TPE 4263

TEKNIK PENGUKURAN DAN PENGENDALIAN BIOPROSES

YUSRON SUGIARTO

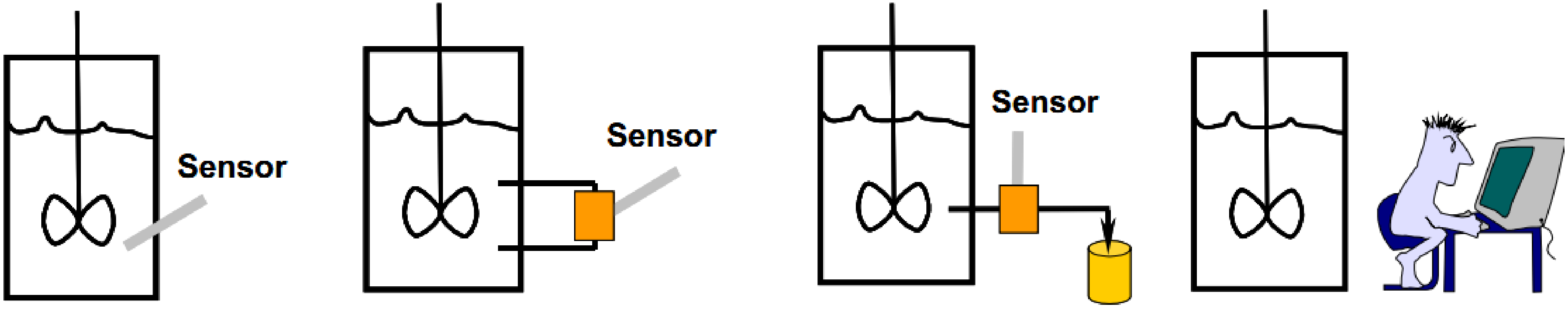
KULIAH 3

MATERI KULIAH

No	TIK	Pokok Bahasan	Sub Pokok Bahasan	Waktu (menit)
1.	Memahami dasar teknik pengukuran dan pengendalian bioproses	Pengantar		2x50
2.	Memahami karakteristik bioreaktor dan variabel pengukuran	- Bioreaktor - Bagian-bagian - Variabel yang diukur		2x50
3.	Memahami pengukuran variabel lingkungan fisik	Pengukuran variabel lingkungan fisik	• Temperatur • Tekanan	2x50
4.	Memahami pengukuran variabel lingkungan fisik (2)	Pengukuran variabel lingkungan fisik (2)	• Laju alir (gas dan cairan) • Kekeruhan • viskositas	2x50
5.	Memahami pengukuran variabel lingkungan kimia	Pengukuran variabel lingkungan kimia	• pH • Oksigen terlarut • Karbondioksida terlarut	2x50
6.	Memahami pengukuran variabel lingkungan kimia (2)	Pengukuran variabel lingkungan kimia (2)		2x50
7.	Memahami pengukuran Cell Mass	Pengukuran Cell Mass		2x50

PHYSIC MEASUREMENT

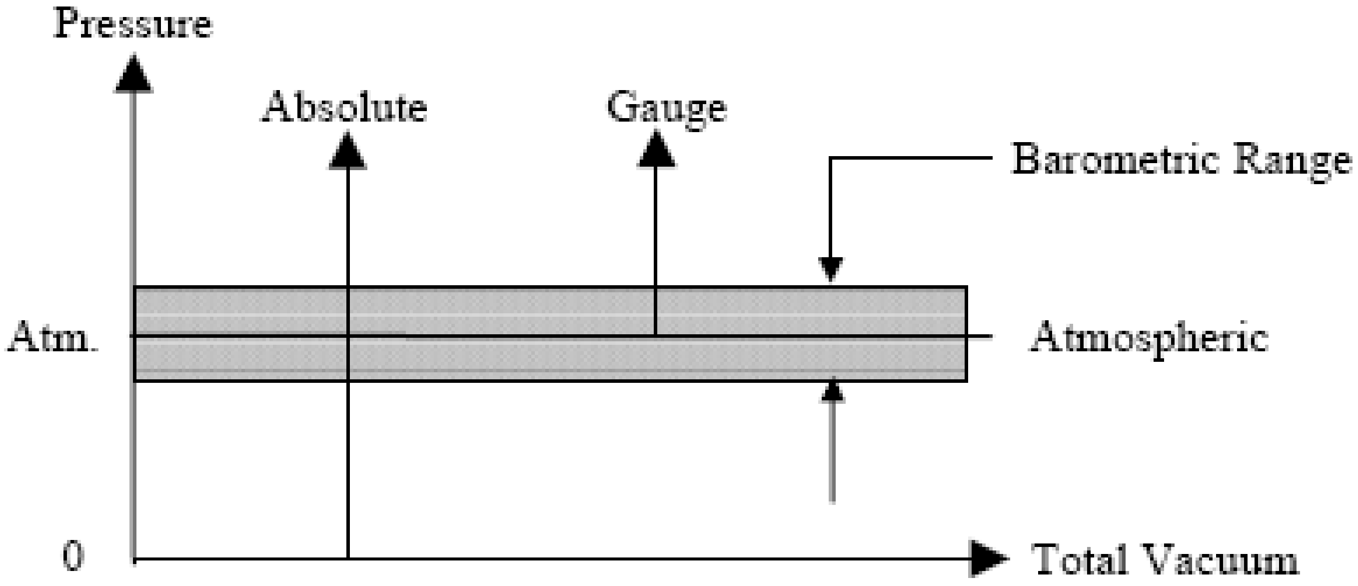
DIFFERENT BIOPROCESS MONITORING METHODS



in situ　*in situ - bypass*　*ex situ*　*off-line*

PRESSURE MEASUREMENT

Definition Of Pressure



Definition Of Pressure

Absolute pressure
The pressure is referenced to zero absolute pressure and has units of psia. Absolute pressure can only have a positive value.

Gauge pressure
The pressure is referenced to atmospheric pressure and by convention is measured in the positive direction, i.e. 7 psig.

Vacuum pressure
The pressure is referenced to atmospheric pressure and by convention is measured in the negative direction, i.e. -50 mm Hg.

Overview

Pressure (P) expresses the magnitude of normal force (F-N) per unit area (A-m^{2}) applied on a surface(Crowe et al. 2005)

$$P = \frac{F}{A} \quad or \quad P = \frac{\Delta F}{\Delta A}$$

Units: Pa(= N/m$^{2)}$, psi(=lbf/in^{2}), bar (=10^{5} Pa=100 kPa), mbar (=100 Pa=1 hPa), atm (=101.3 kPa), mmHg (or Torr), inHg, etc.

Note: For every Unit: hUnit=hectoUnit=100 Unit

$$P_{abs} = P_{atm} + P_{gage}$$

Where P_{abs} : Absolute pressure

P_{atm} : Atmospheric pressure

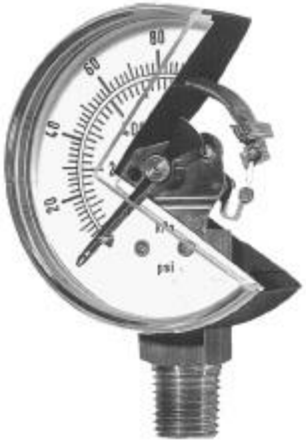
(standard is: 101.3 kPa =14.696 psi=760 mmHg=29.92 inHg)

P_{gage} : Gage pressure

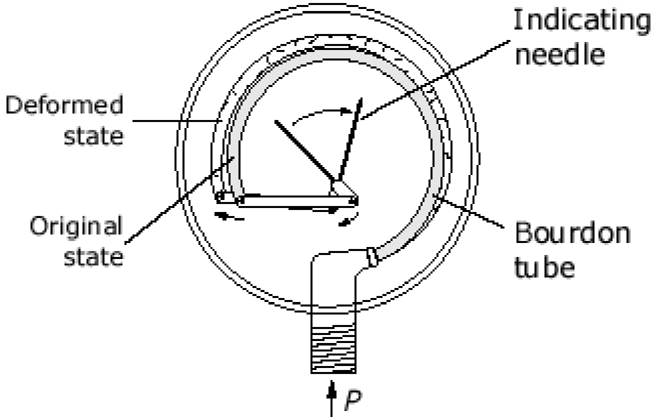
Pressure Measuring Devices

Bourdon Gages

http://www.cpigauges.com/images/gauges/WeldGageStlCsBM400psi.jpg



http://www.hydraulicspneumatics.com/FPE/images/sensors1_1.jpg



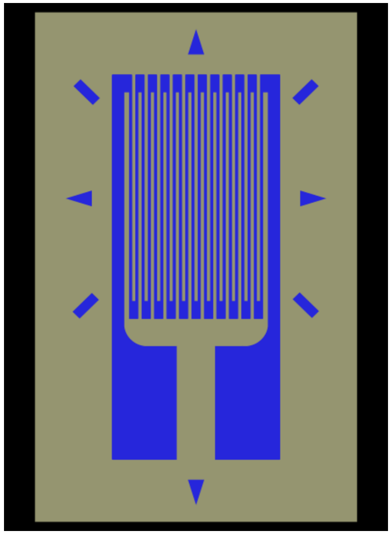
http://www.efunda.com/DesignStandards/sensors/bourdon_tubes/images/Bourdon_tube_A.gif

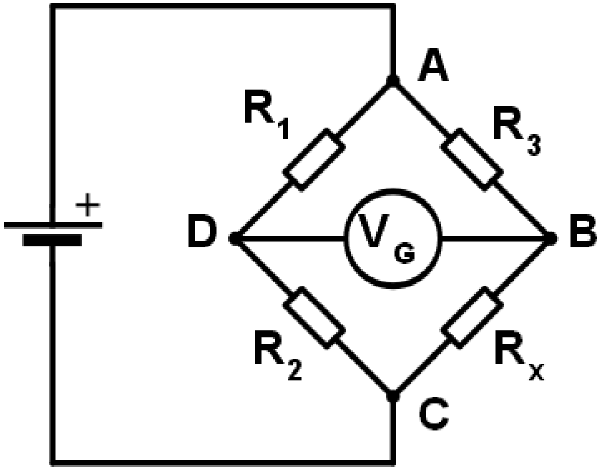
Principles: change in curvature of the tube is proportional to difference of pressure inside from that outside the tube

Applications: tire pressure, pressure at the top or along the walls of tanks or vessels

Pressure Measuring Devices

Strain Gage



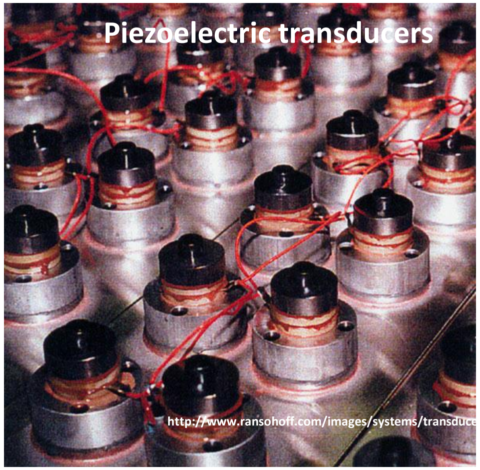


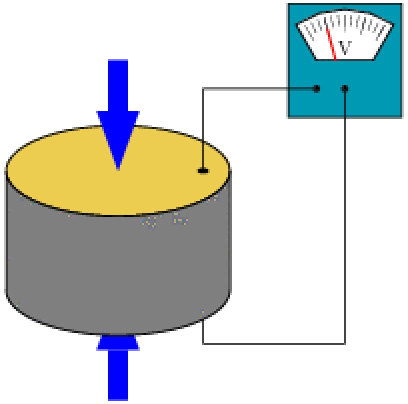
Principles: Δ P → Δ Resistance → Δ Voltage

Applications: Sensors for internal combustion engines, automotive, research etc.

