CAE 553 Measurements and Instrumentation in Architectural Engineering
Fall 2018

September 4, 2018
Fundamentals: Temperature and humidity

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Last week

- Data acquisition
- Uncertainty analysis
- Error propagation
- QA/QC
- Data analysis basics

- Assignment 1 due today

TEMPERATURE MEASUREMENT

Temperature Measurement

- Goal: To quantify temperature beyond qualitative physiological experience

- Temperature measurements are based on the Zeroth Law of Thermodynamics:

  - *"If two bodies are in thermal equilibrium with a third body, they are in thermal equilibrium with each other"*

  - *"Two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact"*

Temperature Scales

- What are the temperature scales?
  - SI System?
  - English (IP) System?
- What is absolute temperature?
- Two-point scales are based on the ice and water temperature. What is the value for:
  - SI system?
  - IP system?

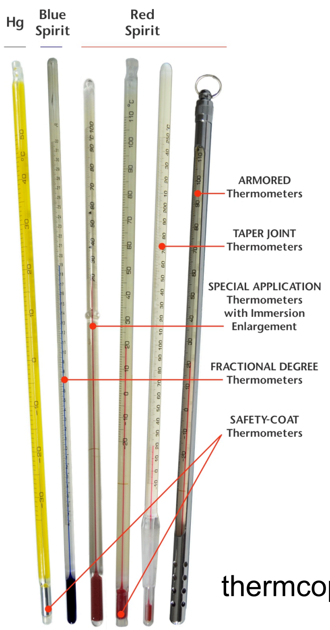
Common Temperature Measurement Techniques

Liquid-in-Glass Mercy
(Discontinued as of March 2011)

Resistance thermometers

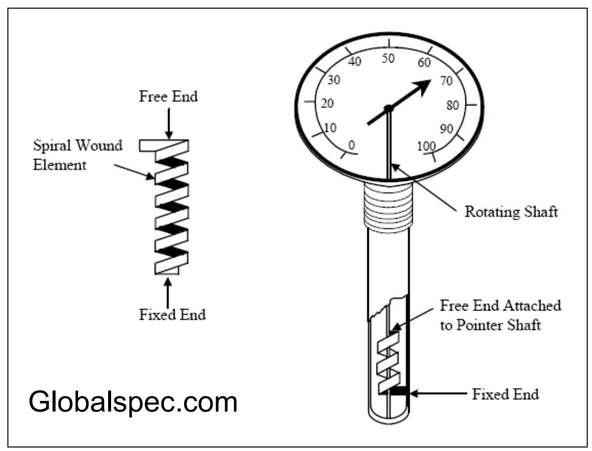
Omega.com

Thermocouple



thermcoproducts.com

Liquid-in-Glass



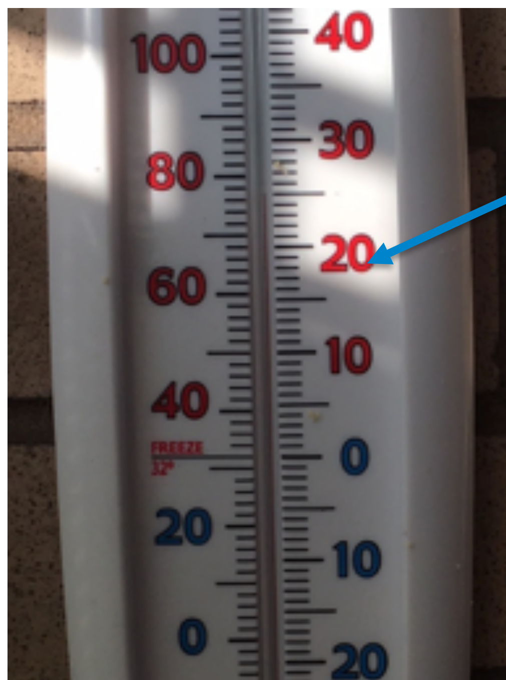
Bimetallic Thermometers

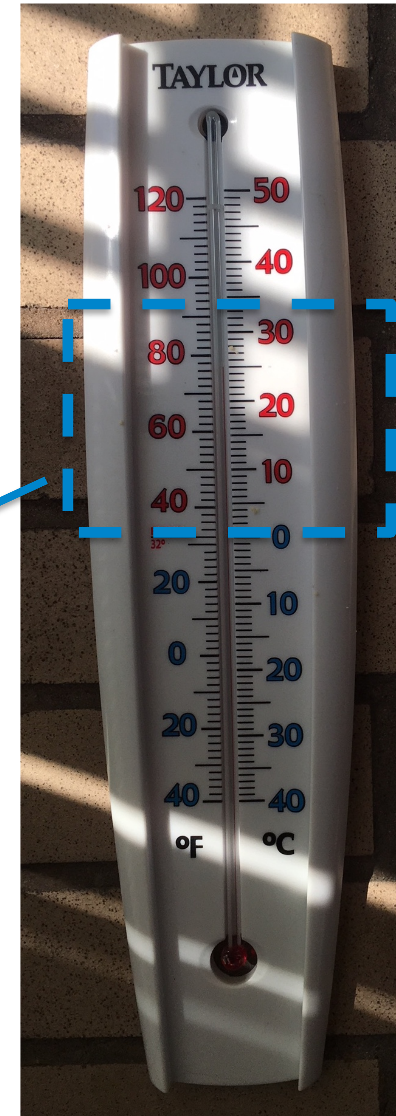
Common Temperature Measurement Techniques

