

## Cryogenic Instrumentation I

### OUTLINE

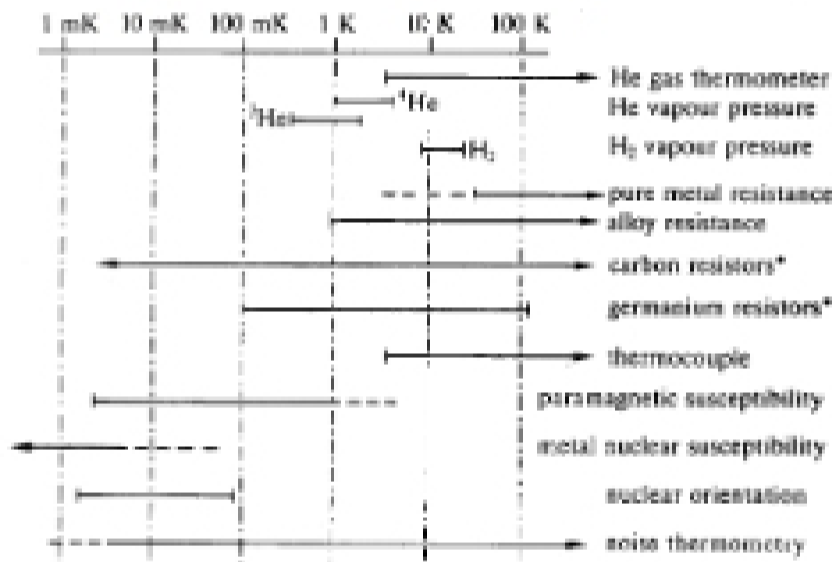
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## Thermometry

### THERMOMETER CHARACTERISTICS AND MEASUREMENT TECHNIQUES

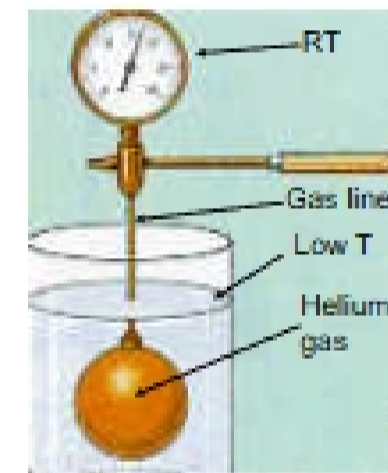
TYPE OF SENSOR	Primary or Secondary	Usual Temperature Range (°C)	Measure Technique	Size of use	Ability to Control Temperature	Typical Sensitivity $\frac{\Delta RT}{RT}$ (% in range of operation)	Magnetic Field Use	Cost
Constant Volume Gas	S	4 to 300	Pressure	Difficult	Medium	0.1	No	Low
Chromel/Cobalt Thermocouple	S	1.5 to 1000	Micro-Millivolt Force	Easy	Good	0.1	No	Low
Antimony-Silicon Diode Antimony Oxide-Carbon Carbon Carbon-Arsenic Platinum-Germanium	S	1.5 to 450 0.5 to 300 0.5 to 450 0.5 to 100 0.5 to 100	Current Voltage	Easy	Good	0.1 (may be made as small as 0.000001)	No Yes Yes Yes No	Modern
Vapor pressure	S	0.1 to 4.2	Pressure	Difficult	Medium	0.01	Yes	Modern
Capacitance	S	0.001 to 100	Capacitive	Medium	Good	0.0001	Excellent	Modern
No-Making Element Noble	F	0.001 to 1	Voltage	Very Difficult	Good	1	Yes	High
CANTHERM	S	0.001 to 0.1	Electronic Magnetic Susceptibility	Difficult	Good	0.001	No	Modern
Working Wire Platinum	S	0.001 to 0.2	AC resistance	Difficult	Good	1	No	Modern
Nuclear Magnetic Resonance (Proton)	S	0.00001 to 0.1	Nuclear Magnetic Susceptibility	Difficult	Poor	0.0	Mostly as Frequency	High
Nuclear Orientation	F	0.001 to 0.01	γ-ray detector	Very difficult	Poor	1	No	High