Pressure Measuring Devices

Quartz Gage


Piezoelectric transducers
http://www.ransohoff.com/images/systems/transduce



http://upload.wikimedia.org/wikipedia/commons/c/c4/SchemaPiezo.gif

Principles: Δ Pressure → Δ Charge → Δ Voltage

Applications: measurements with high accuracy, good repeatability, high resolution.
e g. Quartz Clock

Pressure Measuring Devices

Piezoresistive Gage

Digital Manometer

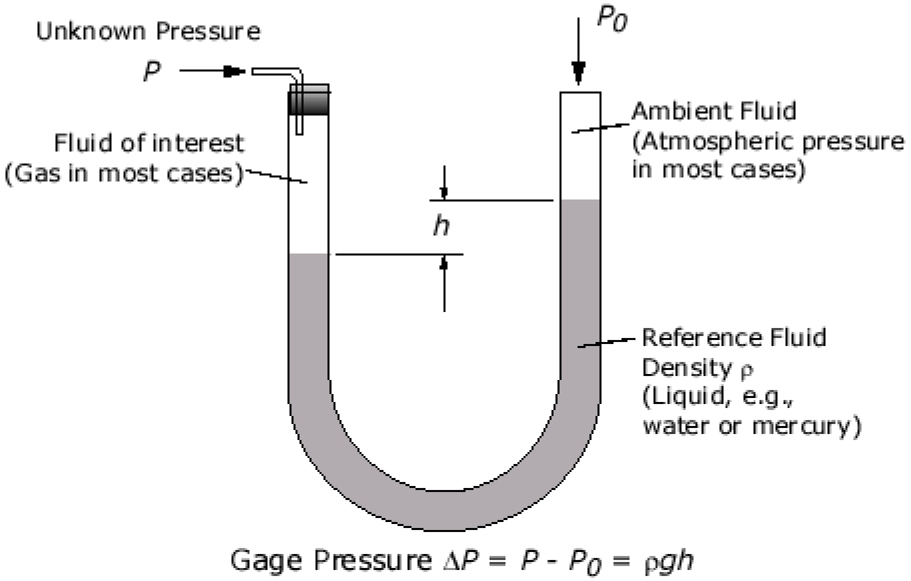
Principles: ΔPressure = ΔCharge = ΔResistance = ΔVoltage

Applications: Very accurate for small pressure differentials

e.g. Difference between indoor and outdoor pressure

Pressure Measuring Devices

U-tube Manometer



http://www.efunda.com/formulae/fluids/images/Manometer_A.gif

Principles: Hydrostatic Law

$$\Delta P=\rho\ g\ h$$

Pressure Measuring Devices

U-tube Manometer

http://www.armfield.co.uk/images/H12.gif

Mercury Water Manometer

http://hyperphysics.phy-astr.gsu.edu/Hbase/fluids/flupic/bern5.jpg

Air Water Manometer

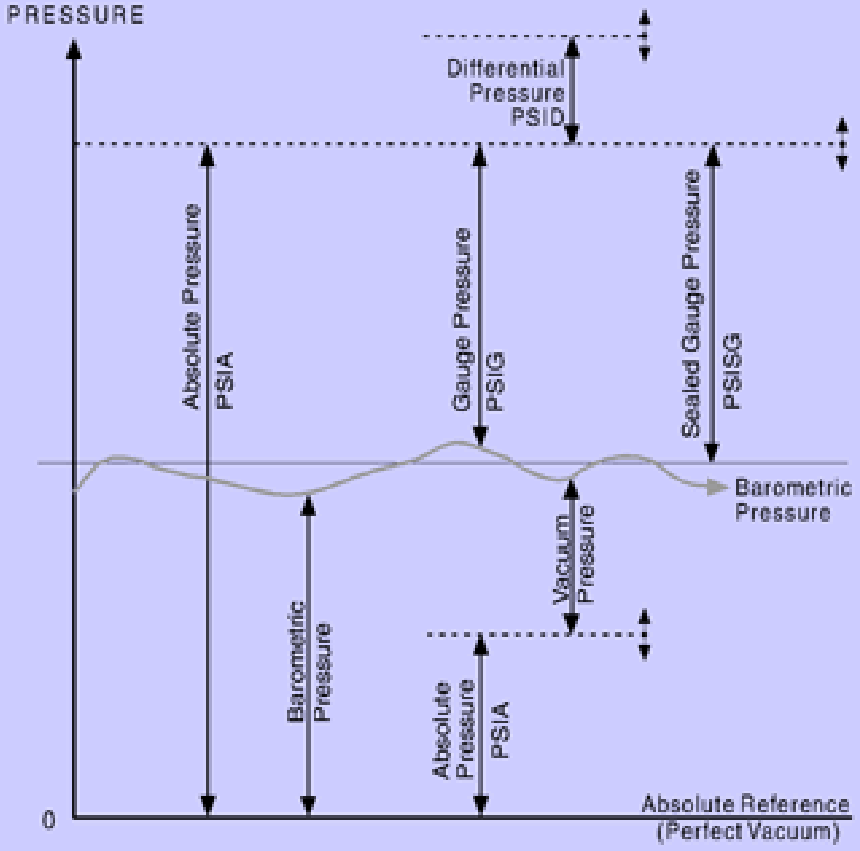
Applications: air pressure, pipe pressure, etc.

Standard Atmospheric Pressure

* *Standard Atmospheric Pressure:*

- *Zero ft altitude*
- *14.69595 psiA*
- *29.9213 in.HgA @ 0°C*
- *1013.250 millibars*
- *760.002 mmHgA*
- *760.002 torr*
- *101.325 kilopascals*
- *33.9596 ft.H_2O @ 20°C*

* *Values are approximate. Refer to Pressure Conversion Tables in the Appendix.*



Pressure Measurement

A number of *measurement units* are used for pressure. They are as follows:

1. Pounds per square foot (psf) or pounds per square inch (psi)
2. Atmospheres (atm)
3. Pascals (N/m^2) or kilopascal (1000Pa)*
4. Torr = 1 mm mercury
5. Bar (1.013 atm) = 100 kPa
6. 14.696 lbf/in2 equals 33.9 feet of H2O
7. 14.696 lbf/in2 equals 29.921 inches of of Hg

Pressure Units

- As previously noted, pressure is force per unit area and historically a great variety of units have been used, depending on their suitability for the application.

- For example, blood pressure is usually measured in mmHg because mercury manometers were used originally.

- Atmospheric pressure is usually expressed in in mmHg for the same reason.

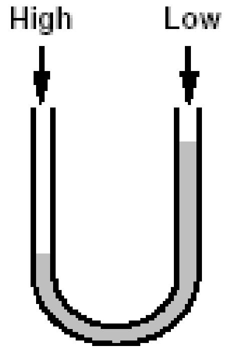
- Other units used for atmospheric pressure are bar and atm.

Pressure Units

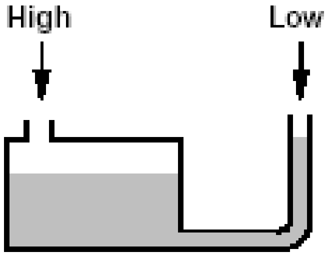
The following conversion factors should help in dealing with the various units:

1 psi= 51.714 mmHg
= 2.0359 in.Hg
= 27.680 in.H2O
= 6.8946 kPa
1 bar= 14.504 psi
1 atm. = 14.696 psi

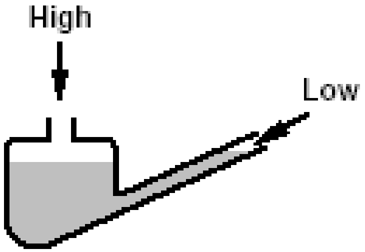
Wet Meters (Manometers)



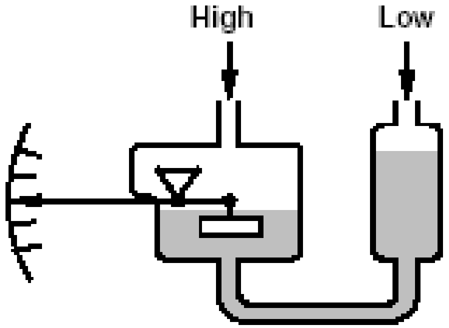
U-TUBE
MANOMETER



WELL (RESERVOIR)
MANOMETER



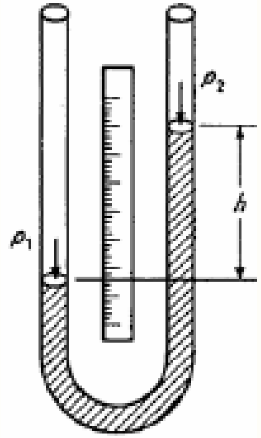
INCLINED
MANOMETER



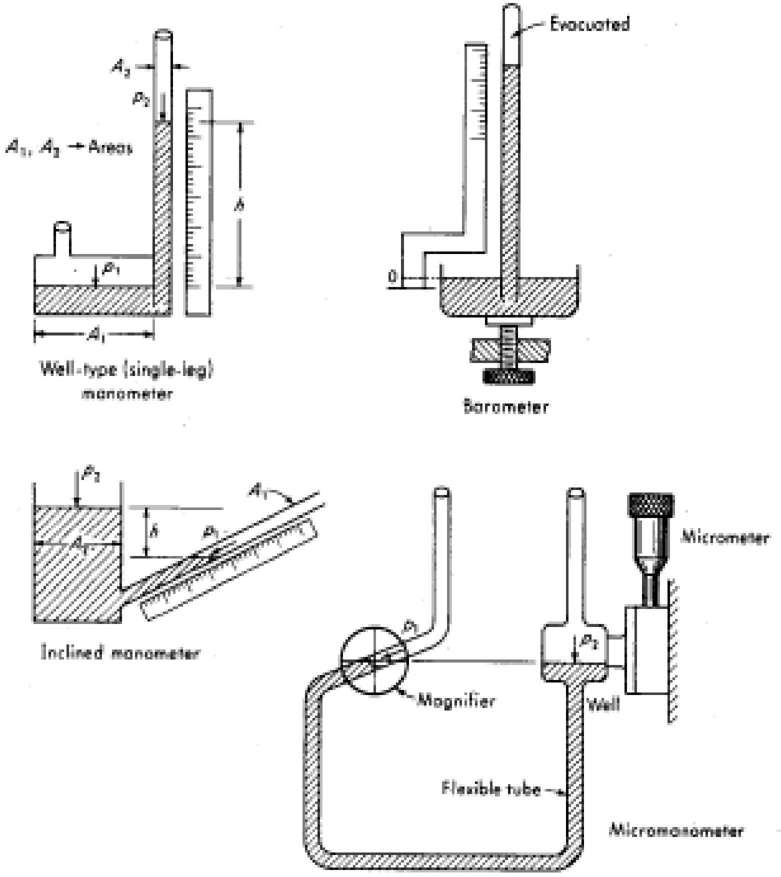
MERCURY FLOAT
MANOMETER

Pressure Gages

- Direct reading gages
  - Manometers



$$h = \frac{p_1 - p_2}{\rho g}$$



- Different fluid provides different uncertainty

Manometer basics

Characterized by its inherent accuracy and simplicity of operation.

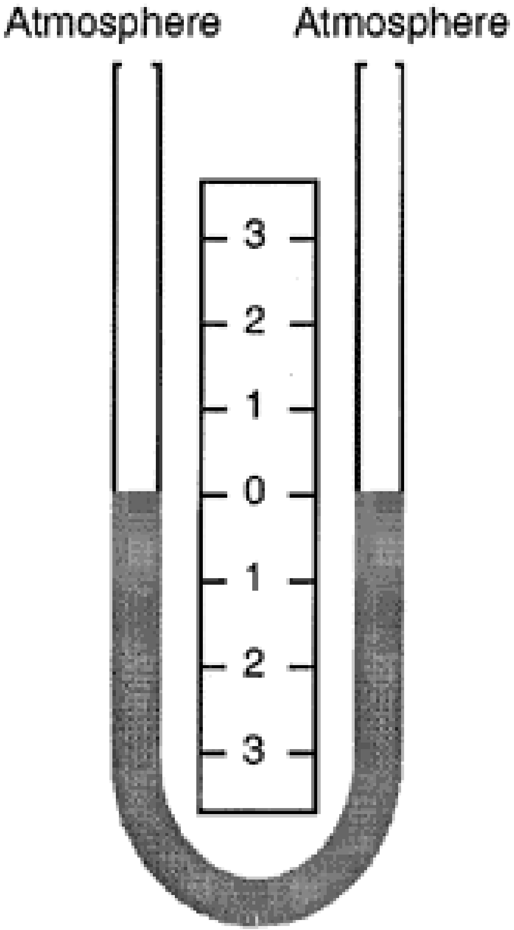
It's the U-tube manometer, which is a U-shaped glass tube partially filled with liquid.

This manometer has no moving parts and requires no calibration.

