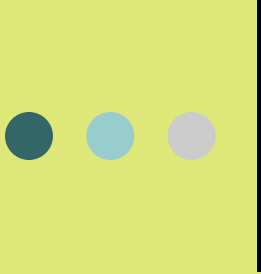
Current output

- 0-20ma and 4-20ma
- Good for long distances because the transmission line resistance is not a factor.
- Requires some conversion to voltage at the DAQ (some newer DAQ boards have this as an option!)
- ***Relatively noise immune!***



Frequency out

- For special cases only
- Requires totally different approach to DAQ.

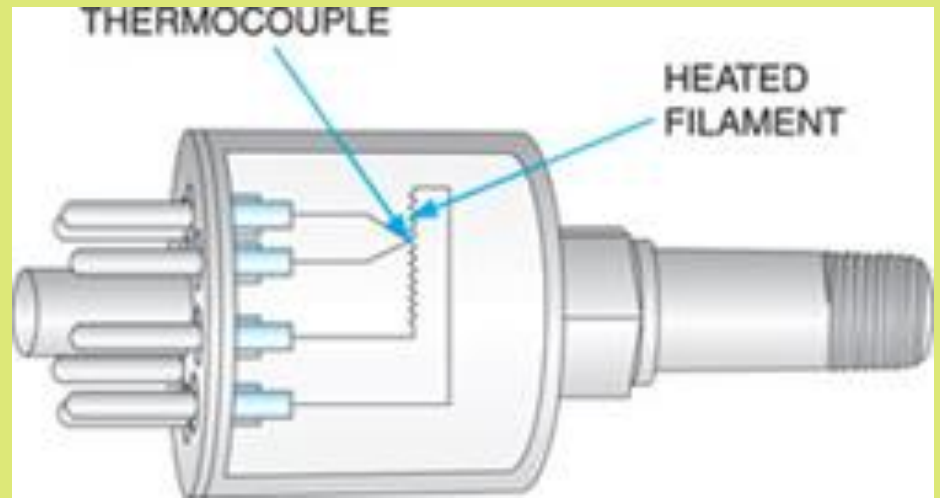


Ultra Low Pressure (High Vacuum)

- Ionization
- Thermal Conductivity

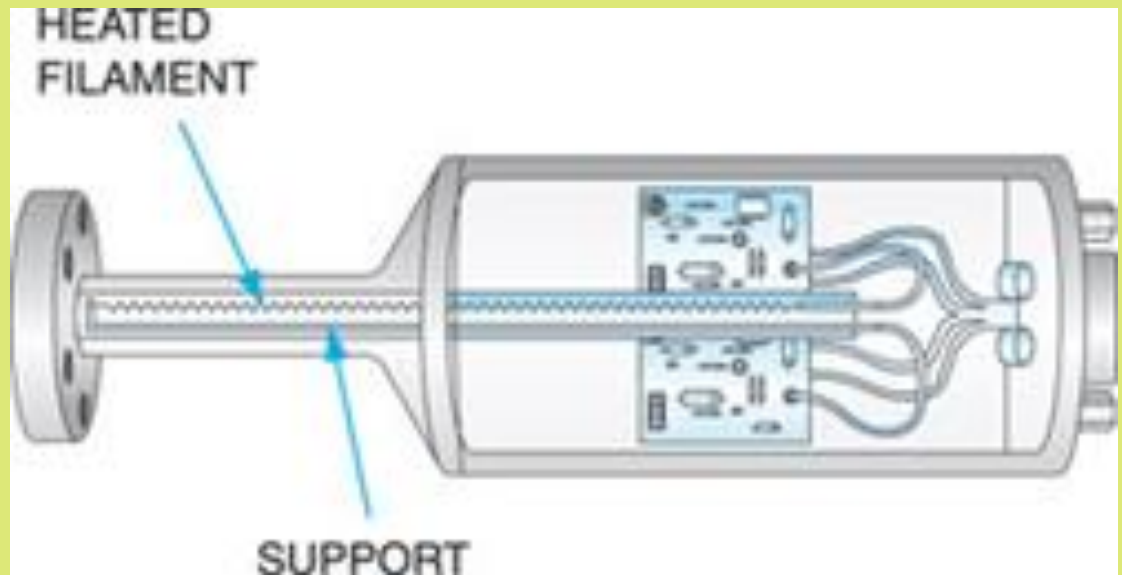
Thermal Conductivity

- Thermocouple gauge
- Good from 10 Torr to 1×10^{-3} Torr
- Constant current heated filament. Temperature controlled by energy extracted by gas.