## Temperature Ranges of Application



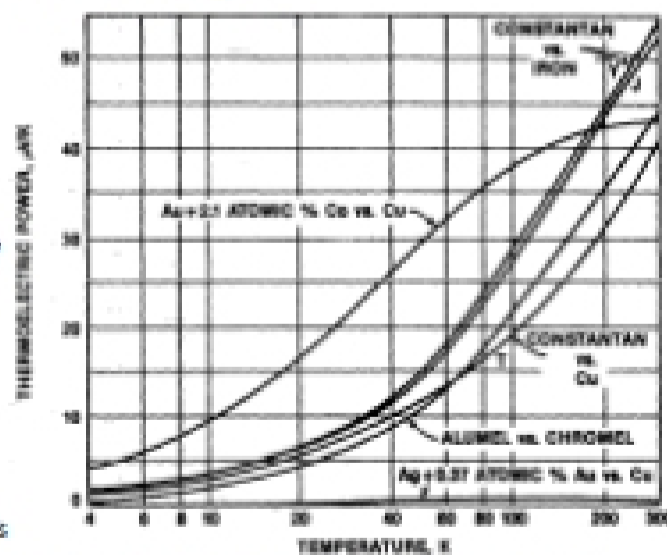
## Constant Volume Thermometer

- Named after Sir Francis Simon
- Helium is an ideal gas down to 5 K
- Modern versions use in situ pressure gauges at low T with electrical read-out (no gas line from RT to Low T)



## Thermocouples

Wires of 2 different metals (pure or alloy) when joined and connected to a volt meter produce a voltage related to temperature. At right is the sensitivity of various common thermocouples, perhaps the simplest, least expensive, and most common thermometer in use. Usually a reference junction in an ice bath is used to make the measurement absolute.



Calibrations are tabulated (e.g. type K)

Figure adapted from *Cryogenic Engineering* by Thomas M. Flynn, Addison-Wiley (1997), p. 138

## Thermometer Time Response Data

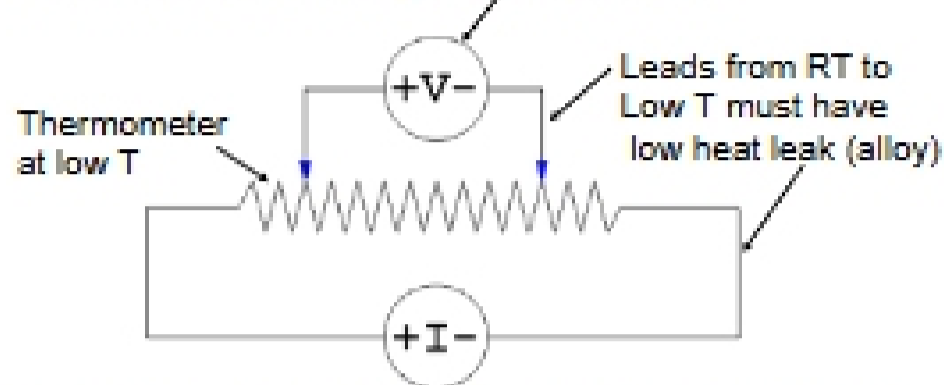
Differences between wet and dry can be exploited for level detection

WET DRY MILLISECONDS		WET DRY MILLI-INCHES	
100	50	200	100
RESISTIVE (Plat wire)	100	RESISTIVE (Thermistor)	10
CAPACITIVE (Type I)	10	RESISTIVE (Plat wire)	10
PIEZO-ELECTRIC	10	OPTICAL	10
MAGNETO-STRUCTIVE	10	PIEZO-ELECTRIC	10
RESISTIVE (Carbon)	10	CAPACITIVE (Type I)	10
OPTICAL	10	MAGNETO-STRUCTIVE	10
CAPACITIVE (Type II)	10	RESISTIVE (Carbon)	10
VIBRATORY	10	CAPACITIVE (Type II)	10
RESISTIVE (Thermistor)	10	VIBRATORY (Paddle)	10

Figure adapted from *Cryogenic Engineering* by Thomas M. Flynn, Addison-Wiley (1997), p. 139