Manometer measurements are functions of gravity and the liquid's density, both physical properties that make the U-tube manometer a NIST standard for accuracy.

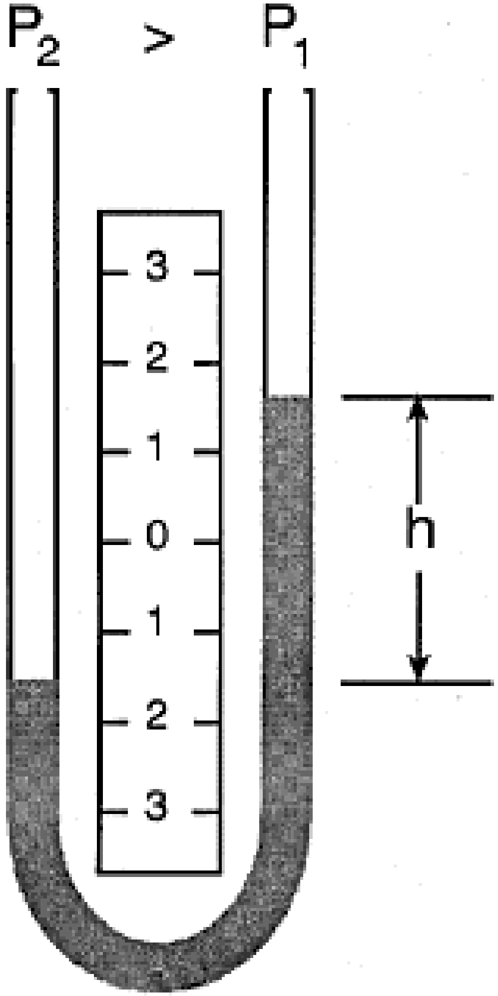
Manometer

With both legs of a U-tube manometer open to the atmosphere or subjected to the same pressure, the liquid maintains the same level in each leg, establishing a zero reference.



Manometer

- With a greater pressure applied to the left side of a U-tube manometer, the liquid lowers in the left leg and rises in the right leg.
- The liquid moves until the unit weight of the liquid, as indicated by h, exactly balances the pressure.



Manometer

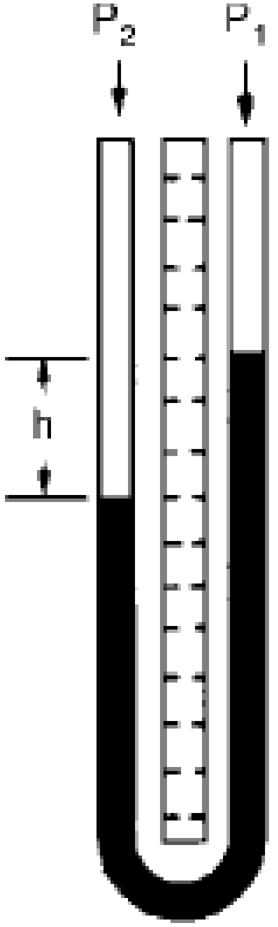
- When the liquid in the tube is mercury, for example, the indicated pressure *h* is usually expressed in inches (or millimeters) of mercury. To convert to pounds per square inch (or kilograms per square centimeter), $P_2 = \rho h$

Where

P_2 = pressure, (kg/cm^2)

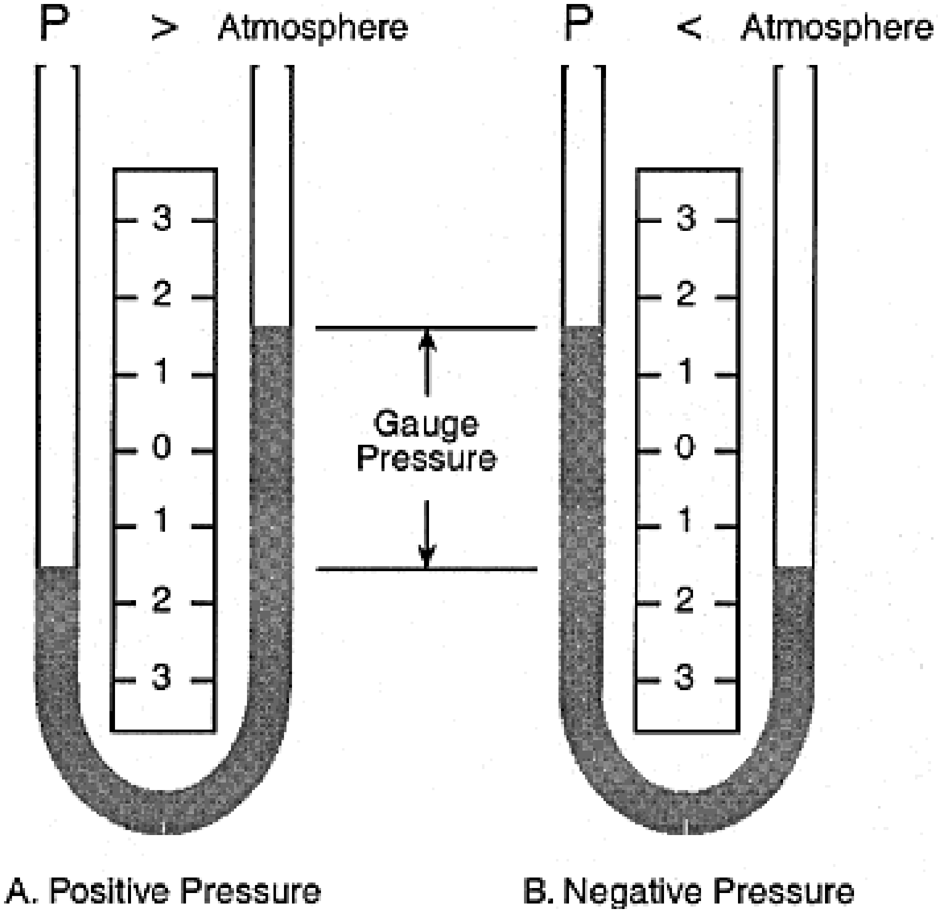
ρ = density, (kg/cm^3)

h = height, (cm)



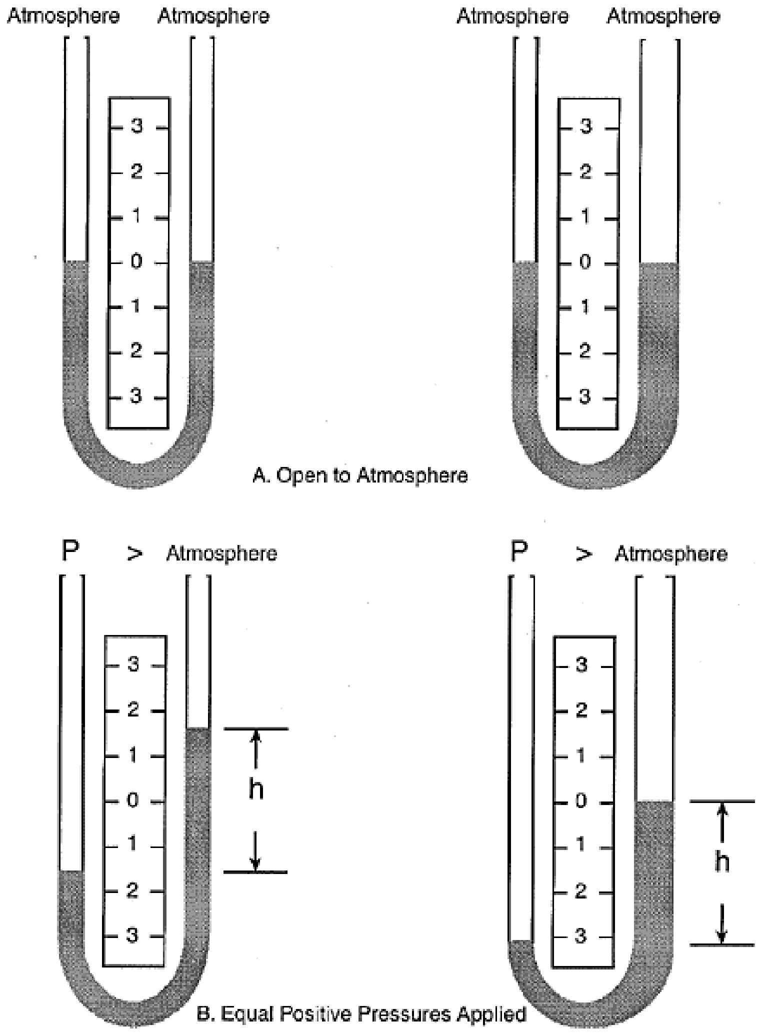
Manometer

- Gauge pressure is a measurement relative to atmospheric pressure and it varies with the barometric reading.
- A gauge pressure measurement is positive when the unknown pressure exceeds atmospheric pressure (A), and is negative when the unknown pressure is less than atmospheric pressure (B).



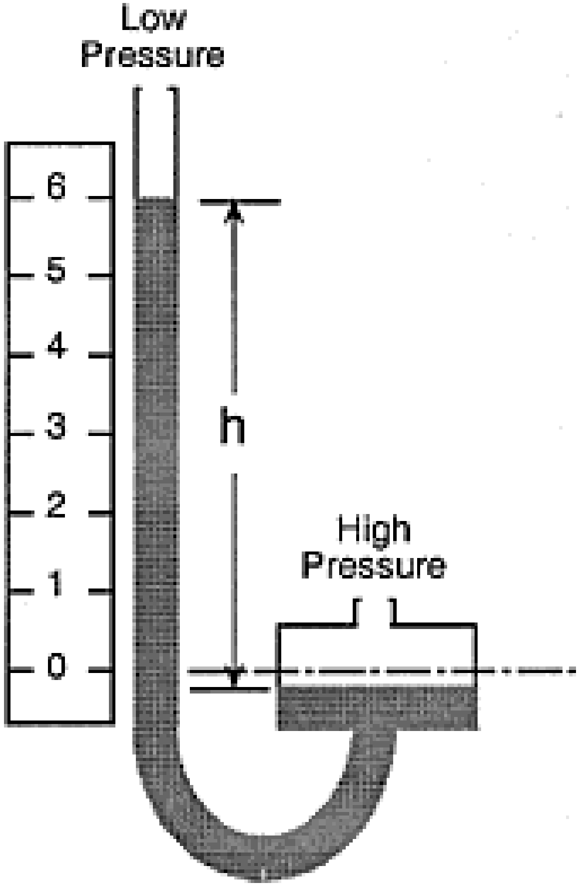
Variations on the U-Tube Manometer

- The pressure reading is always the difference between fluid heights, regardless of the tube sizes.
- With both manometer legs open to the atmosphere, the fluid levels are the same (A).
- With an equal positive pressure applied to one leg of each manometer, the fluid levels differ, but the distance between the fluid heights is the same (B).



Reservoir (Well) Manometer

In a well-type manometer, the cross-sectional area of one leg (the well) is much larger than the other leg. When pressure is applied to the well, the fluid lowers only slightly compared to the fluid rise in the other leg.