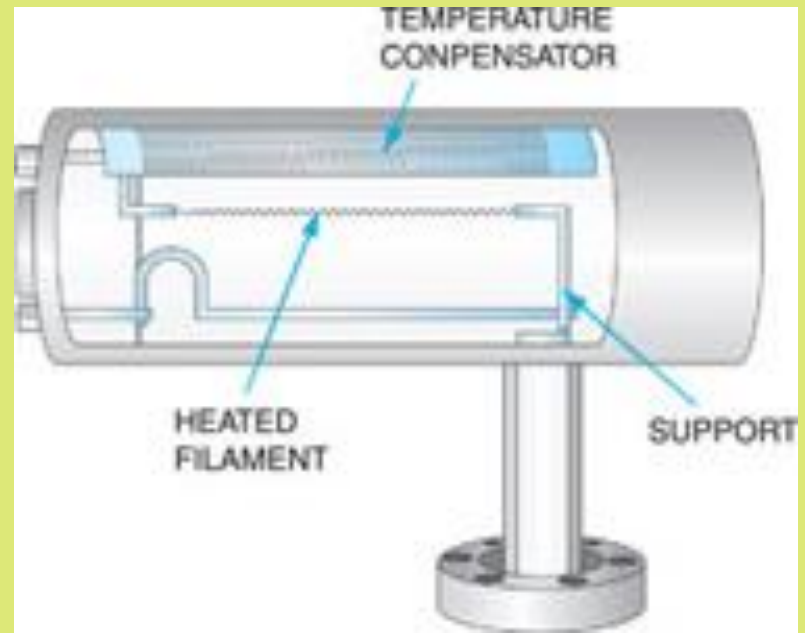
Thermal Conductivity

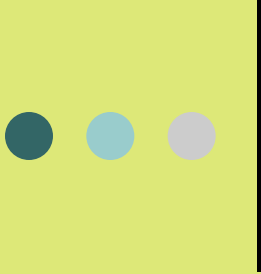
- “Pirani Gauge” (Invented in 1906)
- Good from .5 Torr to 1×10^{-5} Torr
- Uses 2 filaments, one in the unknown and one in the known pressure. Controls the current through the bridge to maintain constant filament temperature.



Thermal Conductivity

- Convection gauge
- Good from Atmospheric to 10 Torr
 - This gauge's mechanism differs from that used in the T/C and Pirani gauges only by using a structure that enables the natural convection in (viscous flow) gases to aid in removing heat from the hot filament.



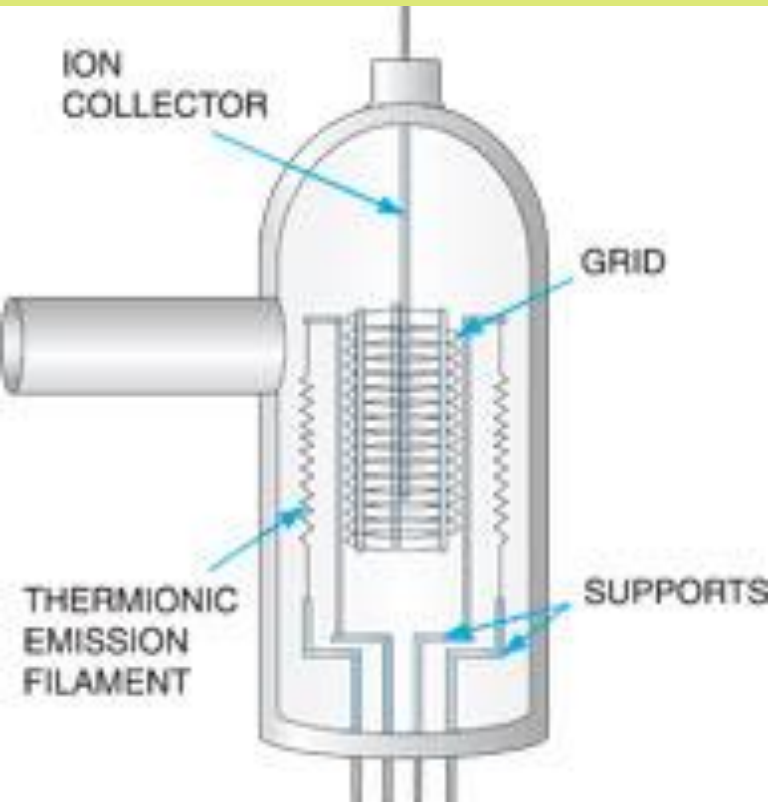


Ionization

○ Hot filament

- The two common hot filament ion gauges, **Bayard/Alpert (B-A)** and **Schulz-Phelps (S-P)**, differ only in the physical size and spacing of their electrodes.
 - Heated filaments biased to give thermionic electrons 70eV.
 - Electrons ionize any residual gas molecules with which they collide.
 - The positive ions formed move to an ion collector held at -150V.
 - The current varies with the gas number density (**the number of molecules in each cc**), which is a direct measure of gas pressure