- These techniques work based on:
  - Increase or decrease in size (e.g. expansion or contraction)
  - Increase in pressure
  - Change of color
  - Change of state
  - Change of surface radiation
  - Change of electrical resistance
  - Generation of electromotive force

- What factors influence the selection of measurement technique?

Common Temperature Measurement Techniques





Common Temperature Measurement Techniques

Measurement Means	Application	Approximate Range, °F	Uncertainty, °F	Limitations
Liquid-in-glass thermometers				
Mercury-in-glass	Temperature of gases and liquids by contact	–36/1000	0.05 to 3.6	In gases, accuracy affected by radiation
Organic fluid	Temperature of gases and liquids by contact	–330/400	0.05 to 3.6	In gases, accuracy affected by radiation
Resistance thermometers				
Platinum	Precision; remote readings; temperature of fluids or solids by contact	–430/1800	Less than 0.0002 to 0.2	High cost; accuracy affected by radiation in gases
Rhodium-iron	Transfer standard for cryogenic applications	–460/–400	0.0002 to 0.2	High cost
Nickel	Remote readings; temperature by contact	–420/400	0.02 to 2	Accuracy affected by radiation in gases
Germanium	Remote readings; temperature by contact	–460/–400	0.0002 to 0.2	
Thermistors	Remote readings; temperature by contact	Up to 400	0.0002 to 0.2	
Thermocouples				
Pt-Rh/Pt (type S)	Standard for thermocouples on IPTS-68, not on ITS-90	32/2650	0.2 to 5	High cost
Au/Pt	Highly accurate reference thermometer for laboratory applications	–60/1800	0.1 to 2	High cost
Types K and N	General testing of high temperature; remote rapid readings by direct contact	Up to 2300	0.2 to 18	Less accurate than Pt-Rh/Pt or Au/Pt thermocouples
Iron/Constantan (type J)	Same as above	Up to 1400	0.2 to 10	Subject to oxidation
Copper/Constantan (type T)	Same as above; especially suited for low temperature	Up to 660	0.2 to 5	
Ni-Cr/Constantan (type E)	Same as above; especially suited for low temperature	Up to 1650	0.2 to 13	
Bimetallic thermometers	For approximate temperature	–4/1200	2, usually much more	Time lag; unsuitable for remote use
Pressure-bulb thermometers				
Gas-filled bulb	Remote reading	–100/1200	4	Use caution to ensure installation is correct
Vapor-filled bulb	Remote testing	–25/500	4	Use caution to ensure installation is correct
Liquid-filled bulb	Remote testing	–60/2100	4	Use caution to ensure installation is correct
Optical pyrometers	For intensity of narrow spectral band of high-temperature radiation (remote)	1500 and up	30	Generally requires knowledge of surface emissivity
Infrared (IR) radiometers	For intensity of total high-temperature radiation (remote)	Any range		
IR thermography	Infrared imaging	Any range		Generally requires knowledge of surface emissivity
Seger cones (fusion pyrometers)	Approximate temperature (within temperature source)	1200/3600	90	