### 4 Terminal Resistance Measurement

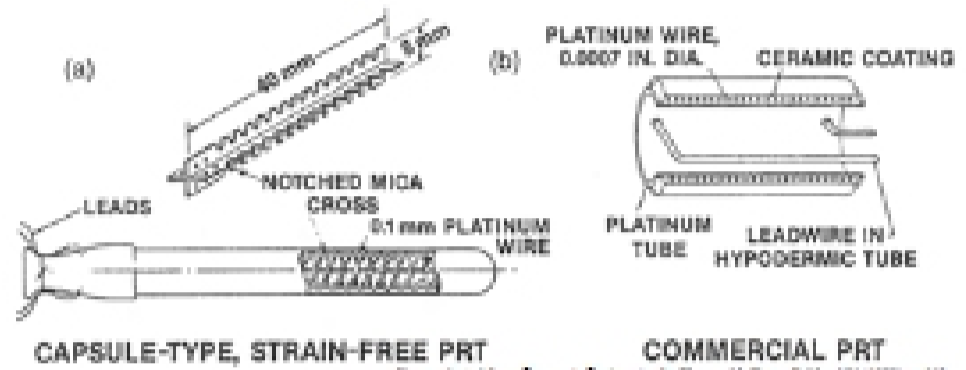
Meter at RT must have high input impedance



Current source must be stable and reversible. Average of readings with current flowing in opposite directions gives correct voltage drop, canceling thermal emfs. Often, low frequency ac source is used, with lock-in detector as volt meter, to improve sensitivity.

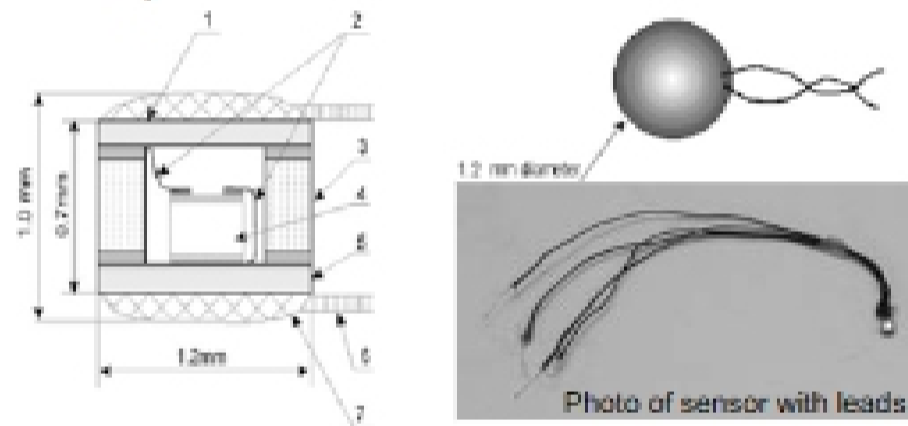
### Pt (pure metal) thermometer

- Resistance thermometer—use 4 terminal set-up
- R is almost proportional to T:  
Callender-VanDusen Equation:  $R(T) = R_0[1 + AT + BT^2 + C(T-10)^3]$   
(0 K < T < 300K)
- Other calibrations available down to 20 K
- Purity determines calibration (A, B, C)-no individual calibration required
- Transfer standard used by NIST

