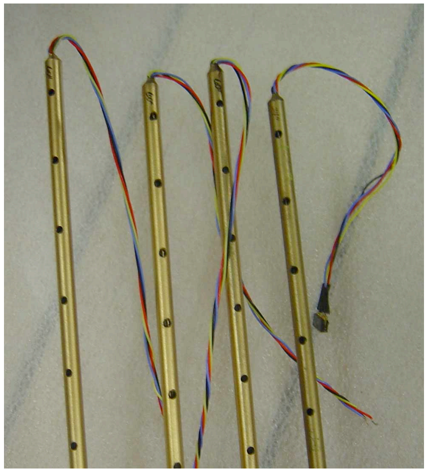
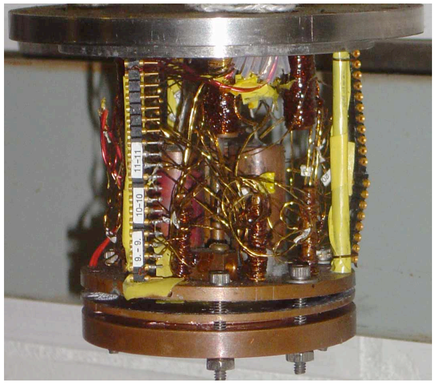


Instrumentation & Measurement Techniques



J.M Pfotenhauer
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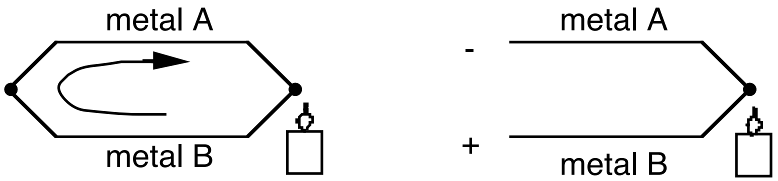
Outline

- Temperature measurement
  - Thermocouples
    - Fundamentals
    - Commercial configurations
    - Thermopiles
  - Resistance thermometers
    - Considerations
    - Options
    - Uncertainties
    - Do’s and don’ts
- Pressure measurement
- Flow measurement
- Level measurement

Thermocouples - Fundamentals

- *Seebeck, 1821: Two wires of dissimilar metals joined at both ends display a continuous current if one end is heated. If the circuit is broken, a voltage is established which is a function of the junction temperature and the composition of the metals.*



- *Because temperature measurements via thermocouples are common and deceptively simple, many errors in their use and interpretation are also common. To avoid these, it is helpful to understand the physical principles behind the signal generated by a thermocouple …*

Thermocouples - Fundamentals

- The electric current, J, associated with the flow of electrons is given by:

$$J = \left(\quad \tilde{} \ / \ e \qquad T \right)$$

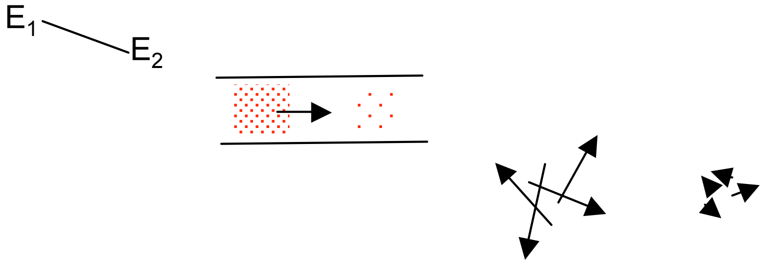
- The thermal current, q, associated with the same flow of electrons is:

$$q = T \quad J \quad k \quad T = \frac{T}{e} \quad \tilde{} \quad \left(T \quad {}^{2} + k \right) \quad T$$

Here

  - , the Seebeck coefficient, is a measure of the tendency of electric currents to carry heat and for heat currents to induce electrical currents.
  - ˜ = – e , where e is the electric charge, the electric potential, and is the chemical potential (which is a function of composition and temperature).
  - and k are the electric and thermal conductivity respectively

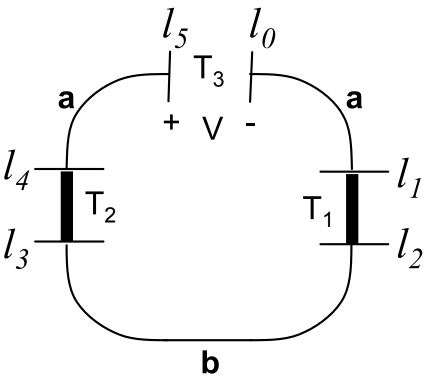
- The net motion of the electrons arises from three different gradients:
  - ▽ (voltage)
  - ▽ (concentration gradient)
  - ▽T (thermal energy gradient)



Thermocouples - Fundamentals

- Consider the circuit as shown connected to a potentiometer: the two ‘leads’ have the same composition and temperature   same chemical potential

$$(l_5) = \quad (l_0) \quad or \quad \tilde{\ }(l_5) \quad \tilde{\ }(l_0) = \quad e \quad (l_5) \quad (l_0)$$



- With zero current flow, J = 0, we have for any position along the path from l_0 to l_5:

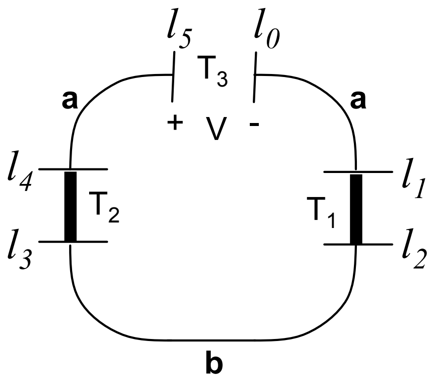
$$\tilde{\ }(l) = \tilde{\ }(l_0) + e \;{}_{0}^{l} \quad (l,T)\frac{dT}{dl}dl$$

- Combining the above two equations, we have:

$$(l_5) \quad (l_0) = \;{}_{l_0}^{l_5} \quad (l,T)\frac{dT}{dl}dl$$

- Note that an open circuit voltage arises from regions where $\frac{dT}{dl} \quad 0$

Thermocouples



- Voltage difference between points 0 and 5:

$$(l_5)\qquad (l_0) = {}_{0}^{l_5}\quad (l,T)\frac{dT}{dl}dl$$

- open circuit voltage arises from regions of dT/dl ≠ 0

$$(l_5)\qquad (l_0) = [\ {}_{0}^{l_1}\quad {}_a(T)\frac{dT}{dl}dl + {}_{l_1}^{l_2}\quad (l,T)\cancelto{0}{\frac{dT}{dl}}dl + {}_{l_2}^{l_3}\quad {}_b(T)\frac{dT}{dl}dl + {}_{l_3}^{l_4}\quad (l,T)\cancelto{0}{\frac{dT}{dl}}dl + {}_{l_4}^{l_5}\quad {}_a(T)\frac{dT}{dl}dl\ ]$$

Note that

$${}_{T_3}^{T_1}\quad {}_a dT + {}_{T_2}^{T_3}\quad {}_a dT$$

$$= {}_{T_1}^{T_2}\quad {}_a dT$$

- Note that although ${}_a$ and ${}_b$ are known, (l,T) in the joint is unknown joints must be in regions where dT/dl = 0. Then:

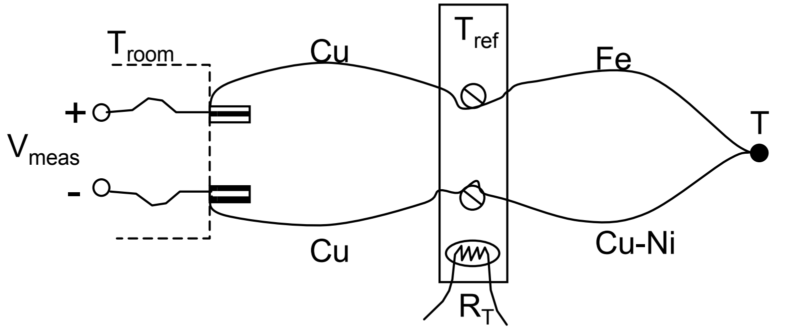
$$(l_5)\qquad (l_0) = {}_{T_1}^{T_2}[\ {}_b(T)\qquad {}_a(T)]dT$$

$$= {}_{T_1}^{T_2}[\ {}_a(T)\qquad {}_b(T)]dT = {}_{T_1}^{T_2}\quad {}_{ab}(T)dT$$

- ${}_{0}^{T_2}\quad {}_{ab}(T)dT$ is found in the tables! It represents the difference in the voltage generated by material a and material b, both spanning the temperatures 0°C and T$_2$.