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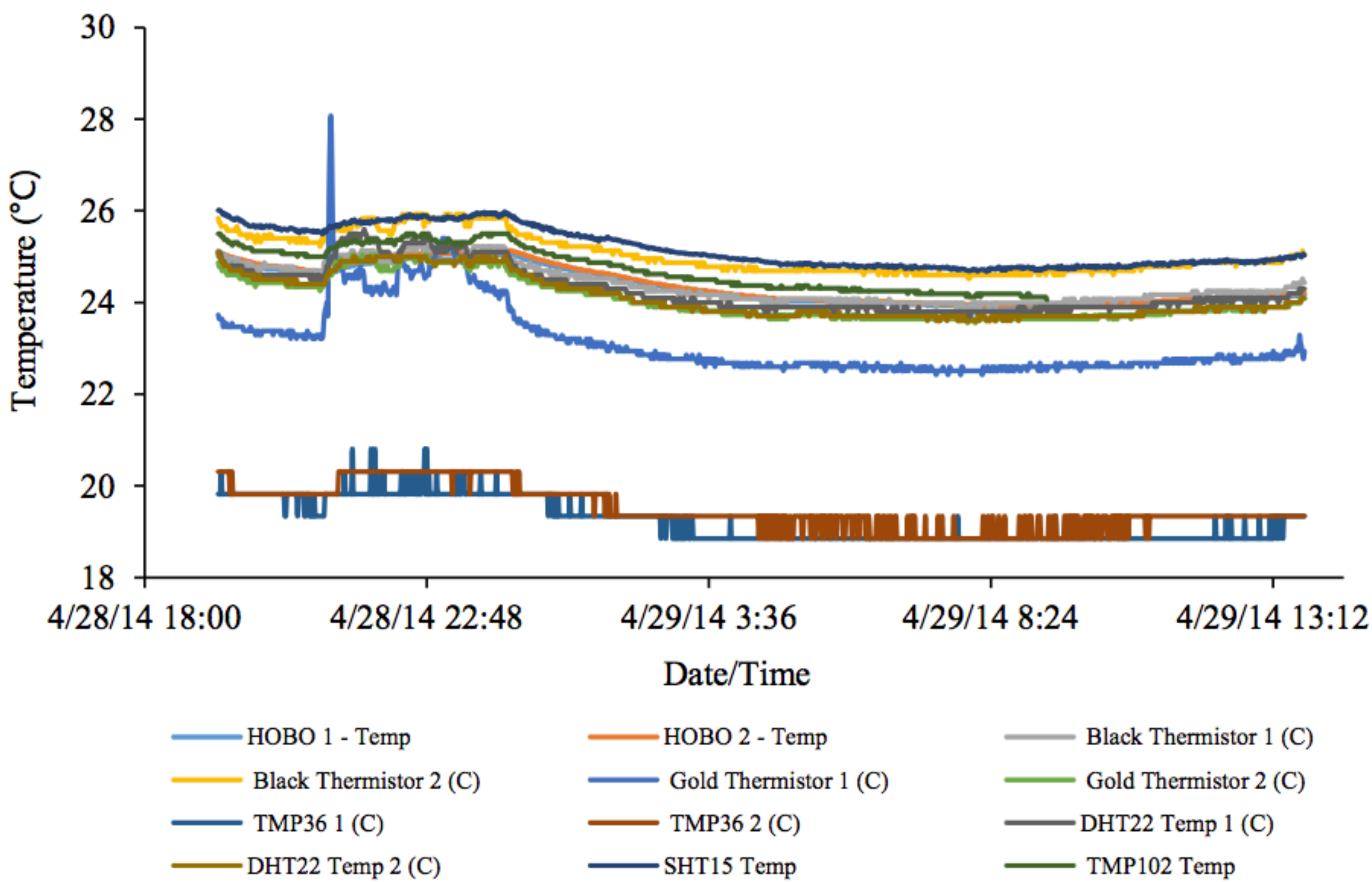
Temperature Measurement

- Relate the temperature sensor output to acceptable temperature scale
- Follow specifications of the manufacturer or calibrate the sensor against a temperature standard
- Rely on the International Temperature Scale of 1990 (ITS-90)
- ITS-90 is an equipment calibration standard for measurements
- Understand that ITS-90:
  - Is in Kelvin (K)
  - Each size equals to the fraction 1/273.16 of the thermodynamic temperature of the triple point of water
  - The National Institute of Standards and Technology (NIST) provides calibration based on this scale for laboratories

Does this stuff really matter?

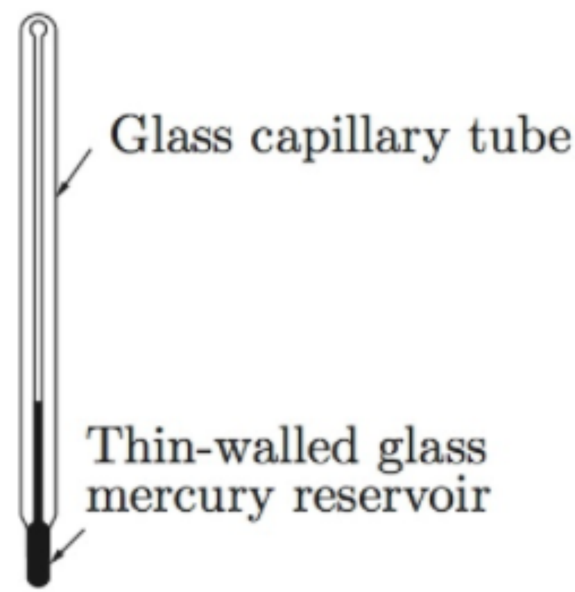


Akram Ali, IIT M.S. thesis 2015

FLUID THERMOMETERS

Mercury-in-Glass Thermometer

- Thermometer entails any device that changes monotonically with temperature
- Typically referred as the liquid-in-glass thermometer
- Very common in temperature measurements
  - Very high accuracy
  - Low cost
- Range of mercury-filled thermometers are from −37.8°F to 1000°F (Discontinued)



Mercury-in-Glass Thermometer

- Why mercury?
- How can we increase the upper limit of measurement? If there is a solution what would be the limiting factor beyond the fluid?
- How about the lower limit?