Reservoir (Well) Manometer

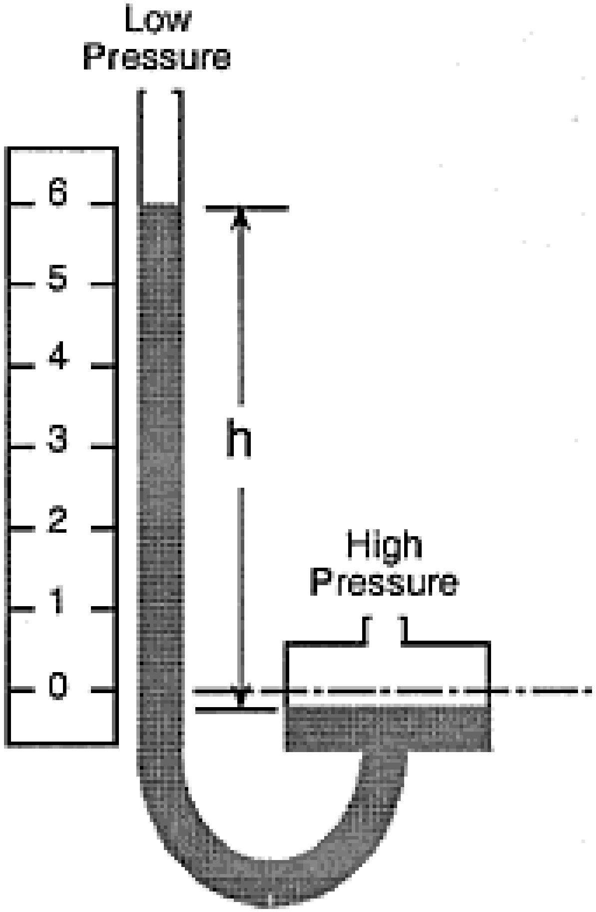
- In this design one leg is replaced by a large diameter well so that the pressure differential is indicated only by the height of the column in the single leg.
- The pressure difference can be read directly on a single scale. For static balance,

$$P_2 - P_1 = d\,(1 + A_1/A_2)\,h$$

Where

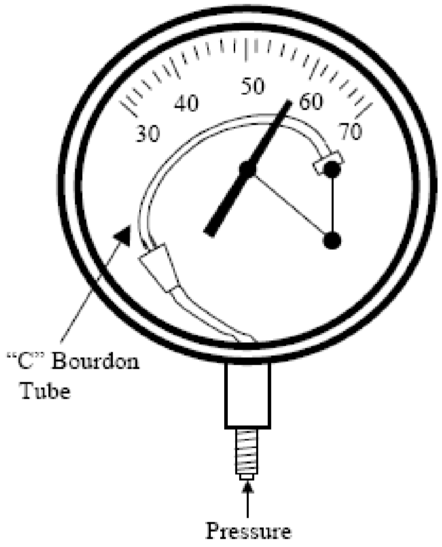
- A_1 = area of smaller-diameter leg
- A_2 = area of well

If the ratio of A_1/A_2 is small compared with unity, then the error in neglecting this term becomes negligible, and the static balance relation becomes $P_2 - P_1 = dh$



Pressure Gauges

- In “C” type Bourdon tube, a section of tubing that is closed at one end is partially flattened and coiled.
- When a pressure is applied to the open end, the tube uncoils.
- This movement provides a displacement that is proportional to the applied pressure.
- The tube is mechanically linked to a pointer on a pressure dial to give a calibrated reading.



Bourdon tube pressure gauge

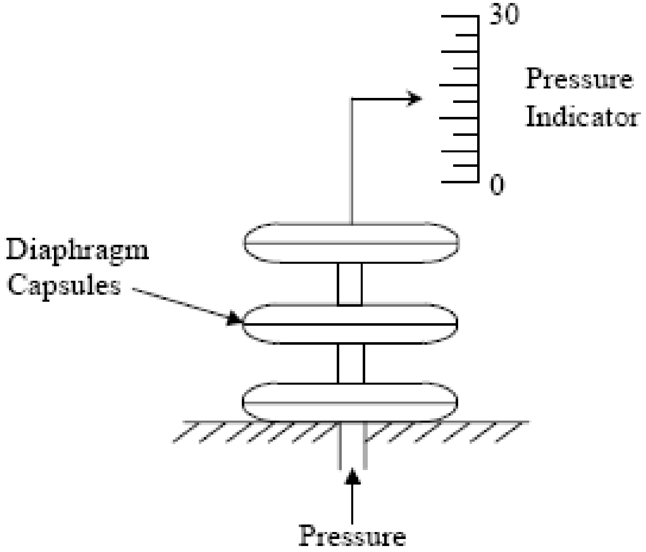
Pressure Gauges

To amplify the motion that a diaphragm capsule produces, several capsules are connected end to end.

Diaphragm type pressure gauges used to measure gauge, absolute, or differential pressure.

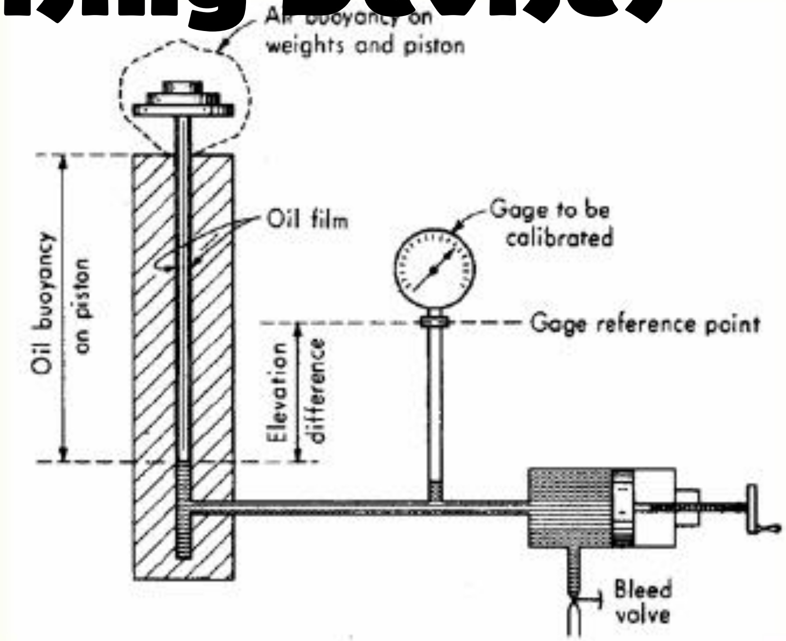
They are normally used to measure low pressures of 1 inch of Hg, but they can also be manufactured to measure higher pressures in the range of 0 to 330 psig.

They can also be built for use in vacuum service.



Diaphragm-type pressure gauge

Calibration of Pressure Sensing Devises



NTU50235100

$$\text{Gauge pressure} = \frac{M g_1\left(1-\dfrac{\rho_{\text{air}}}{\rho_{\text{mass}}}\right)+\pi D T}{A_{(20.\,0)}\cdot\left[1+(\alpha_p+\alpha_c)\cdot(\theta-20)\right]\cdot(1+\lambda P)}-(\rho_{\text{fluid}}-\rho_{\text{air}})\cdot g_1 h$$

From Mechanical to Electronic

- The free end of a Bourdon tube (bellows or diaphragm) no longer had to be connected to a local pointer, but served to convert a process pressure into a transmitted (electrical or pneumatic) signal.
- At first, the mechanical linkage was connected to a pneumatic pressure transmitter, which usually generated a 3-15 psig output signal for transmission over distances of several hundred feet,
- The force-balance and later the solid state electronic pressure transducer were introduced.

Potentiometric type sensor

A mechanical device such as a diaphragm is used to move the wiper arm of a potentiometer as the input pressure changes.

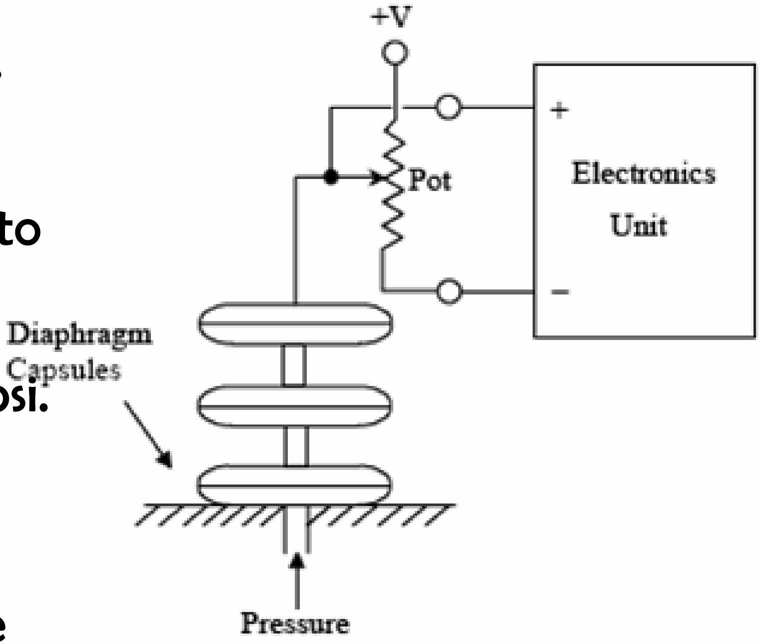
A direct current voltage (DC) V is applied to the top of the potentiometer (pot), and the voltage that is dropped from the wiper arm to the bottom of the pot is sent to an electronic unit.

It normally cover a range of 5 psi to 10,000 psi.

Can be operated over a wide range of temperatures.

Subject to wear because of the mechanical contact between the slider and the resistance element.

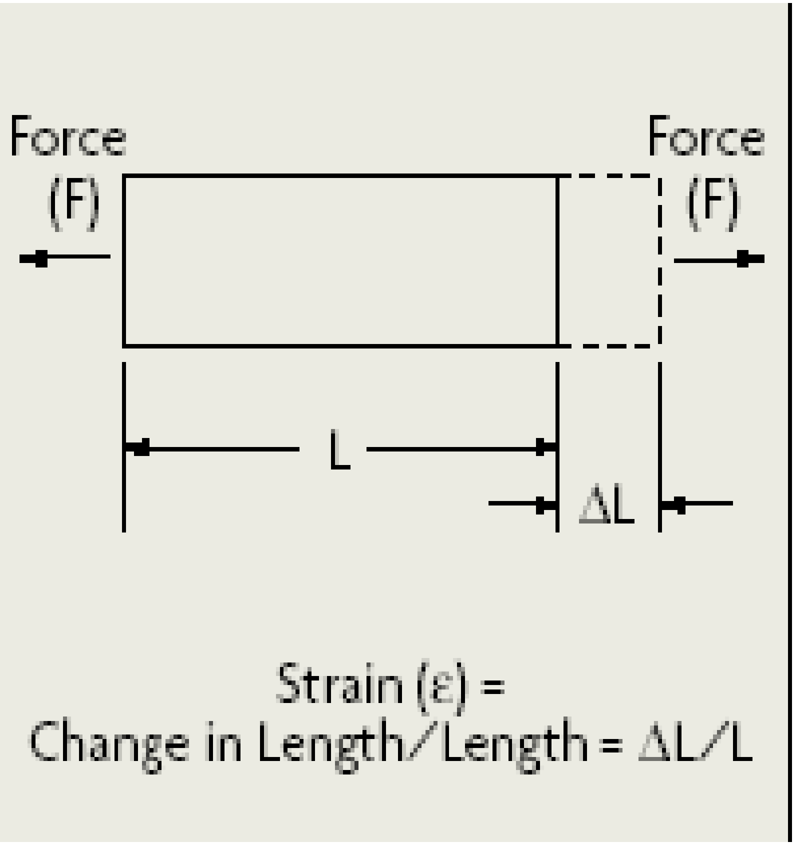
Therefore, the instrument life is fairly short, and they tend to become noisier as the pot wears out.



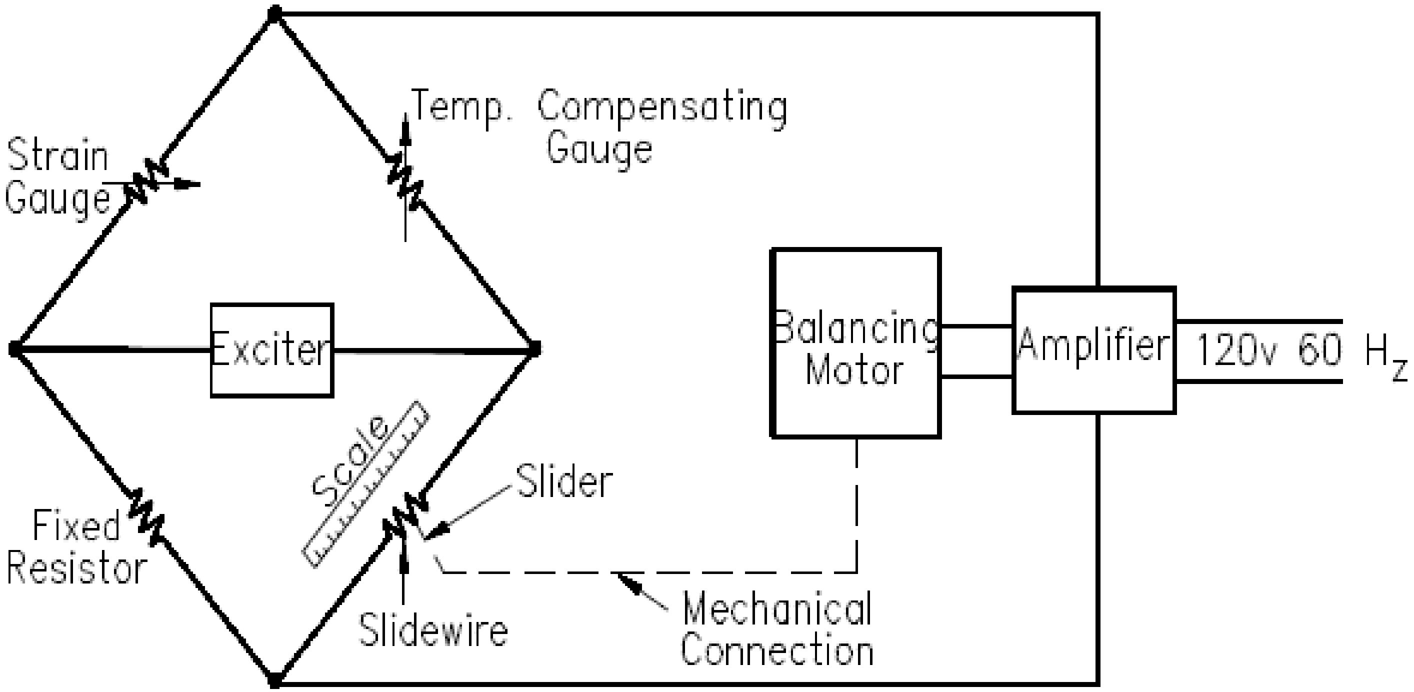
Strain Gage

- If a wire is held under tension, it gets slightly longer and its cross-sectional area is reduced. This changes its resistance (R) in proportion to the strain sensitivity (S) of the wire's resistance.