Ionization

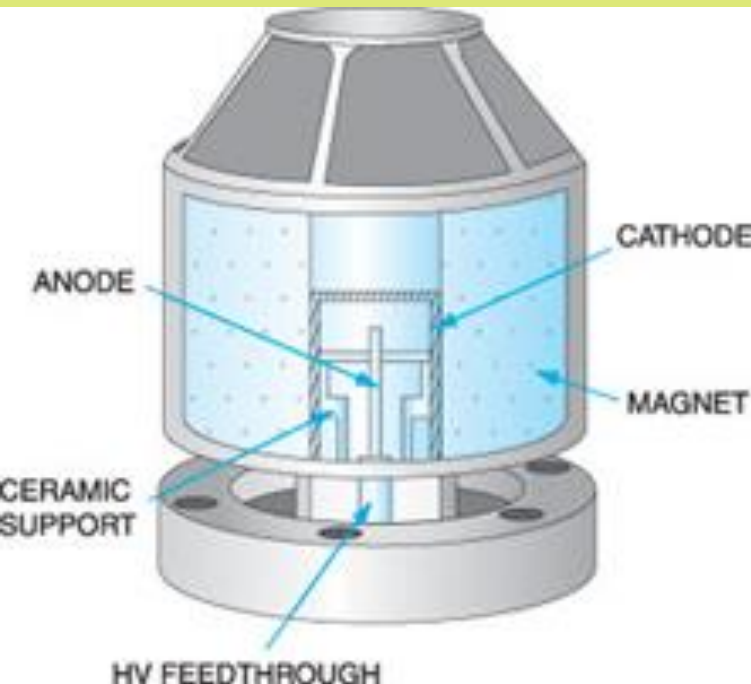


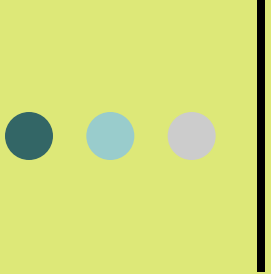
- **Bayard-Alpert (B-A) Ion Gauge**
- Linear response from 1×10^{-4} to 1×10^{-9} Torr (works to 5 Torr)
- Filament gauge using thoria-coated iridium or tungsten

Ionization

○ Cold Cathode

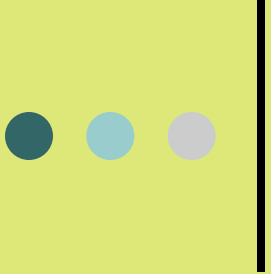
In the CCGs the ionizing electrons are part of a self-sustaining discharge. However, since the CCG has no (thermionic emission) hot filament, the discharge is initiated by stray field emission or external events (cosmic rays or radioactive decay). At low pressures, this can take minutes and CCGs are usually switched on at high pressure. Once started, the gauge's magnetic field constrain the electrons in helical paths, giving them long path lengths and a high probability of ionizing the residual gas. The ions are collected and measured to determine the gas pressure





Ionization (continued)

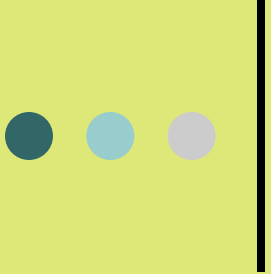
- Magnetron (Penning)
 - The actual Penning design has been replaced by better designs, but most are still called Penning if they have a central wire or ring cathodes.
 - Limited use because they are limited to the top of the high vacuum range and get little commercial attention



Ionization (continued)

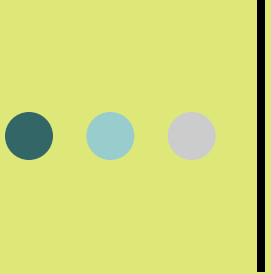
○ Inverted Magnetron

- This design works into the Ultra high vacuum range (1×10^{-11} Torr)
- Its axial central anode enters the cylinder/end plates cathode through voltage guard rings (to prevent field emission affecting the ion current measurement). The anode carries a much higher potential than the normal magnetron ($\sim 6\text{kV}$) and is parallel to the gauge's magnetic field.
- They can take days or hours to start at low pressures.



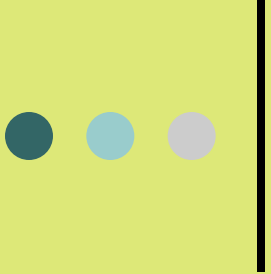
Time to shift thinking

- Transducer vs Switch



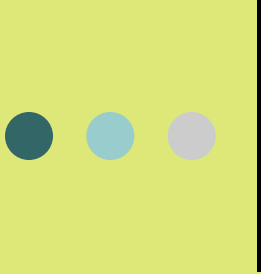
Residual Gas Analyzers

- Special mass spectrometers designed to analyze gases remaining in a vacuum chamber are called residual gas analyzers or RGAs. The wealth of information about experimental or process conditions offered by an RGA makes a permanently attached unit a convenient, often necessary, diagnostic device.



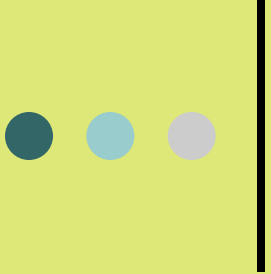
Switches

- On/Off function only
 - No analog output
- Generally use simple diaphragm and switch arrangement
- Newer electronic units work the same way as transducer with an electronic comparator switch



Switches

- Some models are adjustable
- Some are fixed.
- Switches are **CHEAP** compared to a transducer and electronics!!!