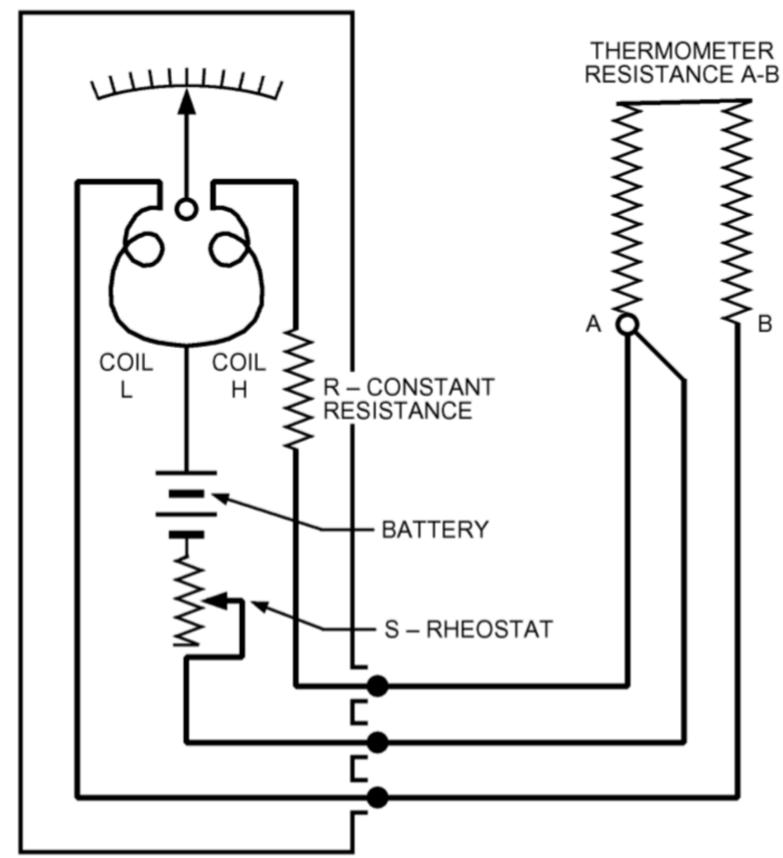
Resistance Thermometers

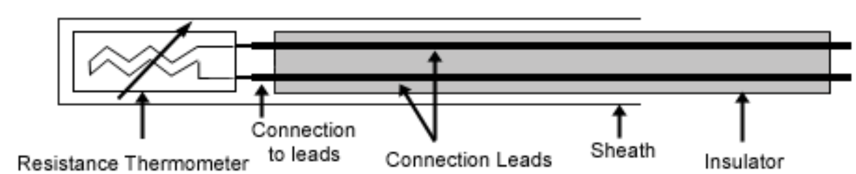
- Depend on a change of the electrical resistance of a sensing element (usually metal; pure material) with a change in temperature