Commercial Configurations

- Software compensation:



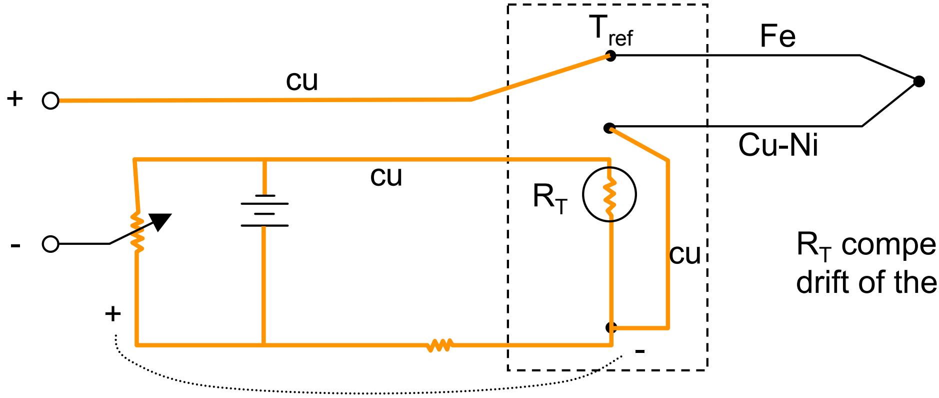
$$V_{meas} = \int_{T_{room}}^{T_{ref}} {}_{cu} dT + \int_{T_{ref}}^{T} {}_{Fe,C} dT + \int_{T_{ref}}^{T_{room}} {}_{cu} dT = \int_{T_{ref}}^{T} {}_{Fe,C} dT$$

$$\underbrace{\int_{T_{ref}}^{T} {}_{Fe,C} dT}_{V_{meas}} = \underbrace{\int_{T_o}^{T} {}_{Fe,C} dT}_{V(T)} \quad \underbrace{\int_{T_o}^{T_{ref}} {}_{Fe,C} dT}_{V_{ref}\text{ (known)}}$$

- Measure R_T to obtain T_{ref} V_{ref}
- Solve for V(T), use tables to determine T

Commercial Configurations

- Hardware compensation

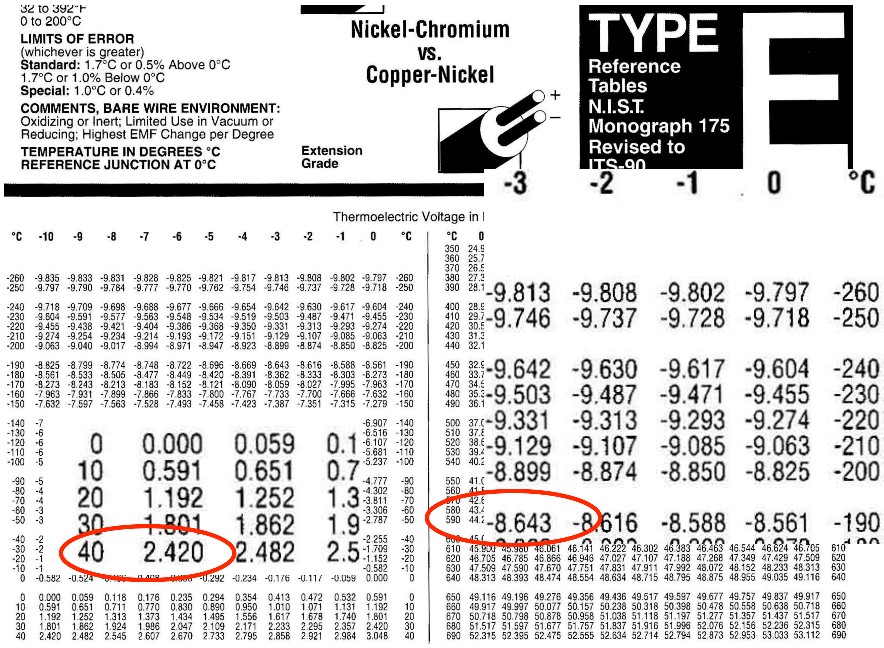


R_T compensates for temperature drift of the reference plate

- A specific voltage is created to buck, or cancel, V_{ref} allowing V(T) to be read directly
  - Advantage: faster than software compensation
  - Disadvantage: compensation voltage is specific to only one type of thermocouple wire at a time

Thermocouple - Example

- A type E thermocouple is used to measure T = 80 K with T_{ref} = 40 °C, (313 K)
  - What voltage is measured at the meter?
  - What is the reference voltage?
  - If the voltage resolution is 0.01 mV, what is the temperature resolution?



32 to 392°F
0 to 200°C

LIMITS OF ERROR
(whichever is greater)
Standard: 1.7°C or 0.5% Above 0°C
1.7°C or 1.0% Below 0°C
Special: 1.0°C or 0.4%

COMMENTS, BARE WIRE ENVIRONMENT:
Oxidizing or Inert; Limited Use in Vacuum or Reducing; Highest EMF Change per Degree

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

Nickel-Chromium
vs.
Copper-Nickel

Extension Grade

TYPE E
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

Thermoelectric Voltage in

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-9.835	-9.833	-9.831	-9.828	-9.825	-9.821	-9.817	-9.813	-9.808	-9.802	-9.797	-260
-250	-9.797	-9.790	-9.784	-9.777	-9.770	-9.762	-9.754	-9.746	-9.737	-9.728	-9.718	-250
-240	-9.718	-9.709	-9.698	-9.688	-9.677	-9.666	-9.654	-9.642	-9.630	-9.617	-9.604	-240
-230	-9.604	-9.591	-9.577	-9.563	-9.548	-9.534	-9.519	-9.503	-9.487	-9.471	-9.455	-230
-220	-9.455	-9.438	-9.421	-9.404	-9.386	-9.368	-9.350	-9.331	-9.313	-9.293	-9.274	-220
-210	-9.274	-9.254	-9.234	-9.214	-9.193	-9.172	-9.151	-9.129	-9.107	-9.085	-9.063	-210
-200	-9.063	-9.040	-9.017	-8.994	-8.971	-8.947	-8.923	-8.899	-8.874	-8.850	-8.825	-200
-190	-8.825	-8.799	-8.774	-8.748	-8.722	-8.696	-8.669	-8.643	-8.616	-8.588	-8.561	-190
-180	-8.561	-8.533	-8.505	-8.477	-8.449	-8.420	-8.391	-8.362	-8.333	-8.303	-8.273	-180
-170	-8.273	-8.243	-8.213	-8.183	-8.152	-8.121	-8.090	-8.059	-8.027	-7.995	-7.963	-170
-160	-7.963	-7.931	-7.899	-7.866	-7.833	-7.800	-7.767	-7.733	-7.700	-7.666	-7.632	-160
-150	-7.632	-7.597	-7.563	-7.528	-7.493	-7.458	-7.423	-7.387	-7.351	-7.315	-7.279	-150
-140	-7										-6.907	-140
-130	-6										-6.516	-130
-120	-6										-6.107	-120
-110	-6										-5.681	-110
-100	-5										-5.237	-100
-90	-5										-4.777	-90
-80	-4										-4.302	-80
-70	-4										-3.811	-70
-60	-3										-3.306	-60
-50	-3										-2.787	-50
-40	-2										-2.255	-40
-30	-2										-1.709	-30
-20	-1										-1.152	-20
-10	-1										-0.582	-10
0	-0.582	-0.524				-0.292	-0.234	-0.176	-0.117	-0.059	0.000	0
0	0.000	0.059	0.118	0.176	0.235	0.294	0.354	0.413	0.472	0.532	0.591	0
10	0.591	0.651	0.711	0.770	0.830	0.890	0.950	1.010	1.071	1.131	1.192	10
20	1.192	1.252	1.313	1.373	1.434	1.495	1.556	1.617	1.678	1.740	1.801	20
30	1.801	1.862	1.924	1.986	2.047	2.109	2.171	2.233	2.295	2.357	2.420	30
40	2.420	2.482	2.545	2.607	2.670	2.733	2.795	2.858	2.921	2.984	3.048	40