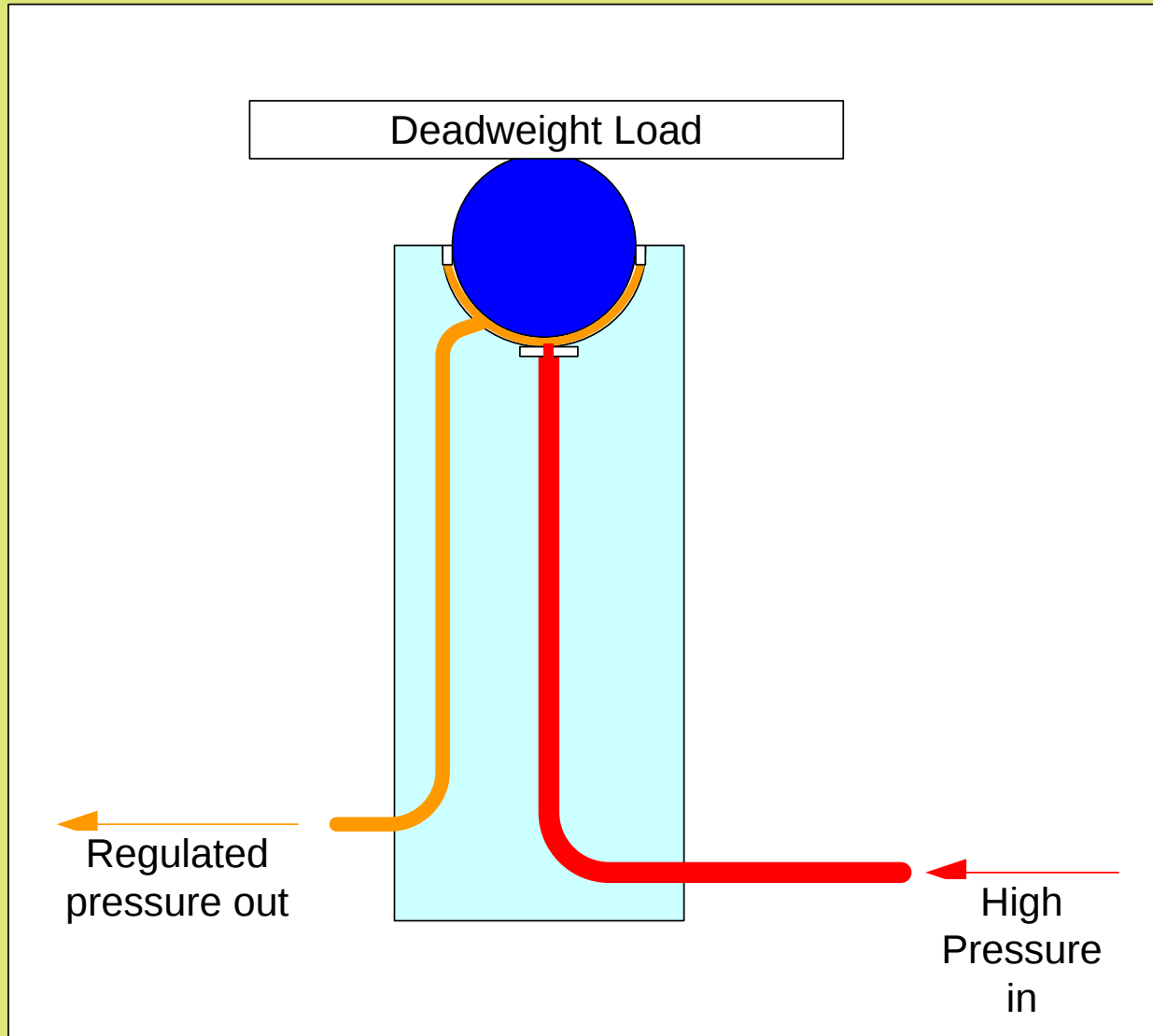
Calibrators

- Dead weight most common method
- Air or hydraulic.

● ● ● | Air deadweight calibrator



Deadweight tester



Hydraulic deadweight tester



Pressure Control systems



Valves

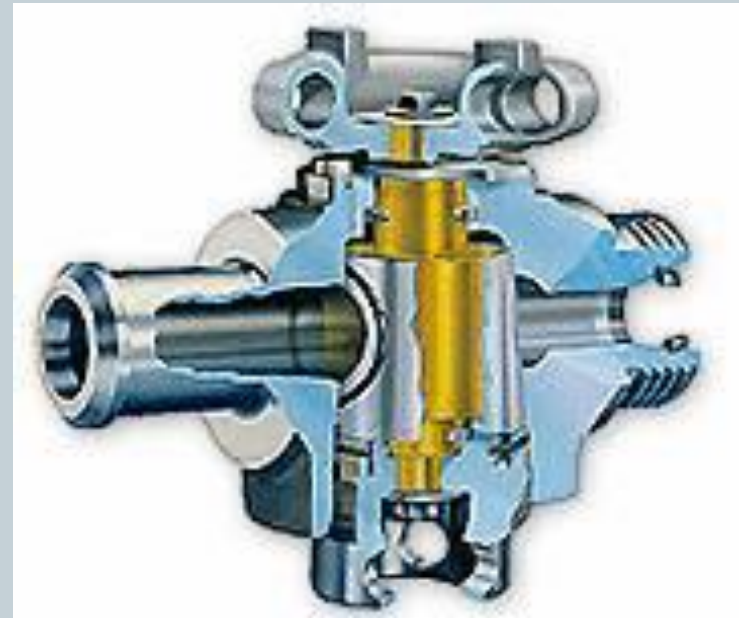


- Shutoff valves
 - One way or multi-way
 - ✦ Ball Valves
 - ✦ Plug valves
 - One way only (on / off)
 - ✦ Butterfly valves
 - ✦ Gate valves