- Increase in resistance due to the increases in temperature

- Avoid using it for temperature measurements over 1000°F

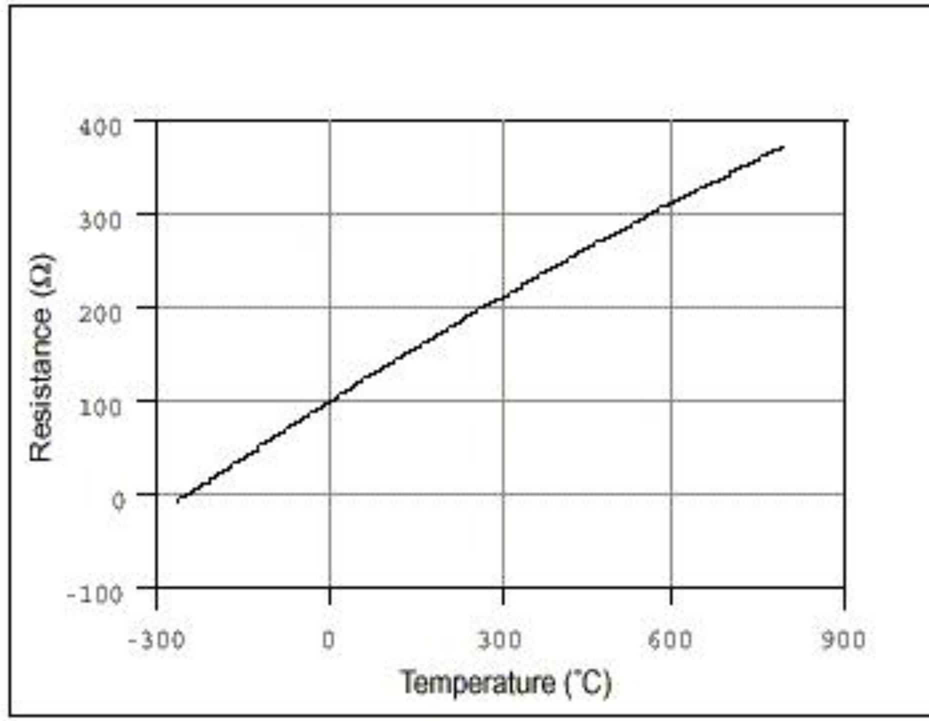
- Typically 3 lead metals





Resistance Temperature Devices

- Categorized by the material:
  - Platinum
  - Rhodium-iron
  - Nickel
  - Nickel-iron
  - Tungsten
  - Copper
- Also by:
  - Simple circuit designs
  - High degree of linearity
  - Good sensitivity
  - Excellent stability
- What’s the selection criteria?

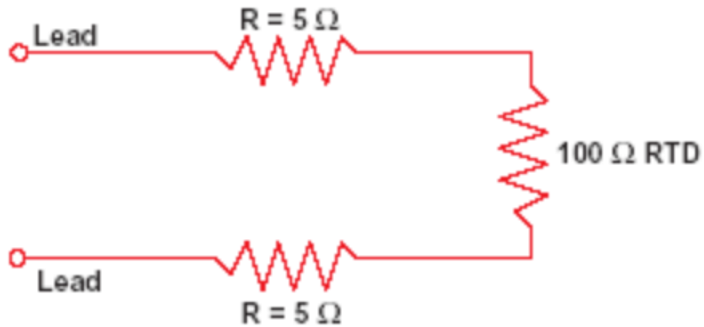


Resistance Temperature Devices

- Platinum RTDs:
  - Widely used for HVAC applications
  - Are extremely stable and corrosion-resistant
  - Are highly malleable and can thus be drawn into fine wires
  - Can be manufactured inexpensively as thin films
  - Have wide range of applications from 13.8033 K (triple point of equilibrium hydrogen) to 1234.93 K (freezing point of silver)
  - Have one of the most linear relationships
  - Designed with a resistance of 100 Ω at 32 °F