- The strain sensitivity, which is also called the gage factor (GF), is given by: GF = (∆ R/R)/(∆ L/L) = (∆ R/R)/ Strain

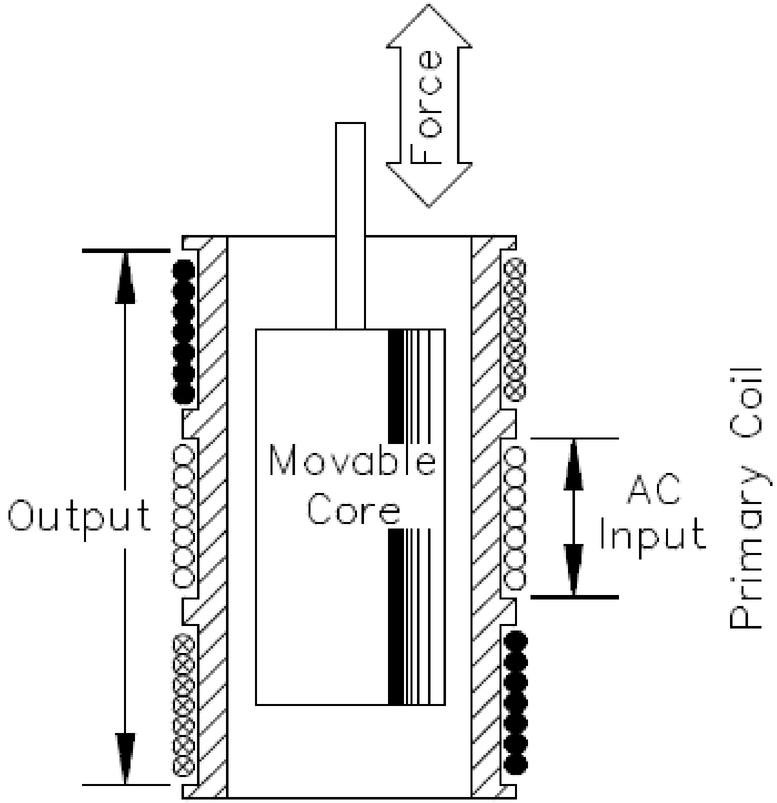


Strain Gauge Used in a Bridge Circuit



LVDT

- Another type of inductance transducer, utilizes two coils wound on a single tube and is commonly referred to as a Differential Transformer or sometimes as a Linear Variable Differential Transformer (LVDT).



Electronic Pressure Sensor Range

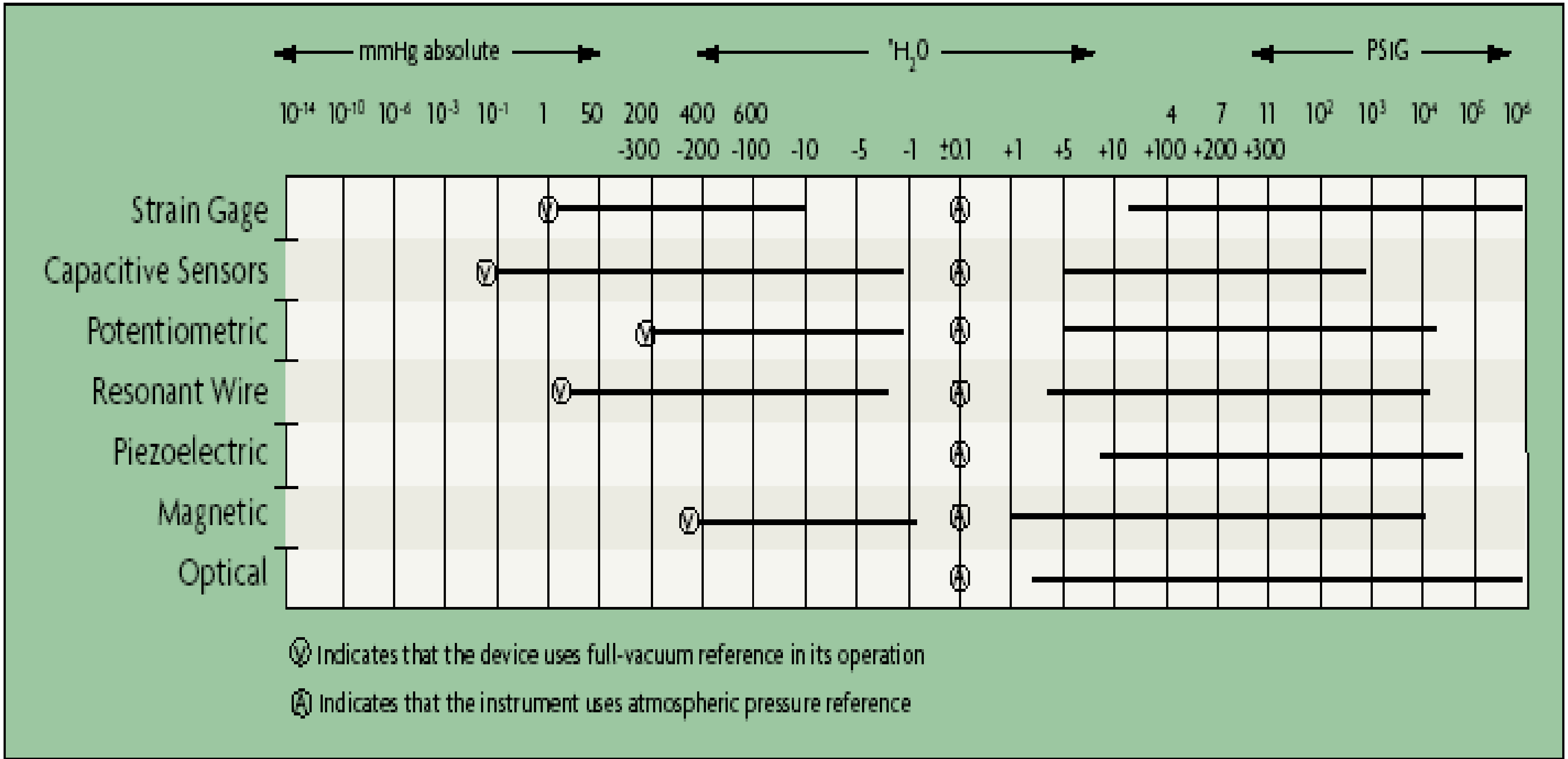
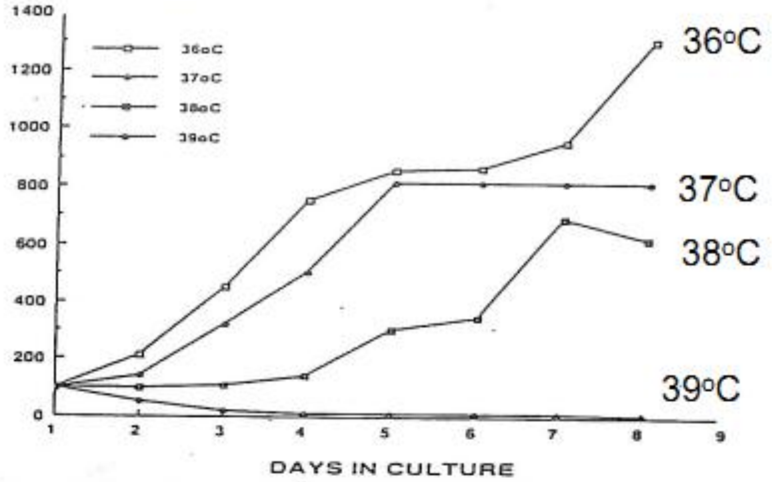
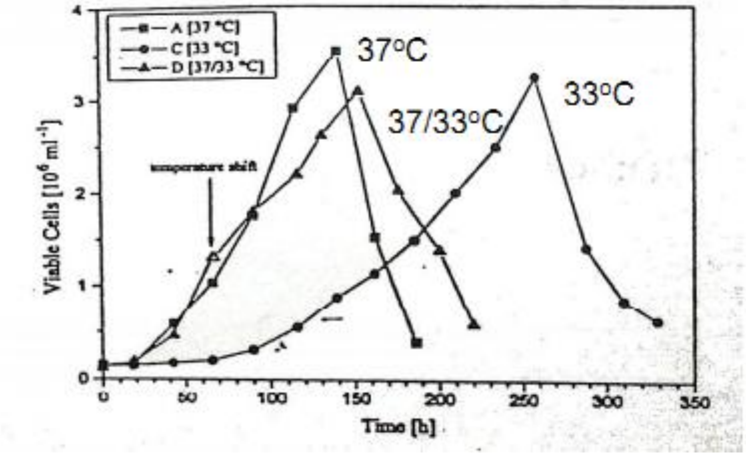


Figure 3-3: Electronic Pressure Sensor Ranges

Overview of Temperature Measurement

Optimal Temperature may not the same





Outline

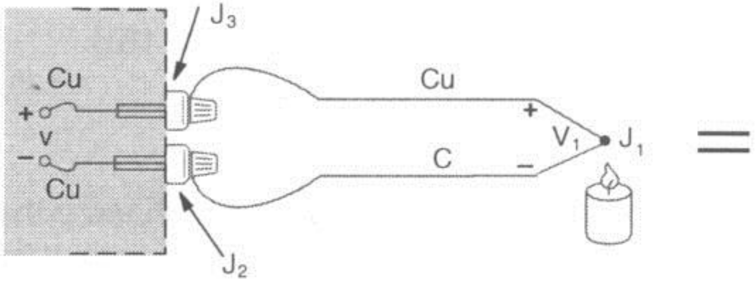
- Thermocouples
  - overview, reference junction, proper connections, types, special limits of error wire, time constants, sheathing, potential problems, DAQ setup
- RTDs
  - overview, bridges, calibration, accuracy, response time, potentail problems
- Thermistors
- Infrared Thermometry
  - fundamentals, emissivity determination, field of view
- Other
  - Non-electronic measurement, thin-film heat flux gauge
- Temperature Controllers
- How to Choose
  - Standards, cost, accuracy, stability, sensitivity, size, contact/non-contact, temperature range, fluid type

Thermocouples

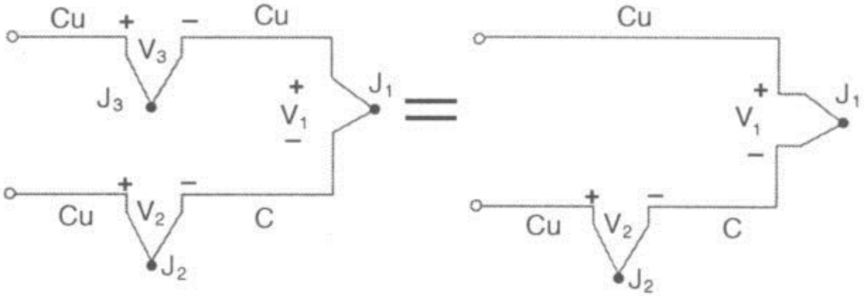
- Seebeck effect
  - If two wires of dissimilar metals are joined at both ends and one end is heated, current will flow.
  - If the circuit is broken, there will be an open circuit voltage across the wires.
  - Voltage is a function of temperature and metal types. $\Delta V = \alpha \Delta T$
  - For small ΔT's, the relationship with temperature is linear
  - For larger ΔT's, non-linearities may occur.