Ball and plug Valves

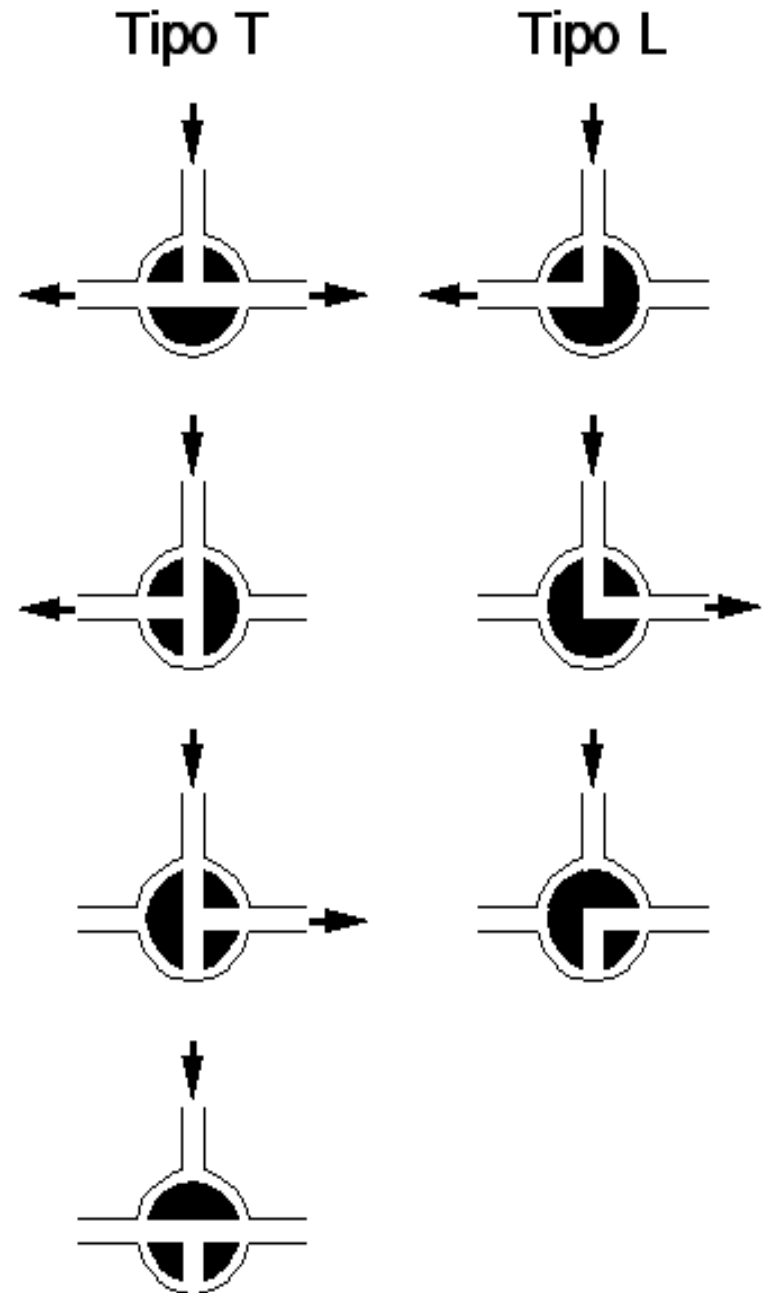


- Ball valves are a round ball with a hole through it
- Plug valve is a cylinder with a hole through it