Resistance Temperature Devices

2-wire

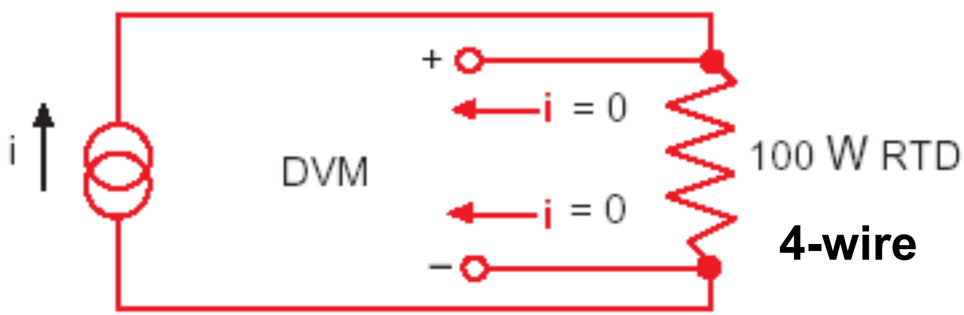


EFFECT OF LEAD RESISTANCE

3-wire

WHEATSTONE BRIDGE

4-wire

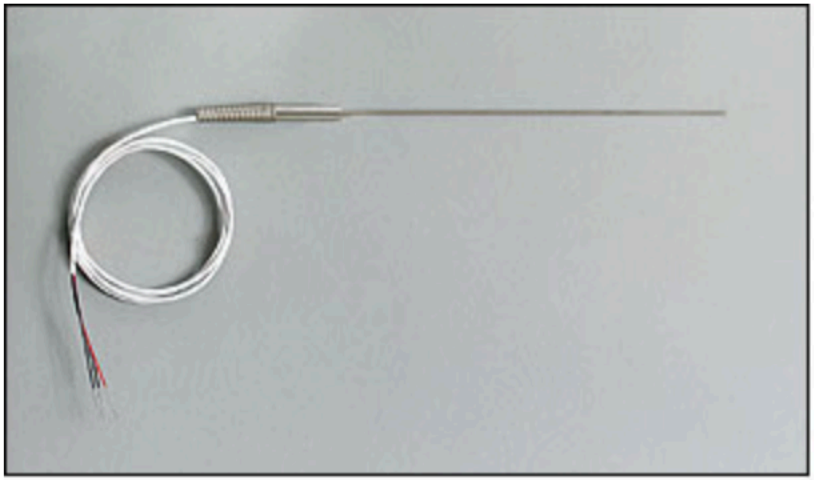


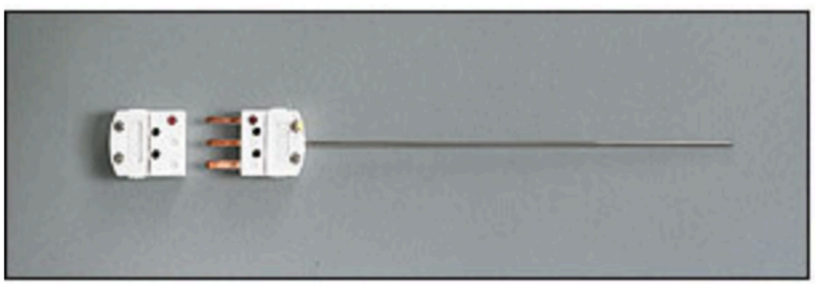
4-WIRE OHMS MEASUREMENT

Omega.com

https://www.omega.com/techref/rtd-measurement-and-theory.html

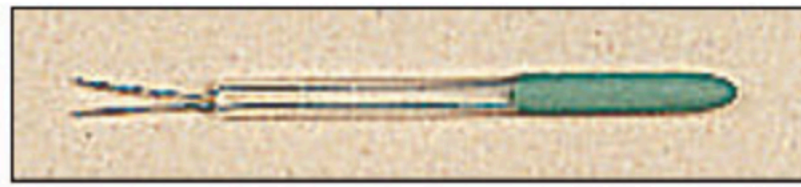
Resistance Temperature Devices



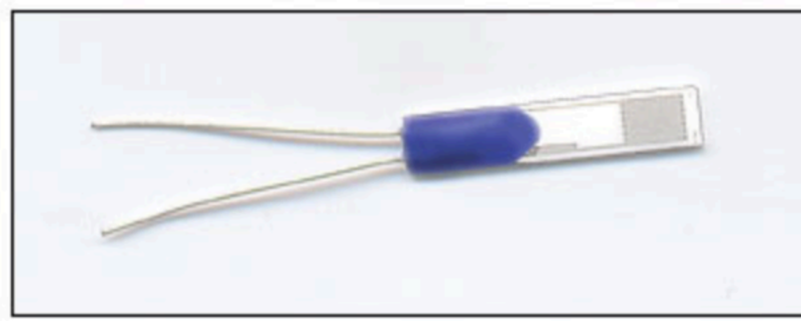


Typical RTD Probes

Thick Film Omega Film Element



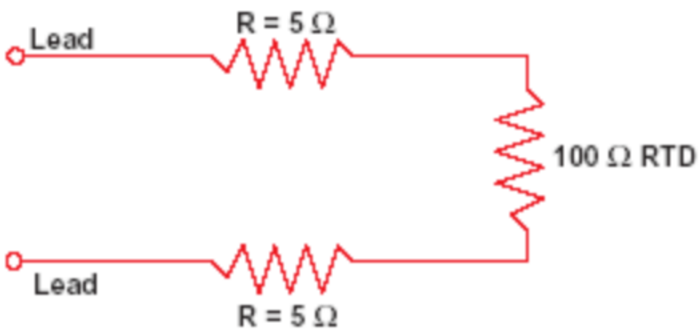
Glass sealed Biflar Winding



Thin Film Omega TFD Element

Omega.com

2-wire Resistance Temperature Measurement



EFFECT OF LEAD RESISTANCE

$R_2 = R_1 = R_L = R_{Lead}$

$R_{total} = R_1 + R_2 + R_{RTD}$

$$R_T = R_0 + R_0 \alpha \left[T - \delta \left(\frac{T}{100} - 1\right)\left(\frac{T}{100}\right) - \beta\left(\frac{T}{100} - 1\right)\left(\frac{T}{100}\right)^3\right]$$

Where:

R_T = Resistance at Temperature T

R_o = Resistance at T = 0ºC

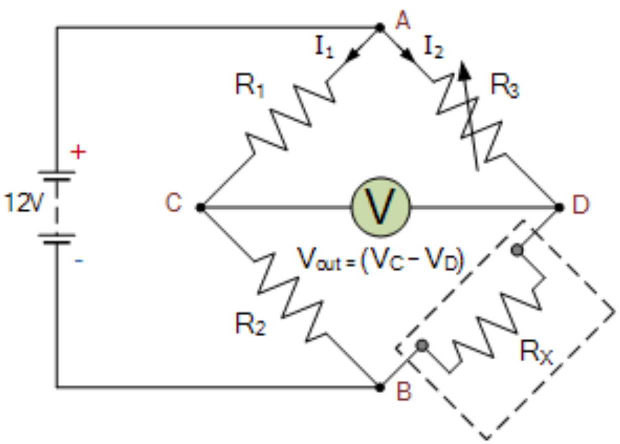
α = Temperature coefficient at T = 0ºC ((typically +0.00392Ω/Ω/ºC))