°C	0											°C
350	24.9											
360	25.7											
370	26.5											
380	27.3											
390	28.1											
400	28.9											
410	29.7											
420	30.5											
430	31.3											
440	32.1											
450	32.9											
460	33.7											
470	34.5											
480	35.3											
490	36.1											
500	37.0											
510	37.8											
520	38.6											
530	39.4											
540	40.2											
550	41.0											
560	41.8											
570	42.6											
580	43.4											
590	44.2											
600	45.0											
610	45.900	45.980	46.061	46.141	46.222	46.302	46.383	46.463	46.544	46.624	46.705	610
620	46.705	46.785	46.866	46.946	47.027	47.107	47.188	47.268	47.349	47.429	47.509	620
630	47.509	47.590	47.670	47.751	47.831	47.911	47.992	48.072	48.152	48.233	48.313	630
640	48.313	48.393	48.474	48.554	48.634	48.715	48.795	48.875	48.955	49.035	49.116	640
650	49.116	49.196	49.276	49.356	49.436	49.517	49.597	49.677	49.757	49.837	49.917	650
660	49.917	49.997	50.077	50.157	50.238	50.318	50.398	50.478	50.558	50.638	50.718	660
670	50.718	50.798	50.878	50.958	51.038	51.118	51.197	51.277	51.357	51.437	51.517	670
680	51.517	51.597	51.677	51.757	51.837	51.916	51.996	52.076	52.156	52.236	52.315	680
690	52.315	52.395	52.475	52.555	52.634	52.714	52.794	52.873	52.953	53.033	53.112	690

0	0.000	0.059	0.1
10	0.591	0.651	0.7
20	1.192	1.252	1.3
30	1.801	1.862	1.9
40	2.420	2.482	2.5

-3	-2	-1	0	°C
-9.813	-9.808	-9.802	-9.797	-260
-9.746	-9.737	-9.728	-9.718	-250
-9.642	-9.630	-9.617	-9.604	-240
-9.503	-9.487	-9.471	-9.455	-230
-9.331	-9.313	-9.293	-9.274	-220
-9.129	-9.107	-9.085	-9.063	-210
-8.899	-8.874	-8.850	-8.825	-200
-8.643	-8.616	-8.588	-8.561	-190

T = 80 K = -193 °C

V_{meas} = V(T) – V_{ref} = -8.643 – 2.420 = -11.063 V

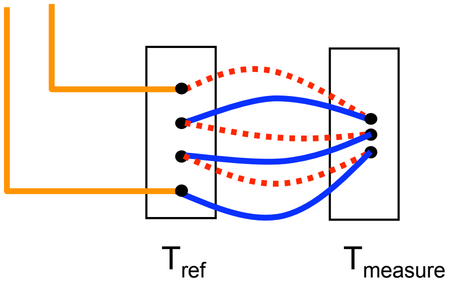
V_{ref} = 2.420 V

@ 80 K, dV/dT = 26.8 V/K

With dV = 10 V dT = 0.37 K

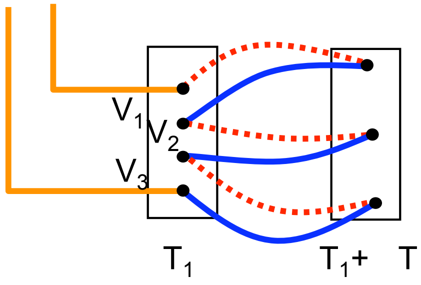
Thermopiles

- To increase signal:



  - A series connection of ‘n’ pairs
    - produces n times the emf
    - Reduces temperature error by ~ $\frac{1}{\sqrt{n}}$

- To determine a spatially averaged temperature



$$V_1 = \quad \left(T_1 + \quad T \qquad\right) \quad T_1 ($$

$$V_2 = \quad \left(T_1 + \quad T\right) \quad T_1 ($$

$$V_3 = \quad \left(T_1 + \quad T + \quad\right) \quad T_1 ($$

$$V_{total} = 3 \quad T$$

Cryogenic Thermocouples

- Commonly used types for cryogenic temperatures:
  - Type E: Ni-Cr, Cu-Ni (constantan)
    - Highest of types E, K, T (best down to 40 K)
    - Low thermal conductivity
  - Type K: Ni-Cr, Ni-Al
    - 8.5 V/K @ 20 K (vs. 4.1 V/K for type E)
  - Type T: Cu, Cu-Ni
  - Ag-Fe: high thermal power, but power decreases with time if stored at room temperature
- Important notes regarding use of thermocouples:
  - Voltage arises from region where dT/dl ≠ 0
  - Joints must be made in regions where dT/dl = 0
  - If used in presence of magnetic fields, ensure that along the TC path, temperature is constant in regions of changing field, or field is constant in regions of changing temperature. (= (H,T))
  - Minimize number of joints
  - Avoid dissimilar material joints at instrumentation feed-thru's
  - Heat sink TC wire before reaching the point of measurement

Thermometers - Considerations

- Temperature range
- Type of signal: voltage, capacitance
- Temperature sensitivity: change in signal per change in temperature
- Response time: size, thermal mass
- Mounting package
- Magnetic field sensitivity
- Strain sensitivity
- Repeatability (thermal cycling)
- Long term stability
- Radiation resistance
- Calibration
- Excitation requirement
- Cost

Thermometers - options

- Diodes (semiconductors): Si, Gas, GAlAs
  - Temperature dependent forward bias voltage
  - Small, fast response
  - Constant current source (10 A)
  - Very field dependent
  - Moderate sensitivity over large T-range
- PTC resistors (metal): Pt, Rh-Fe
  - Positive temperature coefficient
  - Very stable
  - Large size, slow response
  - Sensitive to magnetic fields
  - Fairly good sensitivity
  - Strain sensitive
- NTC resistors (semiconductors): CGR, GR, CR, RuO_2, Cernox™
  - Negative temperature coefficient
  - High sensitivity over limited temperature range (CGR, GR, CR)
  - Negligible field dependence (CGR, Cernox™, RuO_2), large field dependence (GR)
  - Strain sensitive   encapsulated   thermal sensing through the leads
  - Moderate response
- Capacitors
  - Insensitive to magnetic field
  - Sensing circuit requires care and attention

Resistance Thermometers

- Which thermometers would you choose for the following situations?
  - Winding of Tevatron magnet:

    Cernox™, CGR, Rox™
  - Fluids experiment in helium II:

    CGR, GR, Cernox™
  - Characterize performance of LH_2 liquefier:

    GR, Pt, Rh-Fe, Cernox™
  - Cool-down study of an 80 K cryocooler:

    Pt, TC, Si-diode, Cernox™

Thermometers

- Factors contributing to uncertainty:
  - Sensor sensitivity:

$$S_T = \frac{\%\,change\ in\ signal}{\%\ change\ in\ T} \qquad dimensionless\ sensitivity$$