Measuring the Thermocouple Voltage

- If you attach the thermocouple directly to a voltmeter, you will have problems.



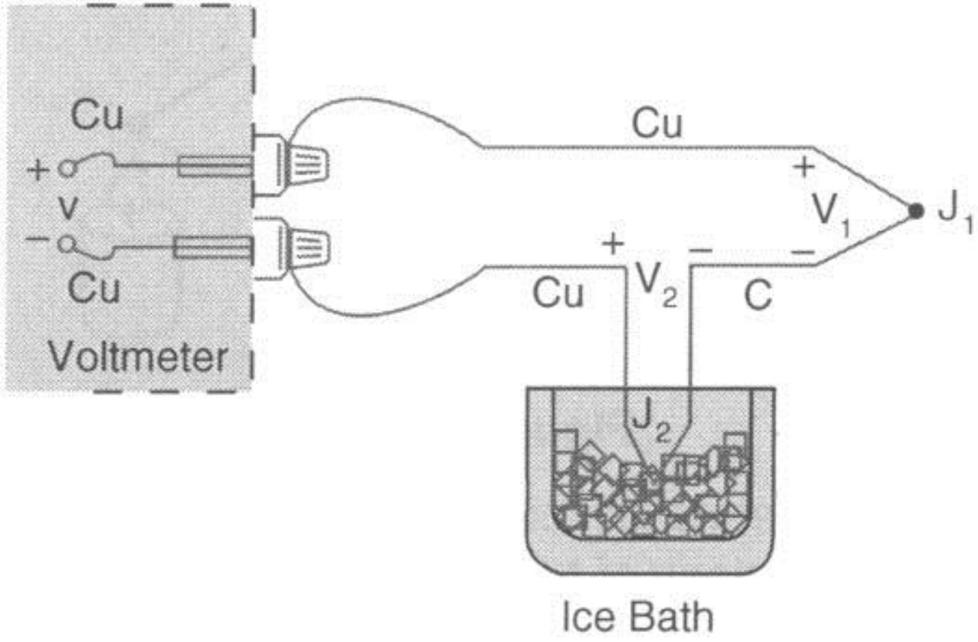
EQUIVALENT CIRCUITS



- You have just created another junction! Your displayed voltage will be proportional to the difference between J_1 and J_2 (and hence T_1 and T_2). Note that this is "Type T" thermocouple.

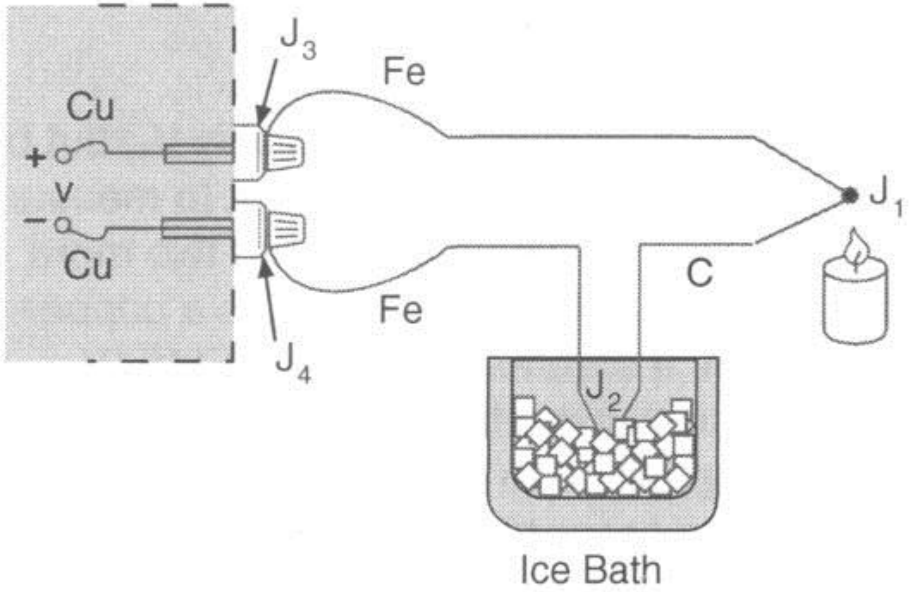
External Reference Junction

- A solution is to put J_2 in an ice-bath; then you know T_2, and your output voltage will be proportional to T_1-T_2.



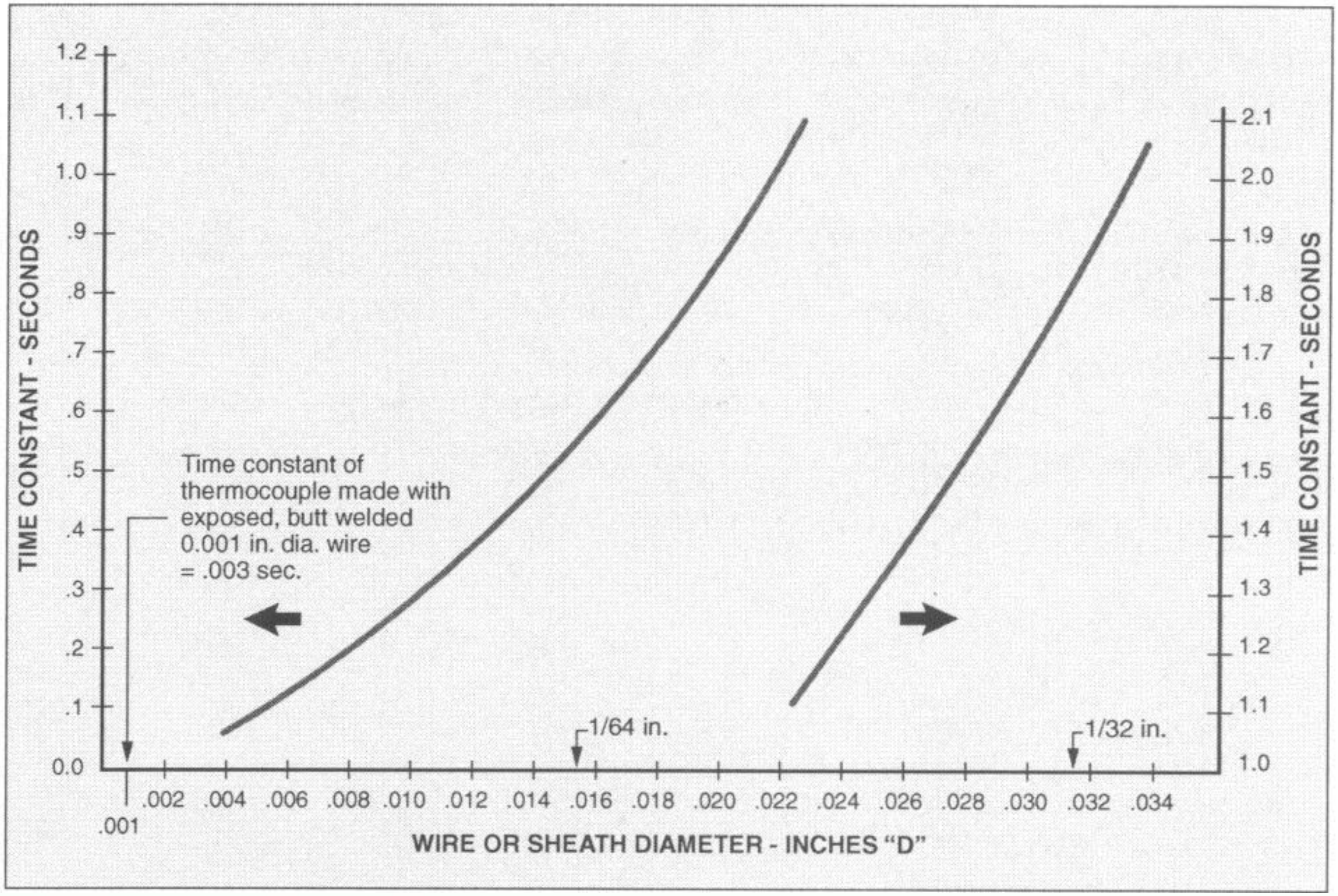
Other types of thermocouples

- Many thermocouples don’t have one copper wire. Shown below is a “Type J” thermocouple.

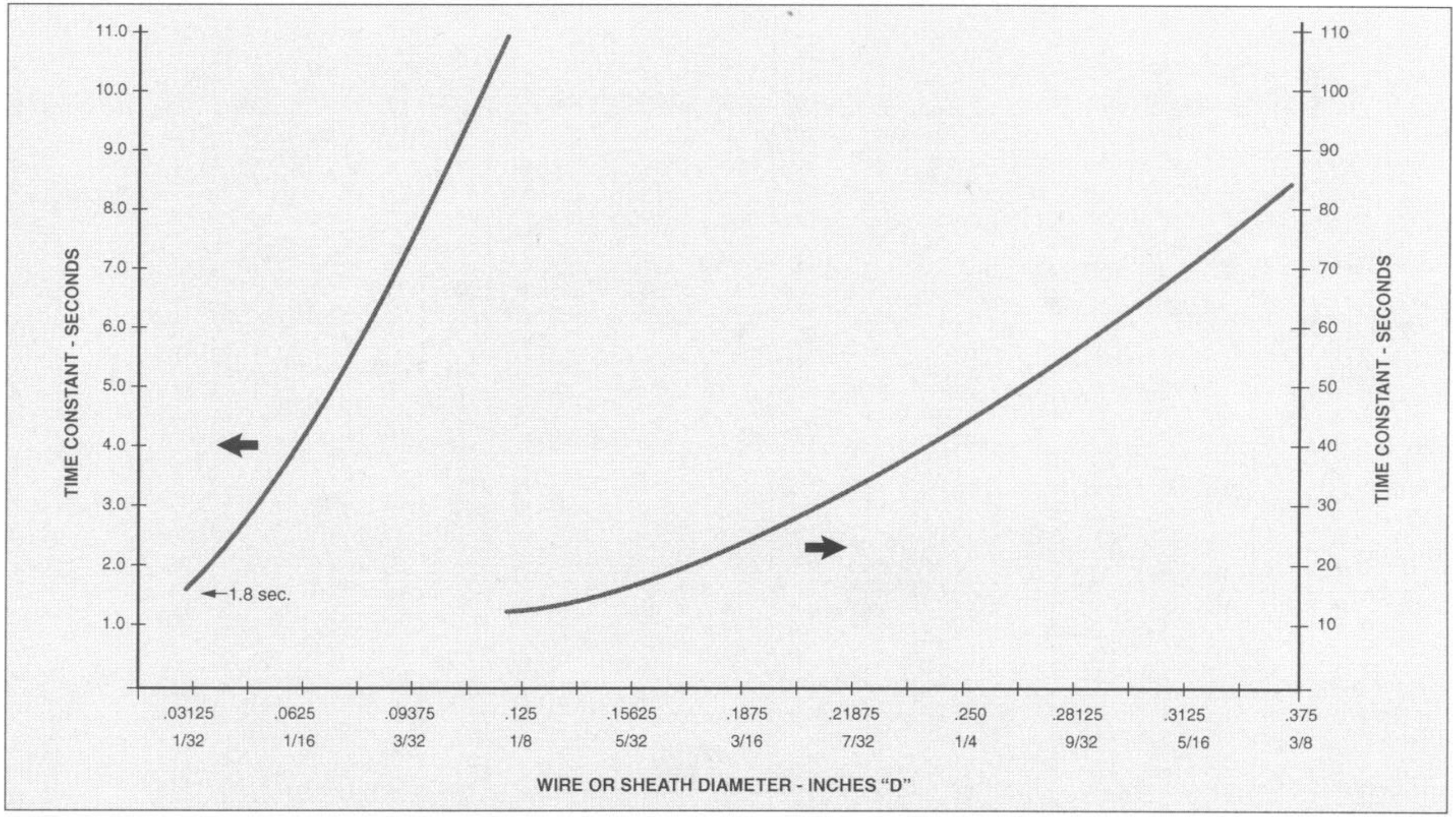


- If the two terminals aren’t at the same temperature, this also creates an error.