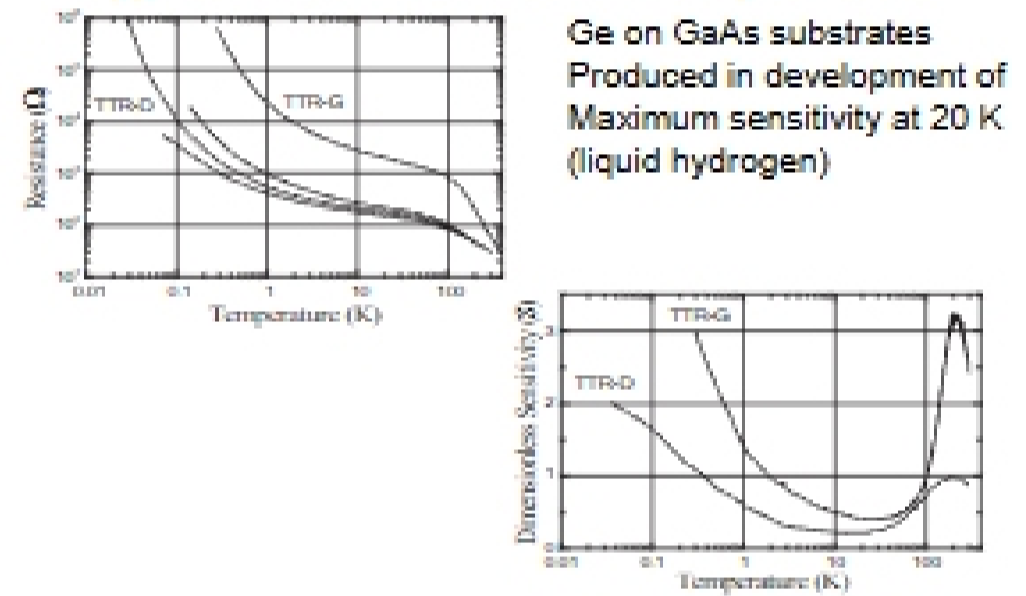


### Typical Resistive Thermal Sensor

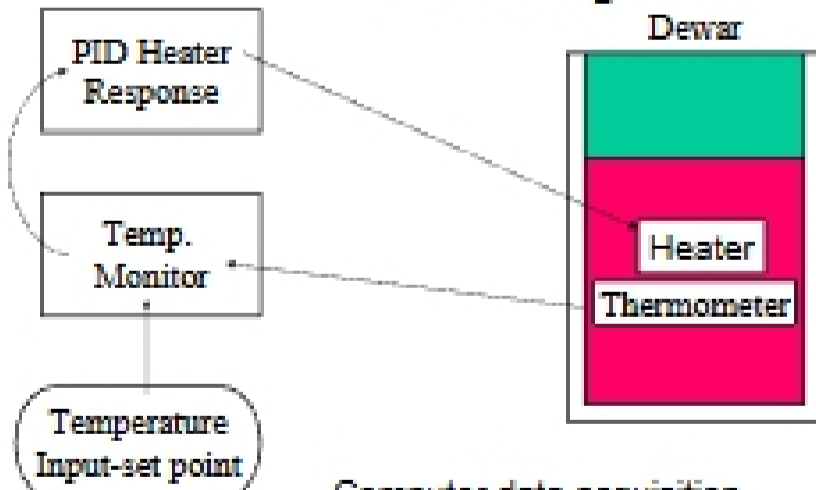
Cross-section: Details of construction showing strain-free mounting of chip (#4) inside hermetically sealed container