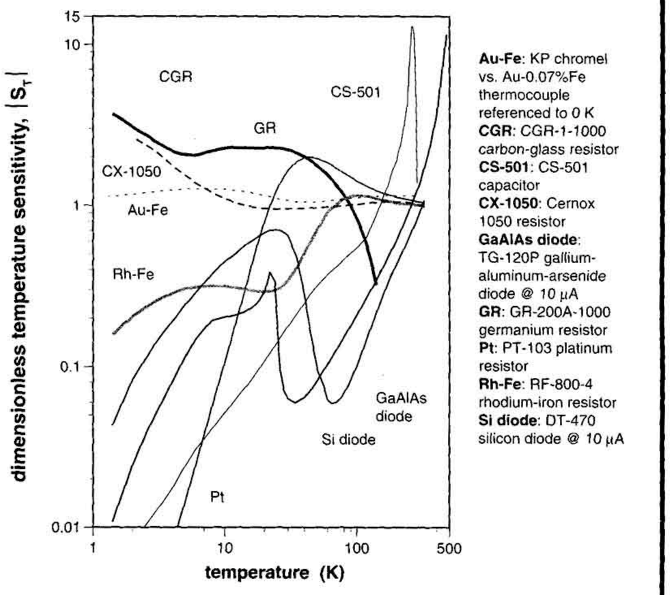
  - Voltmeter uncertainty

$$\frac{U_{T,V}}{T} = \frac{U_V/V}{S_T} = \%uncertainty\ in\ V \bullet \frac{\%change\ in\ T}{\%change\ in\ V}$$

  - Current source uncertainty

$$\frac{U_{T,I}}{T} = \frac{\left(U_I/I\right)\ R_d/R_s}{S_T};\quad R_d = \frac{dV}{dI},\quad R_s = \frac{V}{I}$$

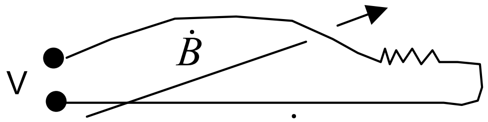
  - Calibration uncertainty – see mfc.
  - Thermal noise – usually negligible
  - Electromagnetic noise: $emf = \frac{dB}{dt} \bullet A$
    - •Twisted pairs
    - •Shielding – connect shield at one end only – preferably at signal source



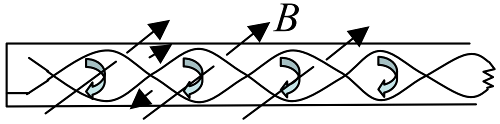
Au-Fe: KP chromel vs. Au-0.07%Fe thermocouple referenced to 0 K
CGR: CGR-1-1000 carbon-glass resistor
CS-501: CS-501 capacitor
CX-1050: Cernox 1050 resistor
GaAlAs diode: TG-120P gallium-aluminum-arsenide diode @ 10 μA
GR: GR-200A-1000 germanium resistor
Pt: PT-103 platinum resistor
Rh-Fe: RF-800-4 rhodium-iron resistor
Si diode: DT-470 silicon diode @ 10 μA

Figure 1. Absolute dimensionless temperature sensitivities of representative Lake Shore sensors.

Problem:



Solution:



- Combined total uncertainty:

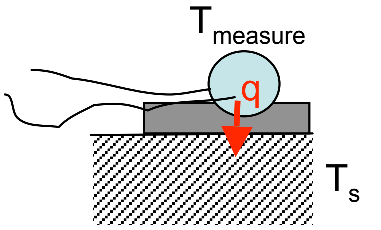
$$U_T = \left(\left(U_{T,V}\right)^2 + \left(U_{T,I}\right)^2 + \left(U_{T,Cal}\right)^2 + \left(U_{T,therm\_noise}\right)^2\right)^{1/2}$$

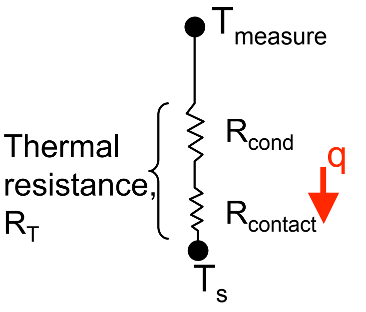
Thermometers

- Factors contributing to error (i.e. bias)

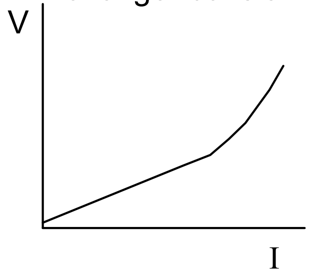
  "A thermometer always indicates a temperature intermediate between that of the region being investigated and any other environment with which the thermometer has thermal communication."

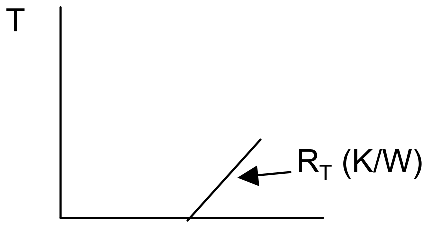
  – Self heating





As the current is increased, if T is no longer constant, then   is no longer constant

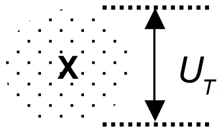




$$q(W) = I^2 R_e = \frac{T}{R_T}$$

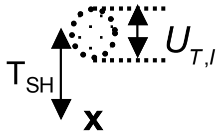
A compromise must be made between signal uncertainty and self-heating error

Low I:



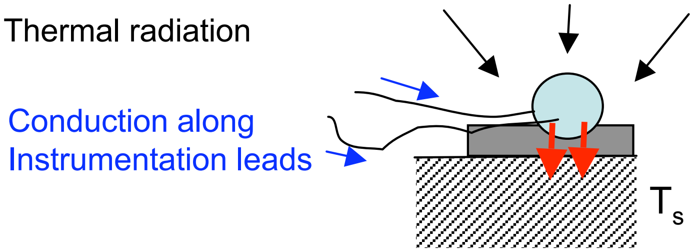
$$U_{T,I} = T\frac{U_I/I}{S_T}$$

High I:



Thermometers:
error factors (cont)

- Parasitic heat leak



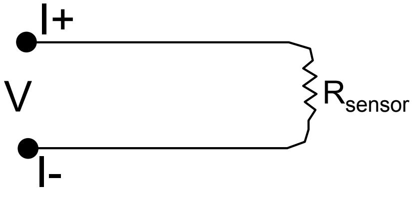
Example: 1 pair of 26 AWG (d=0.4 mm) copper wire, L = 1 m, T = 220 K

$$q_{cond} = \frac{A}{L} \; k(T)\,dT = 2\,\frac{\left(4x10^{\;4}\right)^2}{4}\,92x10^3 = 23\,mW$$

T = 23 mK, when R_T ~ 10 K/W

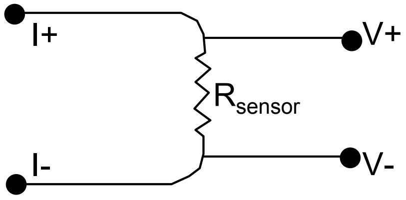
- Lead resistance

Problem:



V = I(R_{sensor} + R_{leads})

Solution: 4-wire connection



Thermometers:

error factors (cont)

- Thermal emf

Problem: the Seebeck coefficient of different materials, in regions of T produces a thermal emf, even when no current is flowing

Solution: reversing polarity, or multiple current levels

$$V = \left(V_1 + V_{emf}\right) \quad \left(\quad V_1 + V_{emf}\right) \; / \, 2 \qquad \left(\mathit{reverse\ polarity}\right)$$

$$V = \left(I_1 R + V_{emf}\right) \quad \left(I_2 R + V_{emf}\right) \qquad \left(\mathit{known\ values\ of\ I}\right)$$

$$R = \frac{\left(V\right)}{\left(I_1 \quad I_2\right)}$$

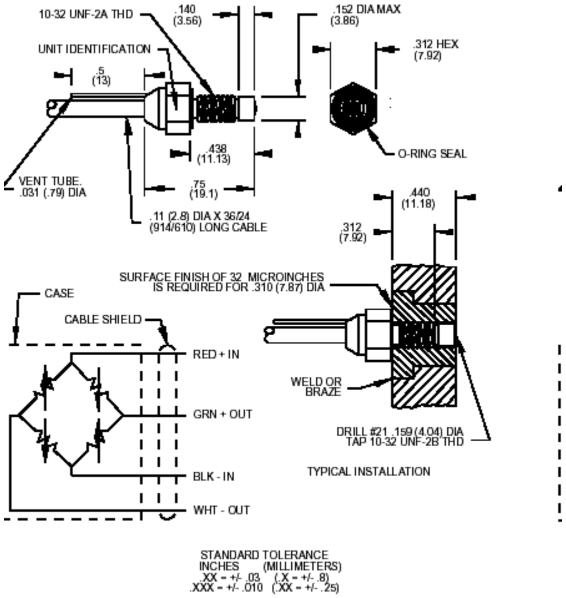
Thermometers: Do’s & Don’ts

- Thermally anchor leads as close to measurement temperature as possible (5 -10 cm length)
- Use twisted, shielded leads to minimize electromagnetic noise (connect shield at one end only)
- Minimize conduction heat load by using long lengths, small diameters, low thermal conductivity materials
- Follow recommended excitation levels to avoid self heating
- Isolate low-level signal leads from high-level signal leads
- Reverse polarity to cancel thermal emf components