δ = 1.49 (typical value for .00392 platinum)

β = 0 T > 0
0. 11 (typical) T < 0

Multi-wire Bridge Resistance Temperature Measurement

WHEATSTONE BRIDGE



$$\frac{R_1}{R_2} = \frac{R_3}{R_X} = 1 \text{ (Balanced)}$$

$$V_{OUT} = \left(V_C - V_D\right) = \left(V_{R2} - V_{R4}\right) = 0$$

$$R_C = \frac{R_2}{R_1 + R_2} \quad \text{and} \quad R_D = \frac{R_4}{R_3 + R_4}$$

$$\text{At Balance: } R_C = R_D \quad \text{So, } \frac{R_2}{R_1 + R_2} = \frac{R_4}{R_3 + R_4}$$

$$\therefore\ R_2\left(R_3 + R_4\right) = R_4\left(R_1 + R_2\right)$$

$$R_2 R_3 + \cancel{R_2 R_4} = R_1 R_4 + \cancel{R_2 R_4}$$

$$\therefore\ R_4 = \frac{R_2 R_3}{R_1} = R_X$$

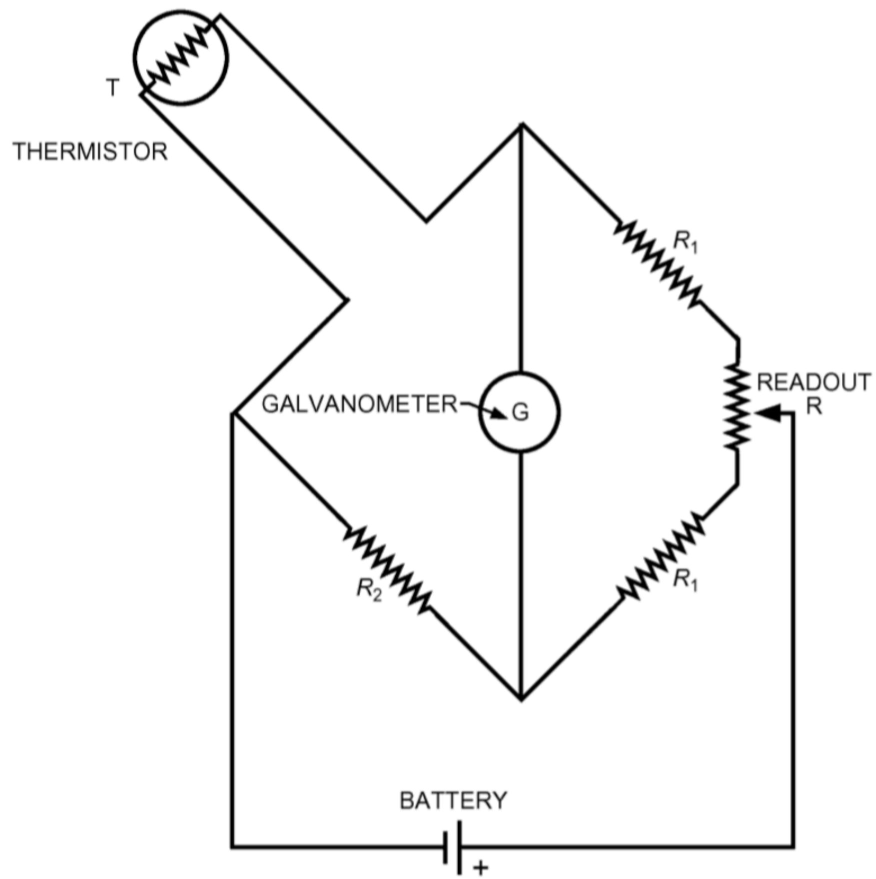
Multiple wires minimizes effects of the lead resistances

https://www.electronics-tutorials.ws/blog/wheatstone-bridge.html

Thermistors

- Certain semiconductor compounds (usually sintered metallic oxides) exhibit large changes in resistance with temperature, usually decreasing as the temperature increases