Multi way

- Number of configurations
- All work as selectors for multiple ports



Butterfly valve



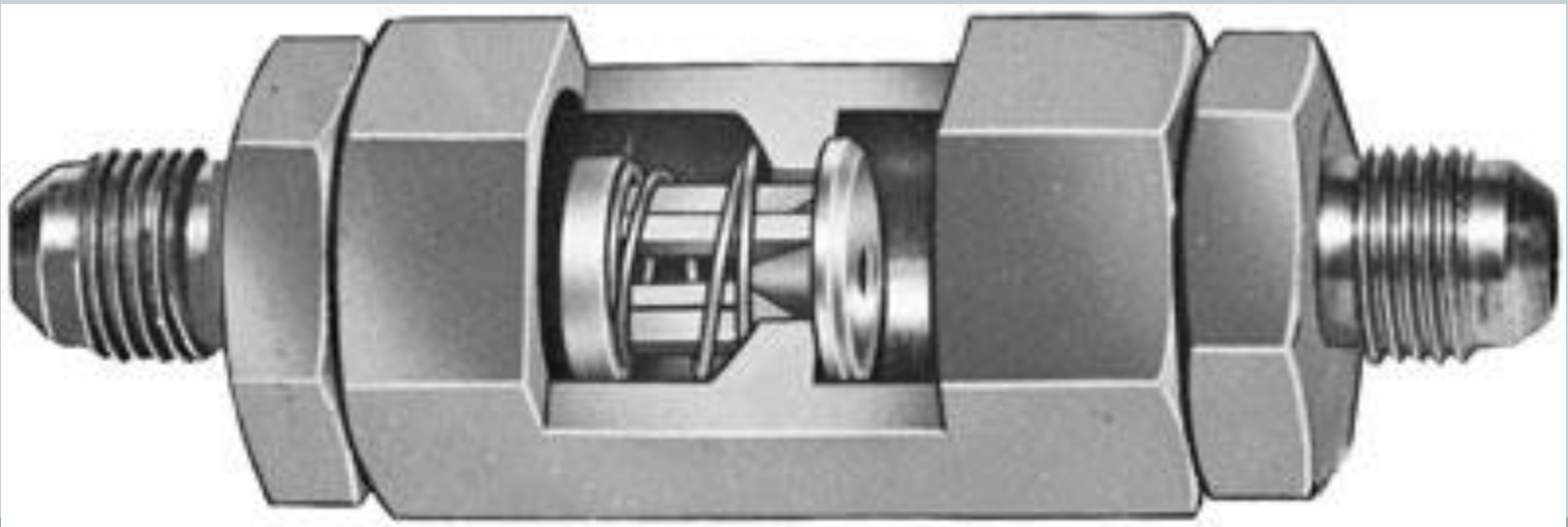
Gate valve