Pressure

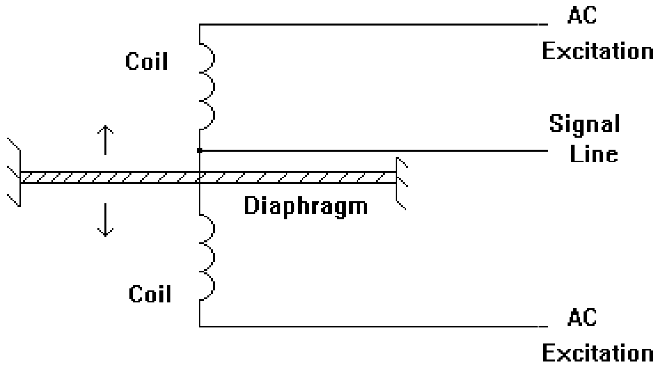
- Piezoresistive transducers
  - Resistance bridge – 4 active arm strain-gauge
  - Calibration required <u>at temperature</u>
  - Example: Endevco 8510B
  - Typical price: ~ $1K per each
- Pressure capillary extension
  - Extend capillary from cold environment up through cryostat to room temperature environment
  - Ensure leak-tight
  - Check mean free path length for low pressure (vacuum) applications

Actual size



Pressure

- Variable reluctance transducers
  - Magnetically permeable stainless steel diaphragm clamped between inductive pick-up coils
  - Diaphragm displacement changes induction of both coils
  - AC bridge / amplifier circuit converts inductive change to proportional DC output voltage



Variable Reluctance Circuit

Cryogenic flow metering techniques

Single phase flows

1. Pressure drop devices based on Bernoulli Principle
   a) Venturi
   b) Orifice plate
   c) Pitot tube

$$p = \frac{1}{2} \quad v^2$$

2. Friction pressure drop (laminar flow elements)
3. Hot wire anemometers based on h = f(v)
4. Acoustic flow meters based on Doppler effect
5. Turbine flow meters where frequency ~ velocity
6. Optical techniques (Laser Doppler)

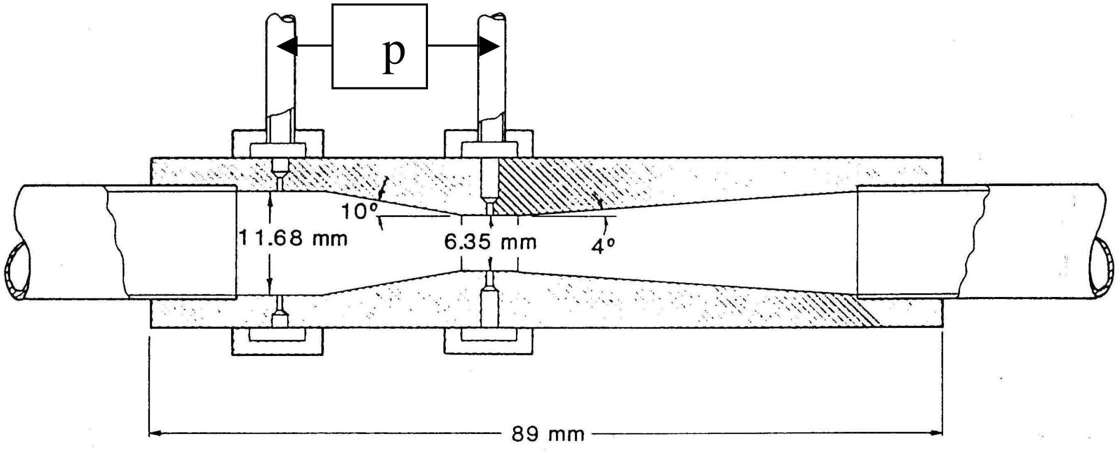
Two phase flows

1. Void fraction measurement (A_v/A)
   a) Capacitance measurement
   b) Optical absorption
2. Quality measurement (m_v/m)

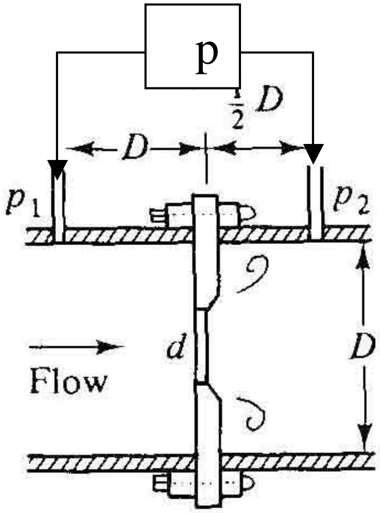
These techniques are for the most part all used in classical fluid flows.

The unique "cryogenic" features have to do with instrumentation used to detect signal and need for low heat leak.

Pressure drop devices



Venturi



Orifice

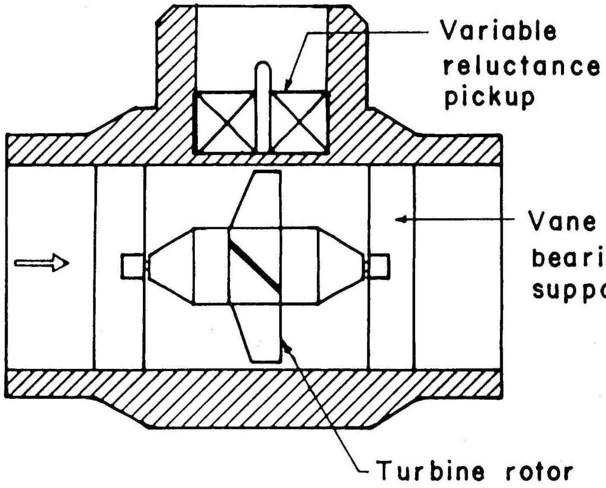
- Venturi flow meters have advantage over orifice plate due to low loss coefficient

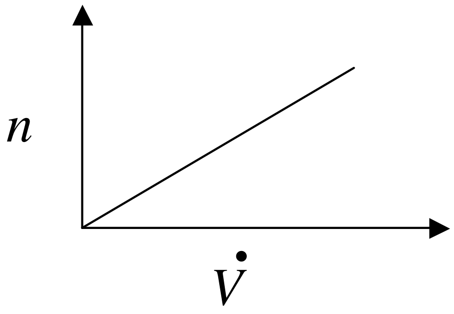
$$\dot{V} = A_t v_t = C_d A_t \, {\frac{2\ \ p/}{1 \qquad {}^{2}}}^{1/2} \qquad \text{where} \quad = D_t/D$$

- C_d is the discharge coefficient (~ 1 for venturi & 0.6 for orifice)
- Pressure transducer should be located at low temperature, if possible
- Require determination of density at meter inlet

Turbine flow meters

- Rotation speed is proportional to volumetric flow rate
- Linear response function allows a wide range of operation