### Typical Resistance and Sensitivity Curves

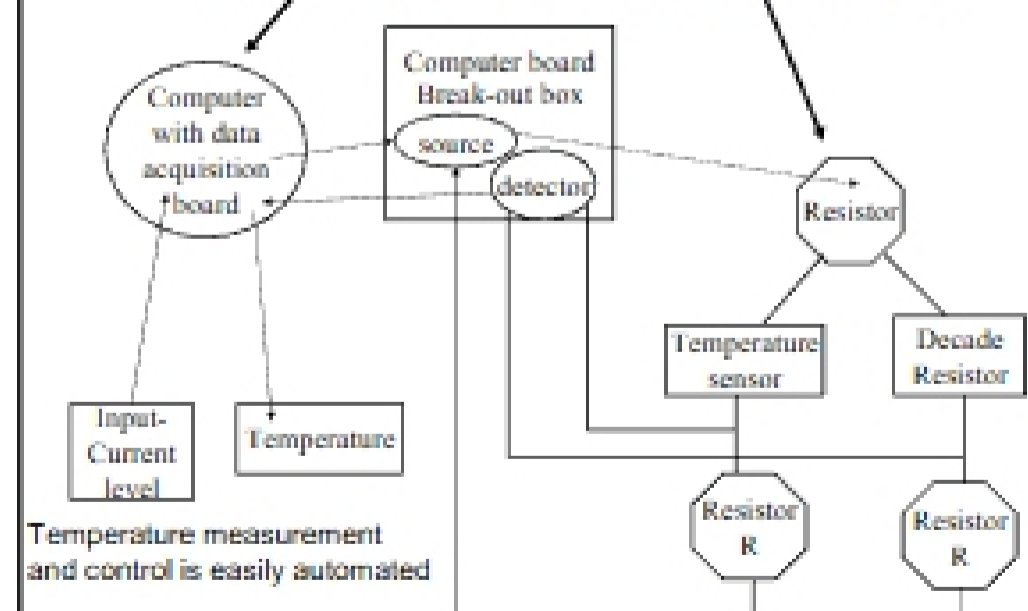


### Thermal Regulation Dewar



Computer data acquisition board may be used for all electronics

### Data Collection/Wheatstone Bridge



## Cryogenic Instrumentation II

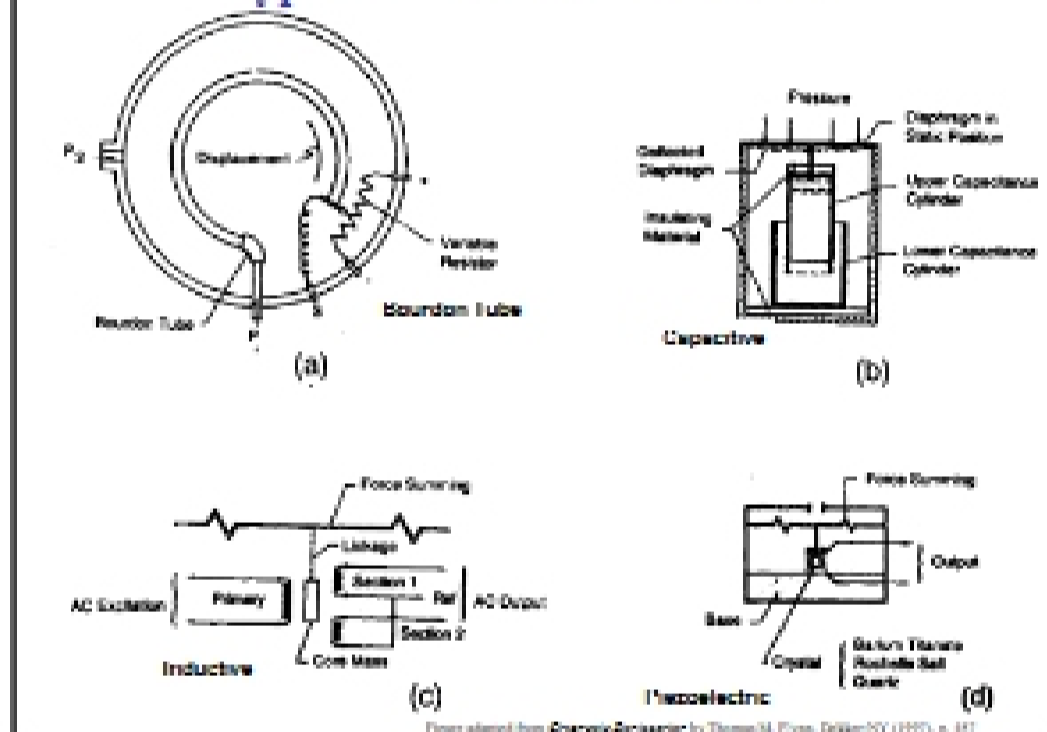
### OUTLINE

1. Pressure Measurements
2. Pressure Transducers Characteristics
3. Thermal Conductivity Measurements
4. Example: Ortho-Para Ratiometer
5. Level Detection-Point
6. Level Detection-Continuous
7. Thermometer Time Response Data-again
8. Flow Metering