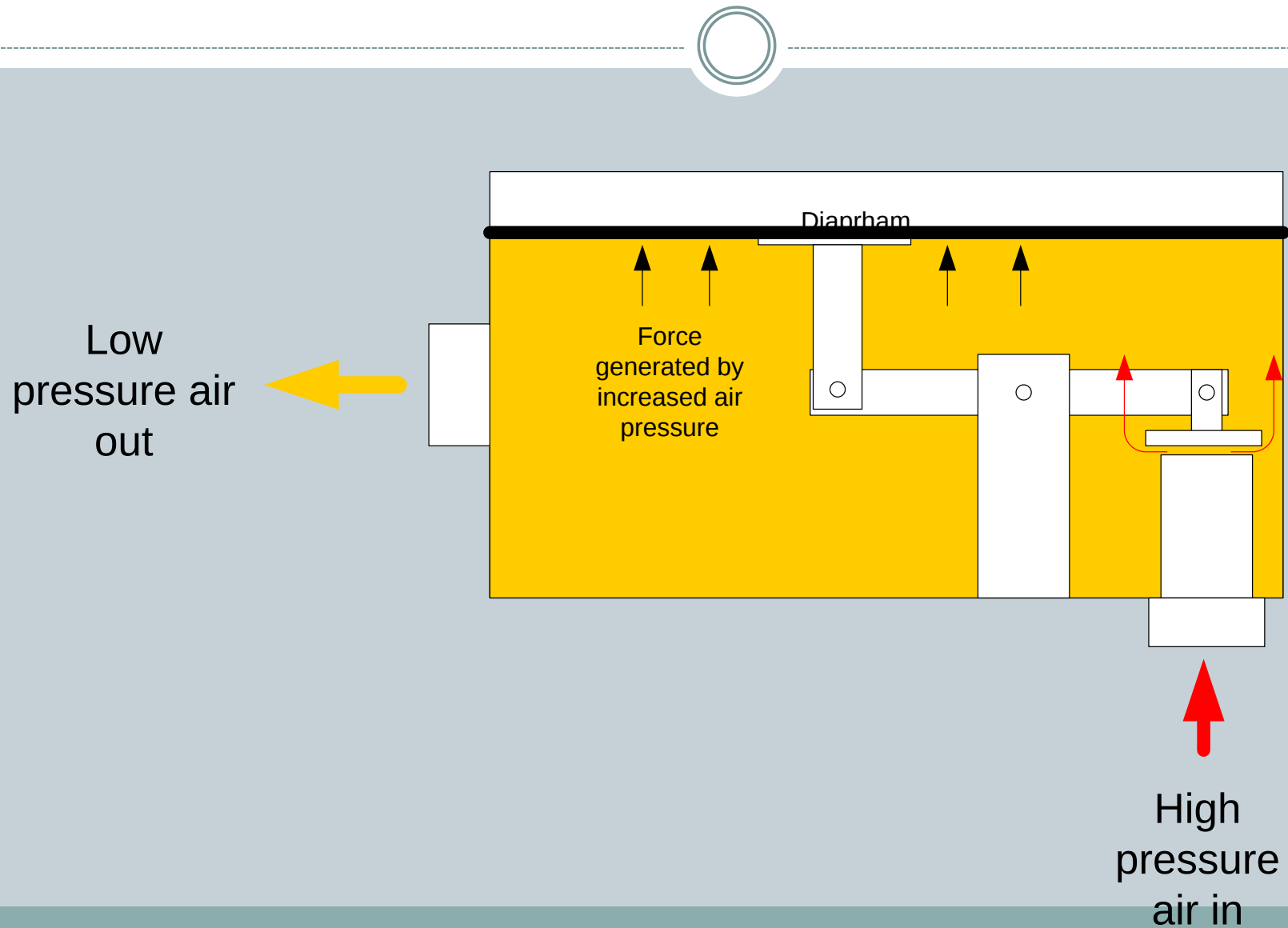
Check valve



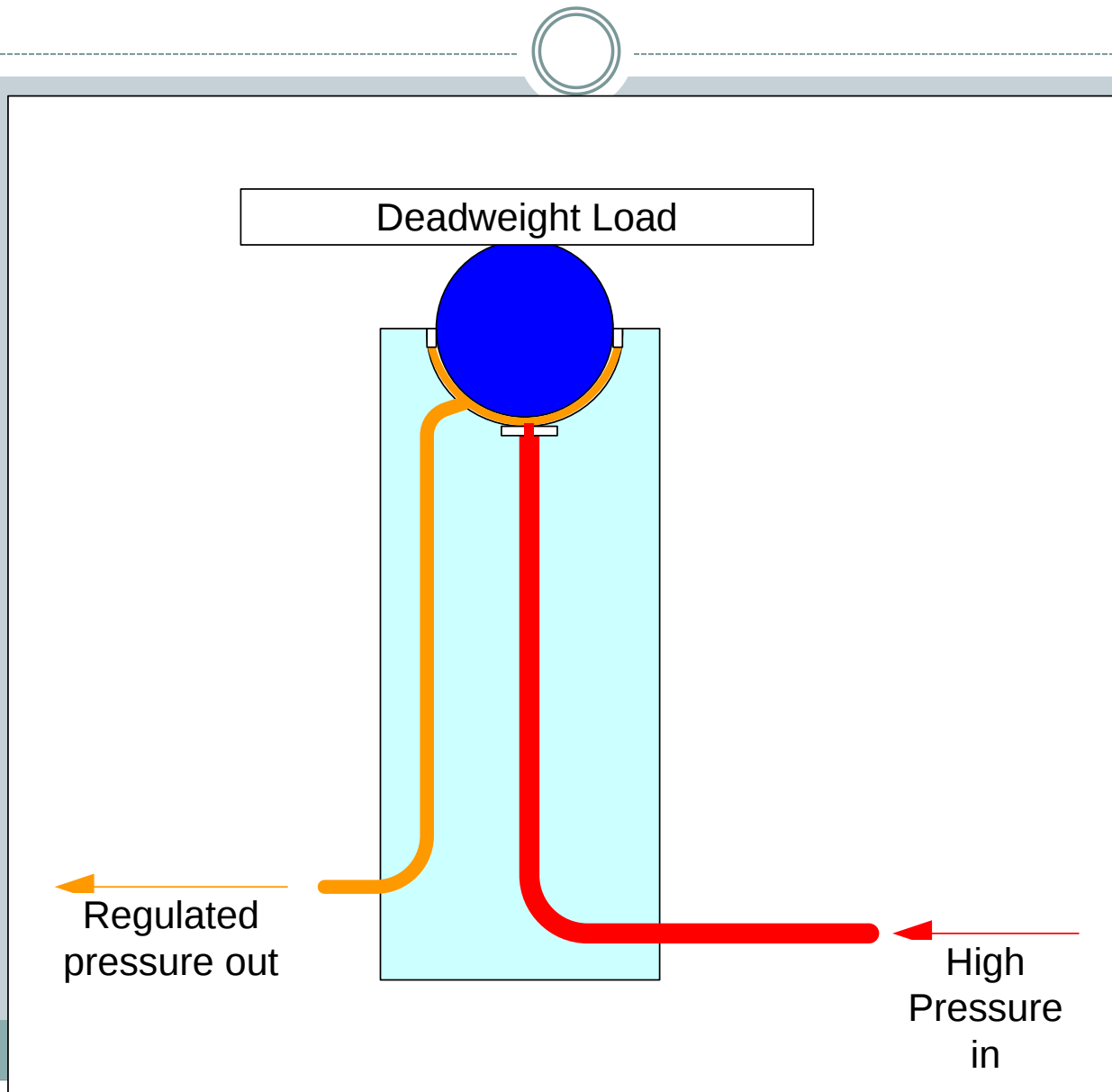
- Flow in only one direction
- “cracking” pressure adjustable with spring force