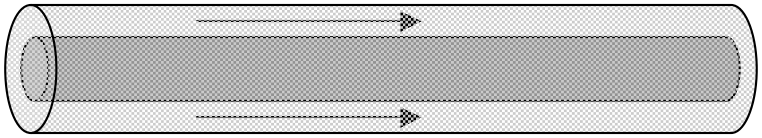




$$\dot{V} = \frac{D_b A_f}{\tan\ {}_b} n = Kn$$

Two phase flow measurement

- Measurement of flow quality (m_v/m) in a two phase mixture (liquid + vapor) is difficult.
  - Vapor velocity and liquid velocity may be different
  - Flow regime is not known
- Measurement of void fraction (A_v/A) is more straightforward
  - Capacitive meter based on different dielectric constant



Co-axial capacitor

  - Optical techniques

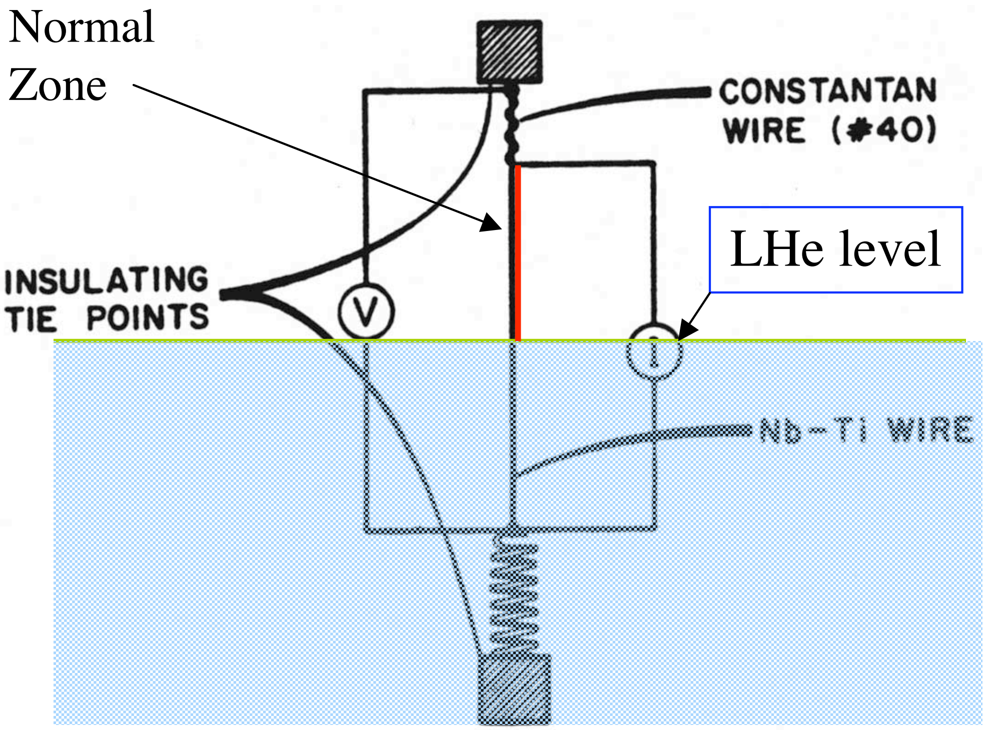
- Total mass flow rate can be determined in some part of the circuit where the fluid is single phase using a conventional flow meter

Liquid level measurement techniques

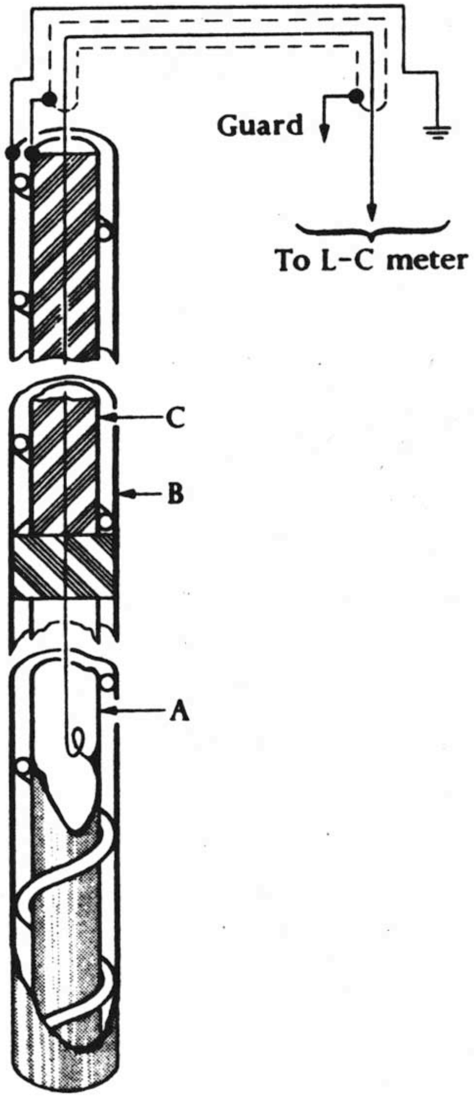
- Continuous level measurement
  - Superconducting wire level device
  - Capacitive level measuring systems
  - Transmission line system
  - Ultrasonic level measurement
  - Hydrostatic (head) level measurement
- Discrete level measurement
  - Liquid-vapor detectors (resistive, superconducting)
  - Acoustic “Dip stick” method
- Mass measurement (gauging)

Superconducting wire level meters

- Developed by Efferson (1970), but now a commercial product
- Heater drives the normal zone of SC wire to the liquid interface, where it stops due to improved heat transfer
- Units are most often calibrated in LHe at 4.2 K
- Variable performance in He II due to improved heat transfer
- Some SC level meters based on HTS materials have been developed for LN_2



Capacitive Level Gauges



Most are custom, some are available
as a prototype commercial units, particularly
for high dielectric constant fluids (e.g. LN_2)

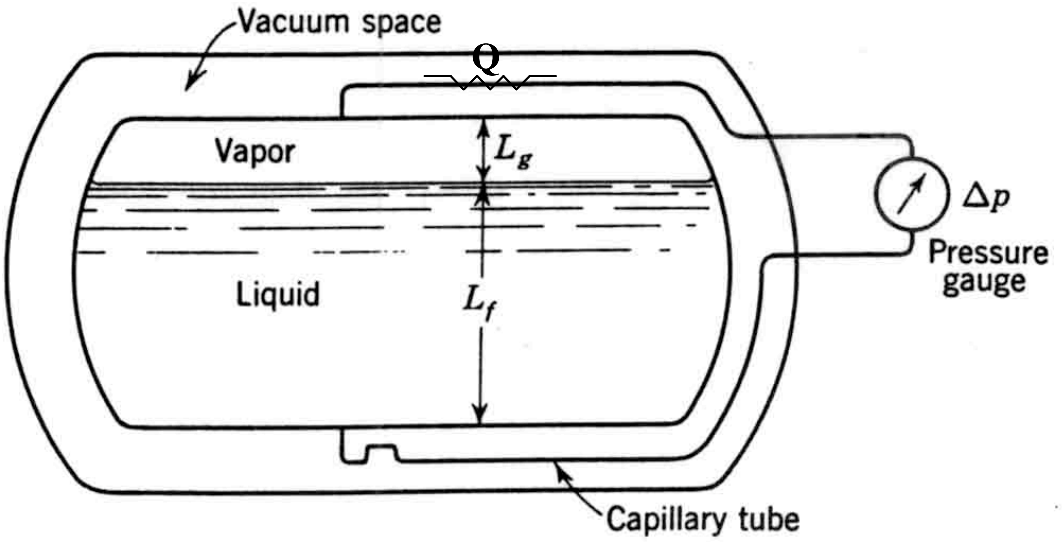
<u>Measurement Methods:</u>

- *AC Bridge*
- High frequency oscillator
- Time constant method
- Phase-lock loop technique

In-situ calibration necessary

Sensitivity = $\frac{dC}{dH_f} = \frac{2 \quad {}_0\left(\quad {}_f \quad\quad {}_g \right)}{\ln\left(D_0 / D_i\right)}$

Differential pressure (head) gauge



Requirements

- Pressure gauge must be located in cryostat
- dp/dL = Δ g

  = 1.42 $(Pa/mm)_{helium}$
- Heat load may be large to keep vapor line dry

$$L_{liquid} = \frac{{}^{p}\!/_{g} \qquad {}_{g}L_{total}}{{}_{l} \qquad {}_{g}}$$