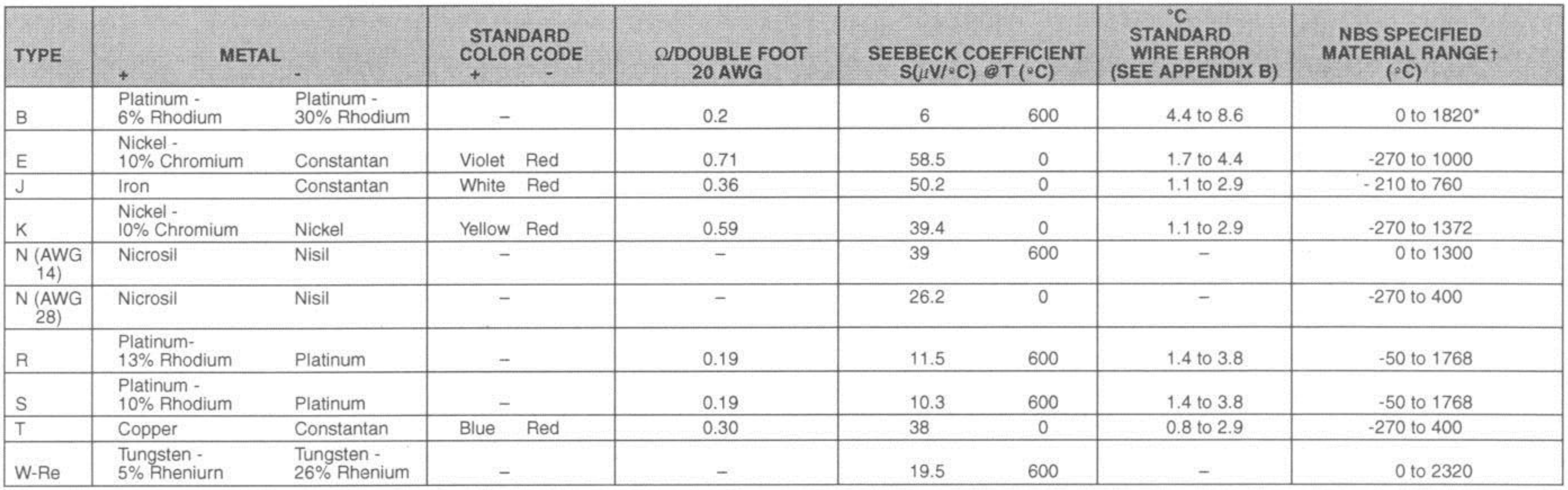
Time Constant vs. Wire Diameter



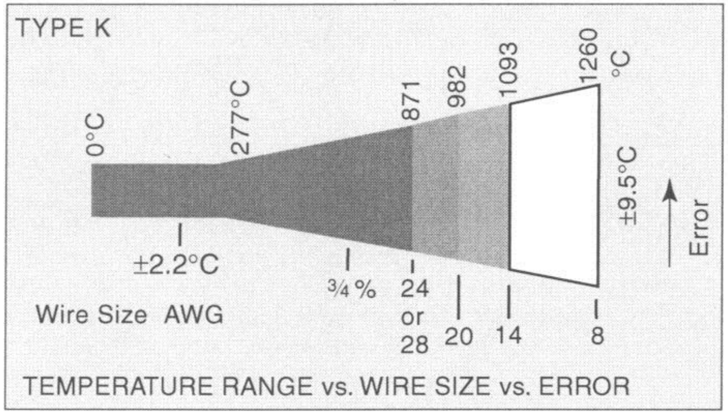
Time Constant vs. Wire Diameter,



Thermocouple Types



TYPE	METAL +	METAL -	STANDARD COLOR CODE +	STANDARD COLOR CODE -	Ω/DOUBLE FOOT 20 AWG	SEEBECK COEFFICIENT S(μV/°C)	@T (°C)	°C STANDARD WIRE ERROR (SEE APPENDIX B)	NBS SPECIFIED MATERIAL RANGE† (°C)
B	Platinum - 6% Rhodium	Platinum - 30% Rhodium	–		0.2	6	600	4.4 to 8.6	0 to 1820*
E	Nickel - 10% Chromium	Constantan	Violet	Red	0.71	58.5	0	1.7 to 4.4	-270 to 1000
J	Iron	Constantan	White	Red	0.36	50.2	0	1.1 to 2.9	-210 to 760
K	Nickel - 10% Chromium	Nickel	Yellow	Red	0.59	39.4	0	1.1 to 2.9	-270 to 1372
N (AWG 14)	Nicrosil	Nisil	–		–	39	600	–	0 to 1300
N (AWG 28)	Nicrosil	Nisil	–		–	26.2	0	–	-270 to 400
R	Platinum- 13% Rhodium	Platinum	–		0.19	11.5	600	1.4 to 3.8	-50 to 1768
S	Platinum - 10% Rhodium	Platinum	–		0.19	10.3	600	1.4 to 3.8	-50 to 1768
T	Copper	Constantan	Blue	Red	0.30	38	0	0.8 to 2.9	-270 to 400
W-Re	Tungsten - 5% Rhenium	Tungsten - 26% Rhenium	–		–	19.5	600	–	0 to 2320



If you do your own calibration, you can usually improve on the listed uncertainties.

Thermocouple Types, cont.

- Type B – very poor below 50ºC; reference junction temperature not important since voltage output is about the same from 0 to 42 ºC
- Type E – good for low temperatures since dV/dT (α) is high for low temperatures
- Type J – cheap because one wire is iron; high sensitivity but also high uncertainty (iron impurities cause inaccuracy)
- Type T – good accuracy but low max temperature (400 ºC); one lead is copper, making connections easier; watch for heat being conducted along the copper wire, changing your surface temp
- Type K – popular type since it has decent accuracy and a wide temperature range; some instability (drift) over time
- Type N – most stable over time when exposed to elevated temperatures for long periods

Data Acquisition Systems for Thermocouples

- Agilent, HP, and National Instruments are probably the most popular DAQ systems
- Example National Instruments DAQ setup for thermocouples and costs

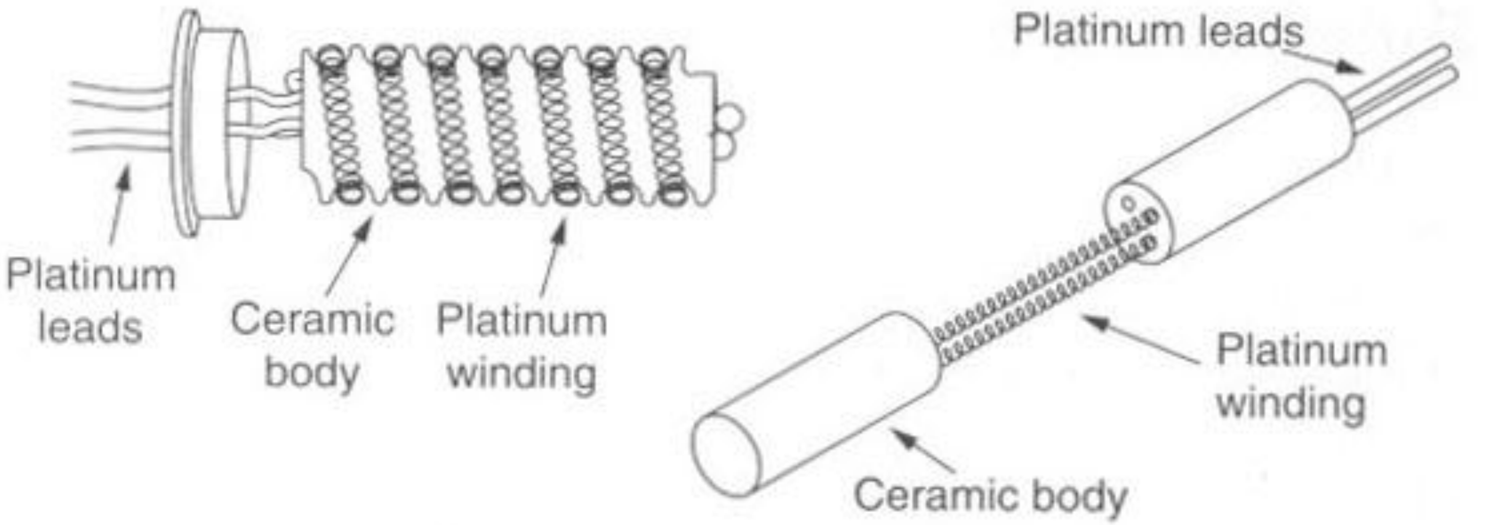
item	part number	cost
16-bit temperature data acquisition card	PCI 6232E	1495
analog input module for thermocouples	SCXI-1112	695
chassis	SCXI-1000	695
terminal block for thermocouples	SCXI-1303	275
shielded cable	SH68-68-EP	95
Total cost:		3255

2

RTDs (Resistance Temperature Detectors)

- Resistivity of metals is a function of temperature.
- Platinum often used since it can be used for a wide temperature range and has excellent stability. Nickel or nickel alloys are used as well, but they aren't as accurate.
- In several common configurations, the platinum wire is exposed directly to air (called a bird-cage element), wound around a bobbin and then sealed in molten glass, or threaded through a ceramic cylinder.
- Metal film RTDs are new. To make these, a platinum or metal-glass slurry film is deposited onto a ceramic substrate. The substrate is then etched with a laser. These RTDs are very small but aren't as stable (and hence accurate).
- RTDs are more accurate but also larger and more expensive than thermocouples.

RTD geometry

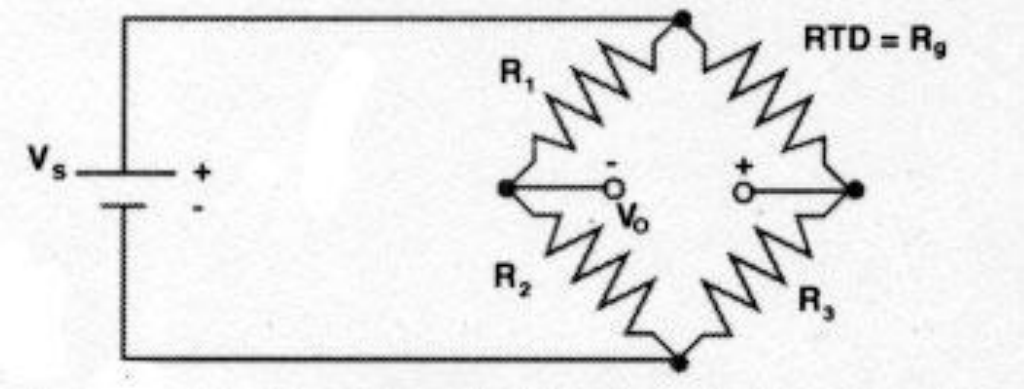


From Nicholas & White, Traceable Temperatures.

- Sheathing: stainless steel or iconel, glass, alumina, quartz
- Metal sheath can cause contamination at high temperatures and are best below 250ºC.
- At very high temperatures, quartz and high-purity alumina are best to prevent contamination.

Resistance Measurement

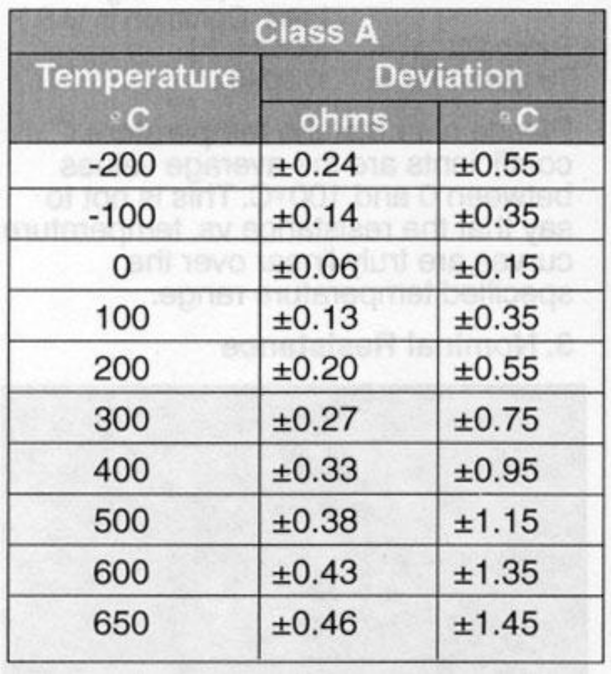
- Several different bridge circuits are used to determine the resistance. Bridge circuits help improve the accuracy of the measurements significantly. Bridge output voltage is a function of the RTD resistance.