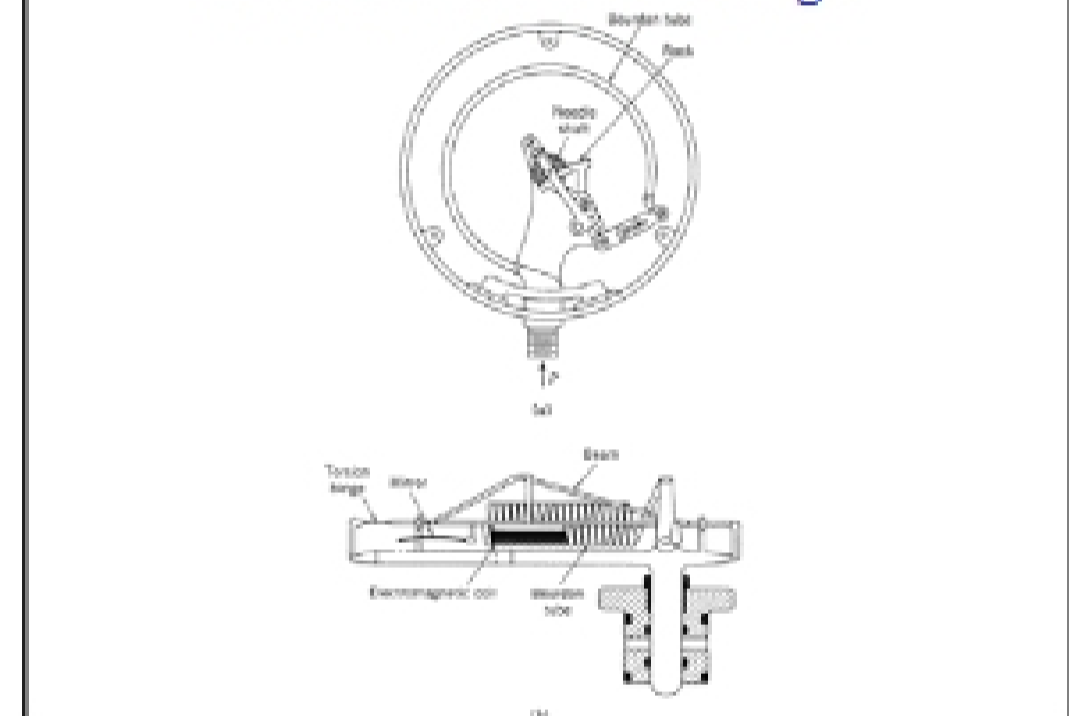
## Pressure measurement at Low Temperature

- Pressure is a force applied to an area, so its measure involves the conversion of a force measurement to some measurable parameter
- Converters, or transducers may be:
  - > Electrical:
    - Capacitive-diaphragm
    - Inductive-reluctive
    - Resistive-strain gauge
  - > Mechanical-spring
  - > Piezoelectric-quartz crystal
- These devices may often be connected to low temperature volumes using small tubes, avoiding cooling the transducer
- Most transducers operate at low temperature, although sensitivity and calibration are usually changed
- Low temperature devices often work better than at room temperature because the environment is more controlled

## Typical Pressure Transducers



## Mechanical Pressure Gauge



## Characteristics of Transducers

Characteristic	Strain gauge	Capacitive	Crystal	Reluctance
Frequency response, Hz	To 40 kHz	To 100 kHz	0.5-1 MHz	1 kHz (approx.)
Maximal sensitivity, % full scale	0.5	1.0	0.5	1.0
Thermal stability	Excellent for compensated inductive winding	Average, temperature drift, 0.02%/°F	Good	Average, 0.02%/°F
Linearity, %	0.1	1.0	0.5	1.0
Response to vibration, shock, acceleration	Negligible for light diaphragm and fully rigid types	Low for reasonable	Can be appreciable; also highly sensitive to electrical noise	Low but noticeable; about 1.0%/100 G
Drift, %	Negligible	1.0 (including compensation)	Negligible	2.0
Hysteresis, %	Approx. 0.1	1.0	Negligible	0.5
Open-circuit full-scale output	Order of 50 mV	Order of 5 V	Order of 1 mV	Order of 3 V
Overload, %	Generally about 100 to 500 for special types	Order of 100	Satisfactory for elastic limit of crystal; poor for higher loads	Order of 100
Typical pressure sensing device	Tube or diaphragm	Diaphragm	Crystal	Diaphragm or reeded torsion wire

## Temperature Dependence of Transducer Output