	He	H_2	Ne	N_2	O_2	Ar
l	125	70.8	1240	861	1141	1394
g	16.7	1.33	9.4	4.6	4.47	5.77

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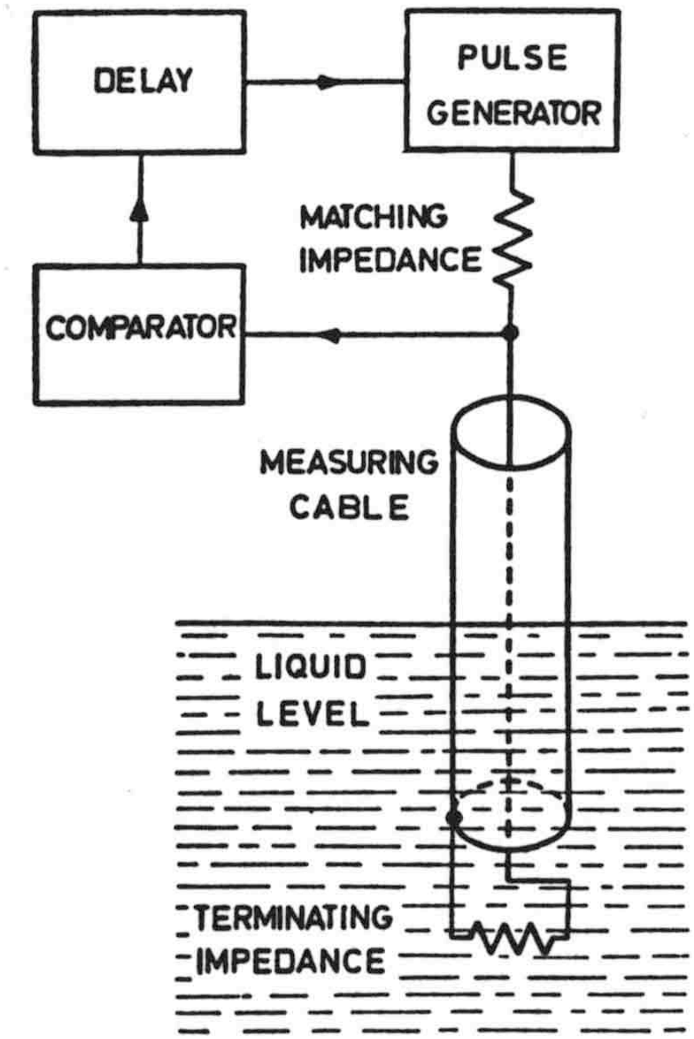
Transmission level technique



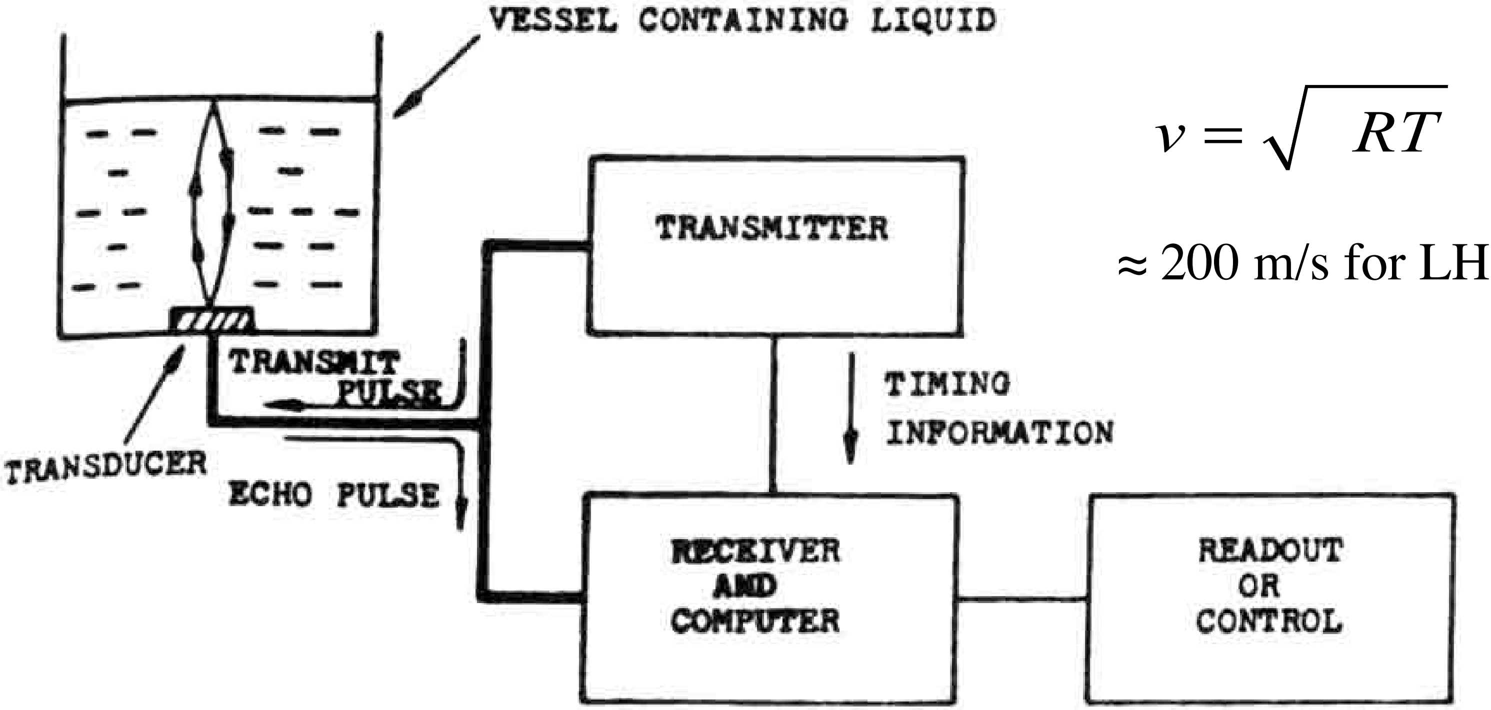
- Original system developed by Lindstrom, et al, Rev Sci Inst. (1970)
- Based on reflected signal in a coaxial line partially filled with liquid

$$Z_f = Z_g \sqrt{\frac{g}{f}}$$

- Probe design is easier than capacitor
- Small heat deposition and fast response makes device attractive