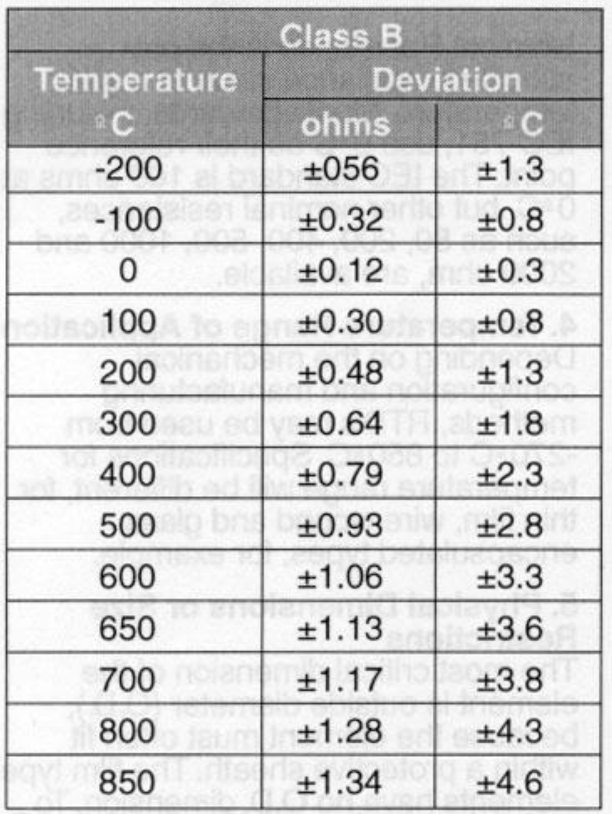
Resistance/Temperature Conversion

- Published equations relating bridge voltage to temperature can be used.
- For very accurate results, do your own calibration.
  - Several electronic calibrators are available.
  - The most accurate calibration that you can do easily yourself is to use a constant temperature bath and NIST-traceable thermometers. You then can make your own calibration curve correlating temperature and voltage.

Accuracy and Response Time



Class A		
Temperature °C	Deviation	
	ohms	°C
-200	±0.24	±0.55
-100	±0.14	±0.35
0	±0.06	±0.15
100	±0.13	±0.35
200	±0.20	±0.55
300	±0.27	±0.75
400	±0.33	±0.95
500	±0.38	±1.15
600	±0.43	±1.35
650	±0.46	±1.45



Class B		
Temperature °C	Deviation	
	ohms	°C
-200	±056	±1.3
-100	±0.32	±0.8
0	±0.12	±0.3
100	±0.30	±0.8
200	±0.48	±1.3
300	±0.64	±1.8
400	±0.79	±2.3
500	±0.93	±2.8
600	±1.06	±3.3
650	±1.13	±3.6
700	±1.17	±3.8
800	±1.28	±4.3
850	±1.34	±4.6

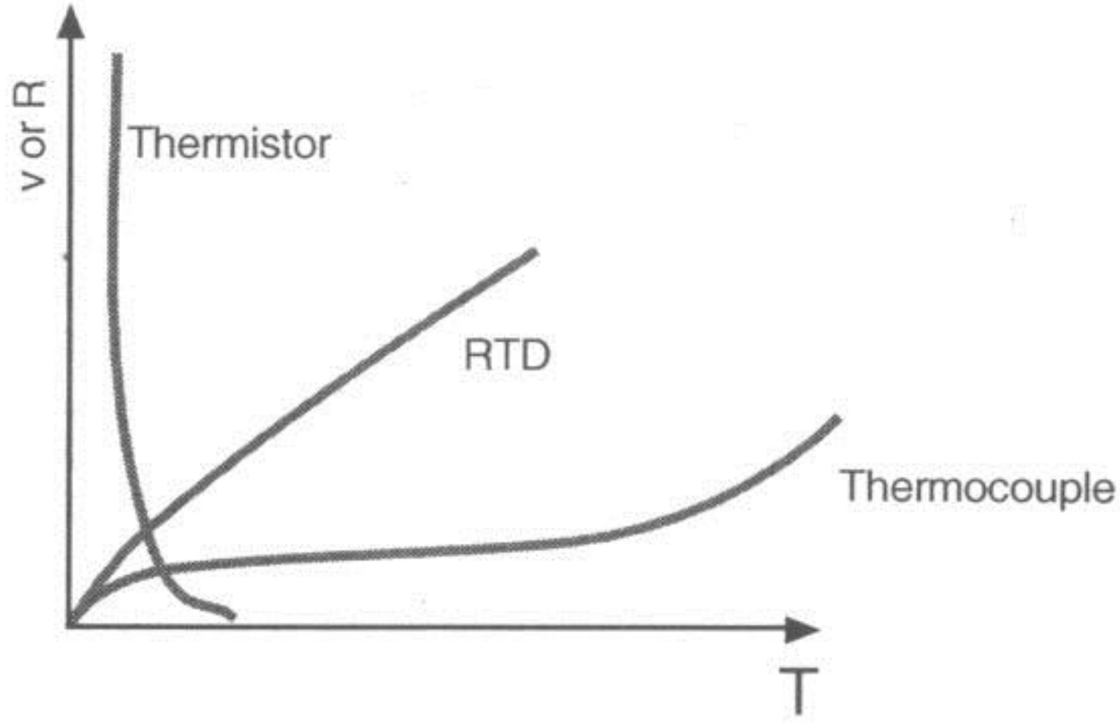
- Response time is longer than thermocouples; for a ¼ sheath, response time can easily be 10 s.

3

Thermistors

- Thermistors also measure the change in resistance with temperature.
- Thermistors are very sensitive (up to 100 times more than RTDs and 1000 times more than thermocouples) and can detect very small changes in temperature. They are also very fast.
- Due to their speed, they are used for precision temperature control and any time very small temperature differences must be detected.
- They are made of ceramic semiconductor material (metal oxides).
- The change in thermistor resistance with temperature is very non-linear.

Thermistor Non-Linearity



Resistance/Temperature Conversion

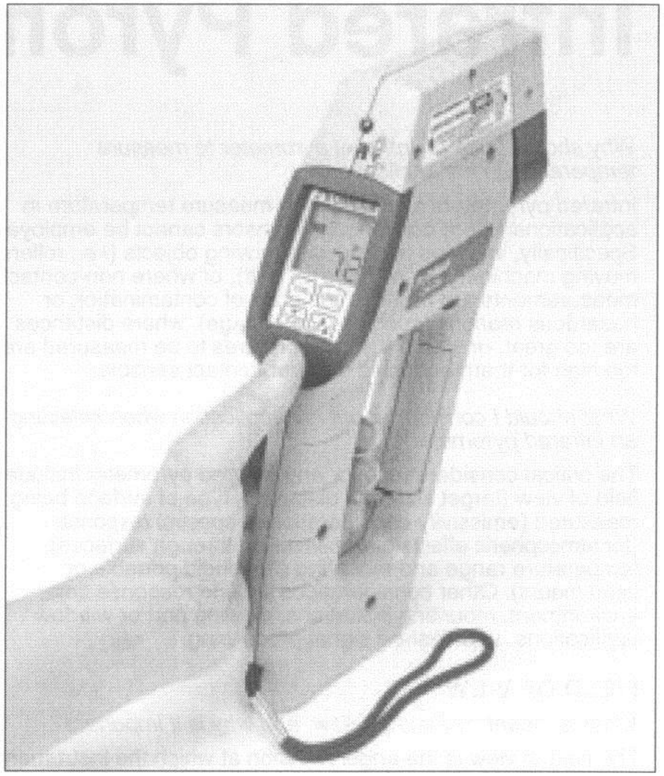
- Standard thermistors curves are not provided as much as with thermocouples or RTDs. You often need a curve for a specific batch of thermistors.
- No 4-wire bridge is required as with an RTD.
- DAQ systems can handle the non-linear curve fit easily.
- Thermistors do not do well at high temperatures and show instability with time (but for the best ones, this instability is only a few millikelvin per year)

Infrared Thermometry

- Infrared thermometers measure the amount of radiation emitted by an object.
- Peak magnitude is often in the infrared region.
- Surface emissivity must be known. This can add a lot of error.
- Reflection from other objects can introduce error as well.
- Surface whose temp you're measuring must fill the field of view of your camera.

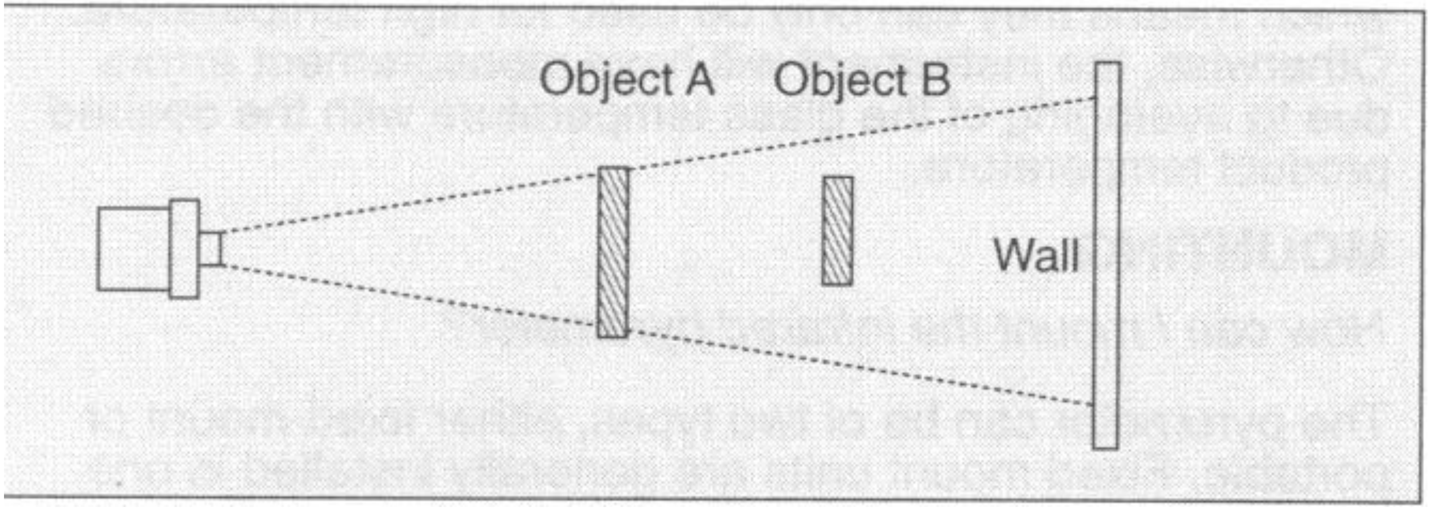
Benefits of Infrared Thermometry

- Can be used for
  - Moving objects
  - Non-contact applications where sensors would affect results or be difficult to insert or conditions are hazardous
  - Large distances
  - Very high temperatures



Field of View

- On some infrared thermometers, FOV is adjustable.



Temperature Controllers

- Consider the following when choosing a controller
  - Type of temperature sensor (thermocouples and RTDs are common)
  - Number and type of outputs required (for example, turn on a heater, turn off a cooling system, sound an alarm)
  - Type of control algarithm (on/off, proportional, PID)
- On/off controllers
  - These are the simplest controllers.
  - On above a certain setpoint, and off below a certain setpoint
  - On/off differential used to prevent continuous cycling on and off.
  - This type of controller can't be used for precise temperature control.
  - Often used for systems with a large thermal mass (where temperatures take a long time to change) and for alarms.

How to Choose a Temperature Control Device or System

- Things to take into account
  - Standards
  - Cost
  - Accuracy
  - Stability over time (esp. for high temperatures)
  - Sensitivity
  - Size
  - Contact/non-contact
  - Temperature range
  - Fluid

Choice Between RTDs, Thermocouples, Thermisters

- Cost – thermocouples are cheapest by far, followed by RTDs
- Accuracy – RTDs or thermisters
- Sensitivity – thermisters
- Speed - thermisters
- Stability at high temperatures – not thermisters
- Size – thermocouples and thermisters can be made quite small
- Temperature range – thermocouples have the highest range, followed by RTDs
- Ruggedness – thermocouples are best if your system will be taking a lot of abuse

THANK YOU

-YUSRON SUGIARTO-