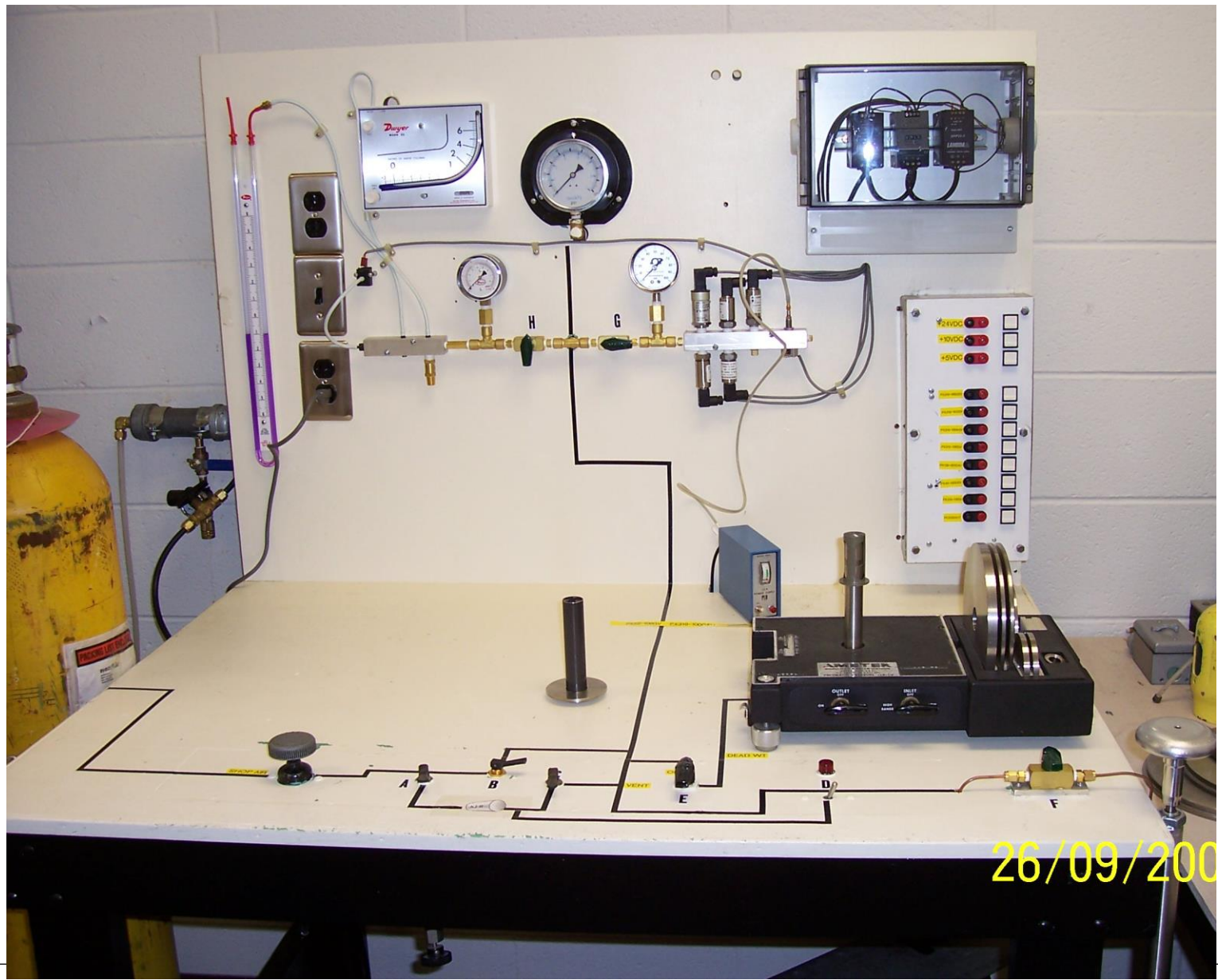
Pressure Regulator



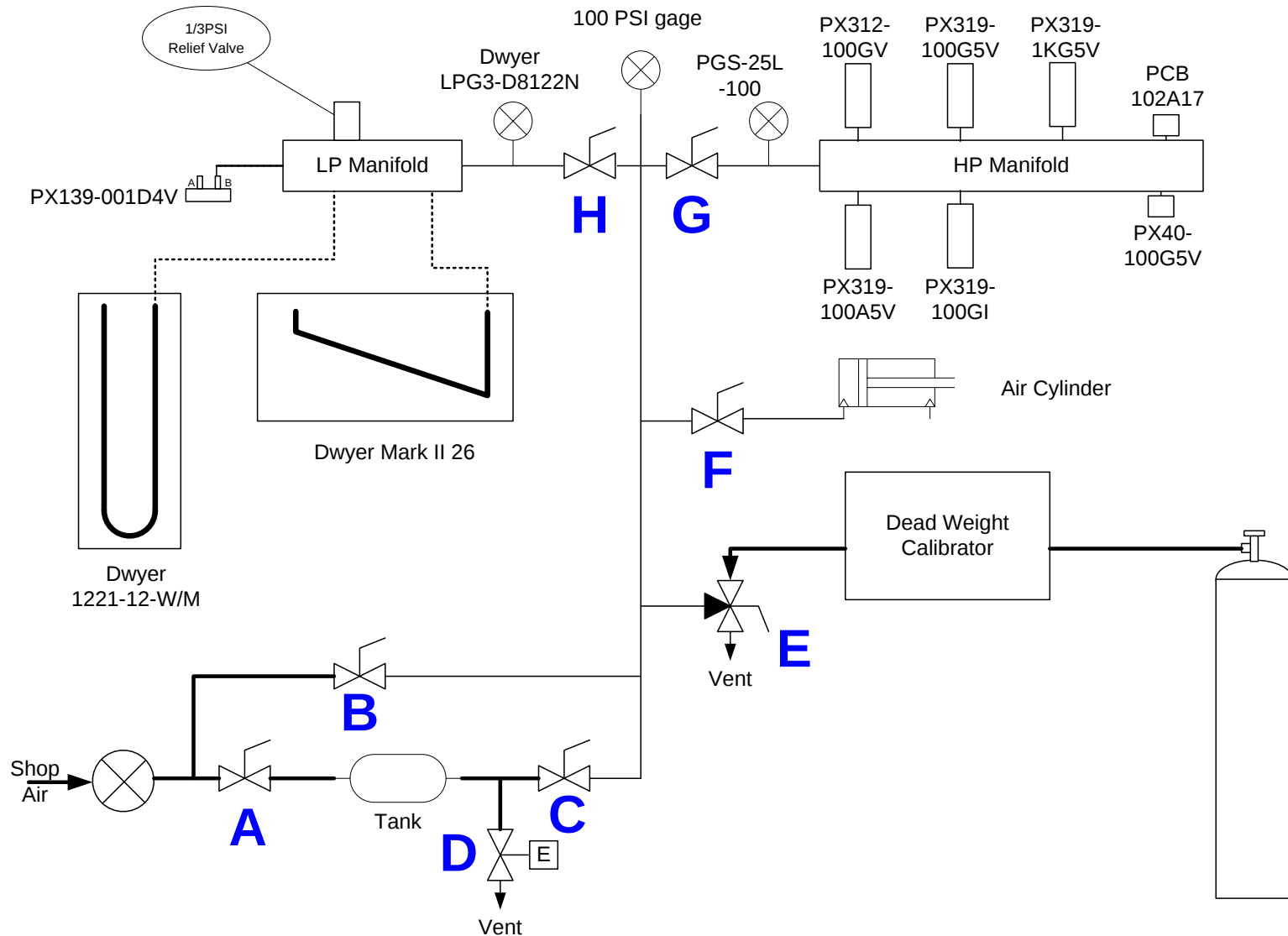
Deadweight tester



Pressure test bench



Bench Plumbing



Dead weight calibrator Carrier