Ultrasonic level measurement

Signal travels at sound speed

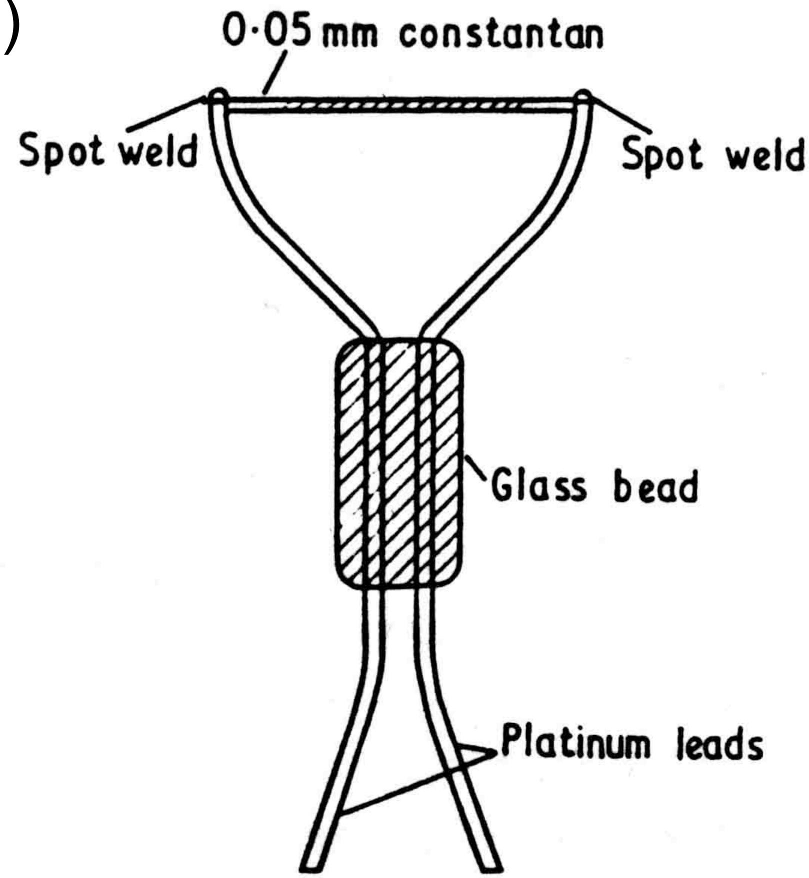


$$v = \sqrt{\ RT}$$

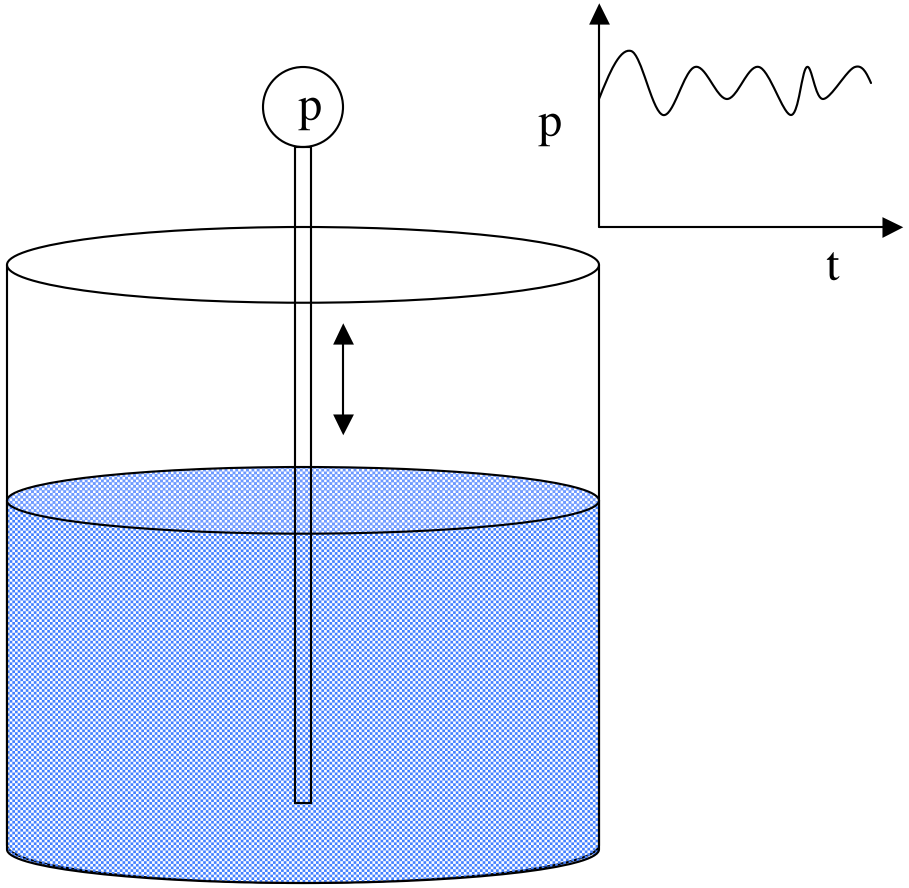
≈ 200 m/s for LHe

Discrete level measurement techniques

- Liquid vapor detection (LVD)
- Types of devices:
  - Superconducting thin films (SnAu)
  - Hot wire or film
  - Semiconductors
- Operating current must be sufficient to self heat the sensor in vapor, but not in liquid
- Sensor must be small to minimize heat generation in liquid



“Dip Stick” level measurement



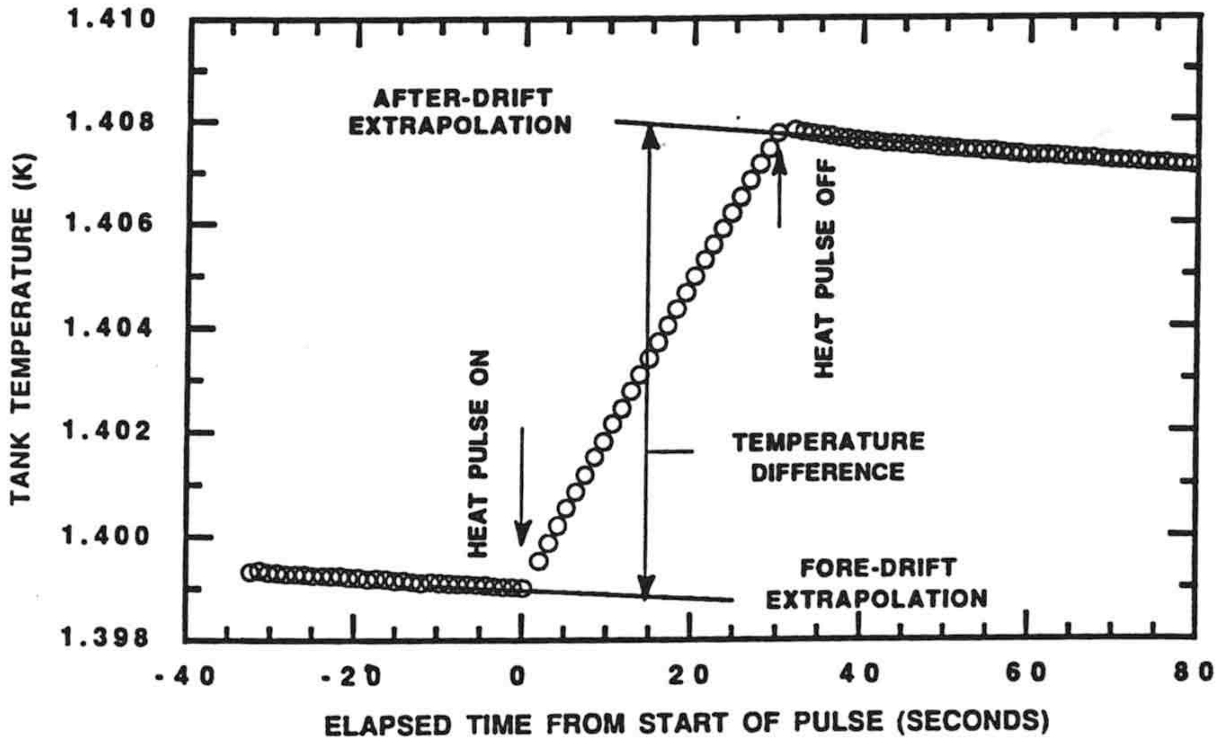
Acoustic oscillation changes frequency & amplitude when capillary leaves liquid

Heat Pulse Mass Gauging

- Measurement of He II volume (mass) by heat pulse technique

→ mass = Q/ h

- Technique used extensively for space based He II cryostats but also pressurized He II systems for superconducting magnets



From Volz, et al
Advances in Cryo. Engn.
Vol 35 (1990)

Summary of Level Measurement Techniques

		Availability	**Readout**	**Range of heat Deposition**
Continuous Level Measurement				
	Capacitive gauge	Prototype	Frequency	Less than 1mW
	Superconducting wire	Commercial	Voltage	Tens of mW's
	Transmission line	Development	Frequency	On the order of W
	Heat transfer based	Development	Power/temperature	Tens of mW's
	Floats	Development	Visual/voltage	Negligible
	Hydrostatic	Development	Pressure	On the order of mW's
	Ulrasonic	Development	Frequency	Less than 1 W
Liquid-Vapor Detectors				
	SC wire	Development	Voltage	On the order of mW's
	Resistive	Development	Voltage	On the order of mW's
	Ultrasonic	Development	Frequency	Less than 1 W
	Optical	Development	Light intensity	Less than 1 W
Mass gauging				
	Internal energy change	Development	Temperature	On the order of 1 Joule