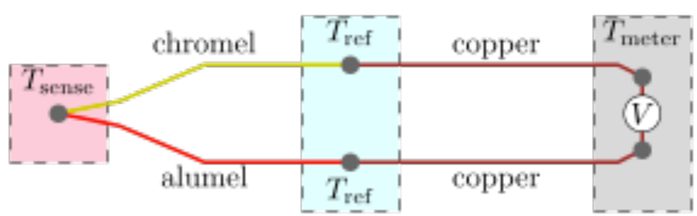
- The thermistor element may be connected by lead wires into a galvanometer bridge circuit and calibrated



$$\frac{1}{T} = a + b\,\ln(R) + c\,(\ln(R))^3$$

Thermocouples

- When two wires of dissimilar metals are joined by soldering, welding, or twisting, they form a thermocouple junction or "thermo-junction"
- An electromotive force (emf) that depends on the wire materials and the junction temperature exists between the wires. This is known as the Seebeck voltage
- The most common instruments of temperature measurement for the range of 32 to 1800°F (except platinum resistance thermometers)
- Because of their low cost, moderate reliability, and ease of use, thermocouples are widely accepted



Thermocouples

Table 2 Thermocouple Tolerances on Initial Values of Electromotive Force Versus Temperature

Thermocouple Type	Material Identification	Temperature Range, °F	Reference Junction Tolerance at 32°F[a]: Standard Tolerance (whichever is greater)	Reference Junction Tolerance at 32°F[a]: Special Tolerance (whichever is greater)
T	Copper versus Constantan	32 to 700	±1.8°F or ±0.75%	±0.9°F or ±0.4%
J	Iron versus Constantan	32 to 1400	±4°F or ±0.75%	±2°F or ±0.4%
E	Nickel-10% Chromium versus Constantan	32 to 1600	±3.1°F or ±0.5%	±1.8°F or ±0.4%
K	Nickel-10% Chromium versus 5% Aluminum, Silicon	32 to 2300	±4°F or ±0.75%	±2°F or ±0.4%
N	Nickel-14% Chromium, 1.5% Silicon versus Nickel-4.5% Silicon, 0.1% Magnesium	32 to 2300	±4°F or ±0.75%	±2°F or ±0.4%
R	Platinum-13% Rhodium versus Platinum	32 to 2700	±2.7°F or ±0.25%	±1.1°F or ±0.1%
S	Platinum-10% Rhodium versus Platinum	32 to 2700	±2.7°F or ±0.25%	±1.1°F or ±0.1%
B	Platinum-30% Rhodium versus Platinum-6% Rhodium	1600 to 3100	±0.5%	±0.25%
T[b]	Copper versus Constantan	−328 to 32	±1.8°F or ±1.5%	c
E[b]	Nickel-10% Chromium versus Constantan	−328 to 32	±3.1°F or ±1%	c
K[b]	Nickel-10% Chromium versus 5% Aluminum, Silicon	−328 to 32	±4°F or ±2%	c

Source: ASTM *Standard* E230, Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples.

[a]Tolerances in this table apply to new thermocouple wire, normally in the size range of 0.01 to 0.1 in. diameter and used at temperatures not exceeding the recommended limits. Thermocouple wire is available in two grades: standard and special.

[b]Thermocouples and thermocouple materials are normally supplied to meet the tolerance specified in the table for temperatures above 32°F. The same materials, however, may not fall within the tolerances given in the second section of the table when operated below freezing (32°F). If materials are required to meet tolerances at subfreezing temperatures, the purchase order must state so.

[c]Little information is available to justify establishing special tolerances for below-freezing temperatures. Limited experience suggests the following special tolerances for types E and T thermocouples:

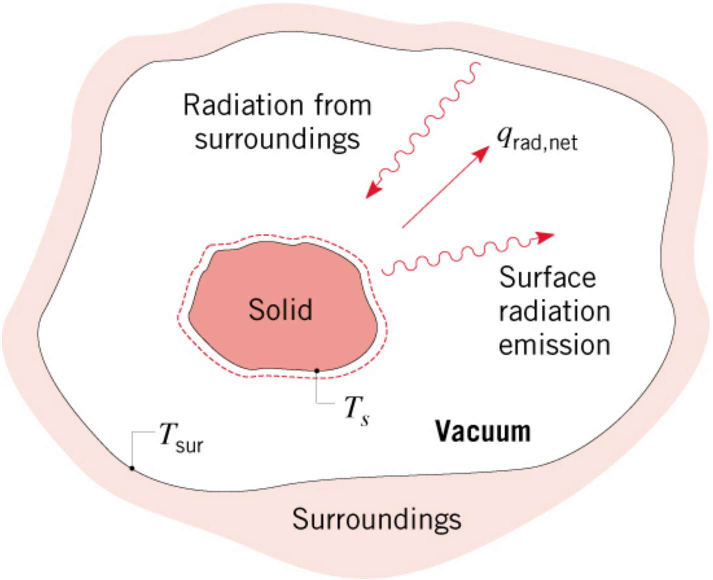
Type E −328 to 32°F; ±2°F or ±0.5% (whichever is greater)

Type T −328 to 32°F; ±1°F or ±0.8% (whichever is greater)

These tolerances are given only as a guide for discussion between purchaser and supplier.

Infrared Radiation Thermometers

- All objects above absolute zero radiate electromagnetic energy according to:



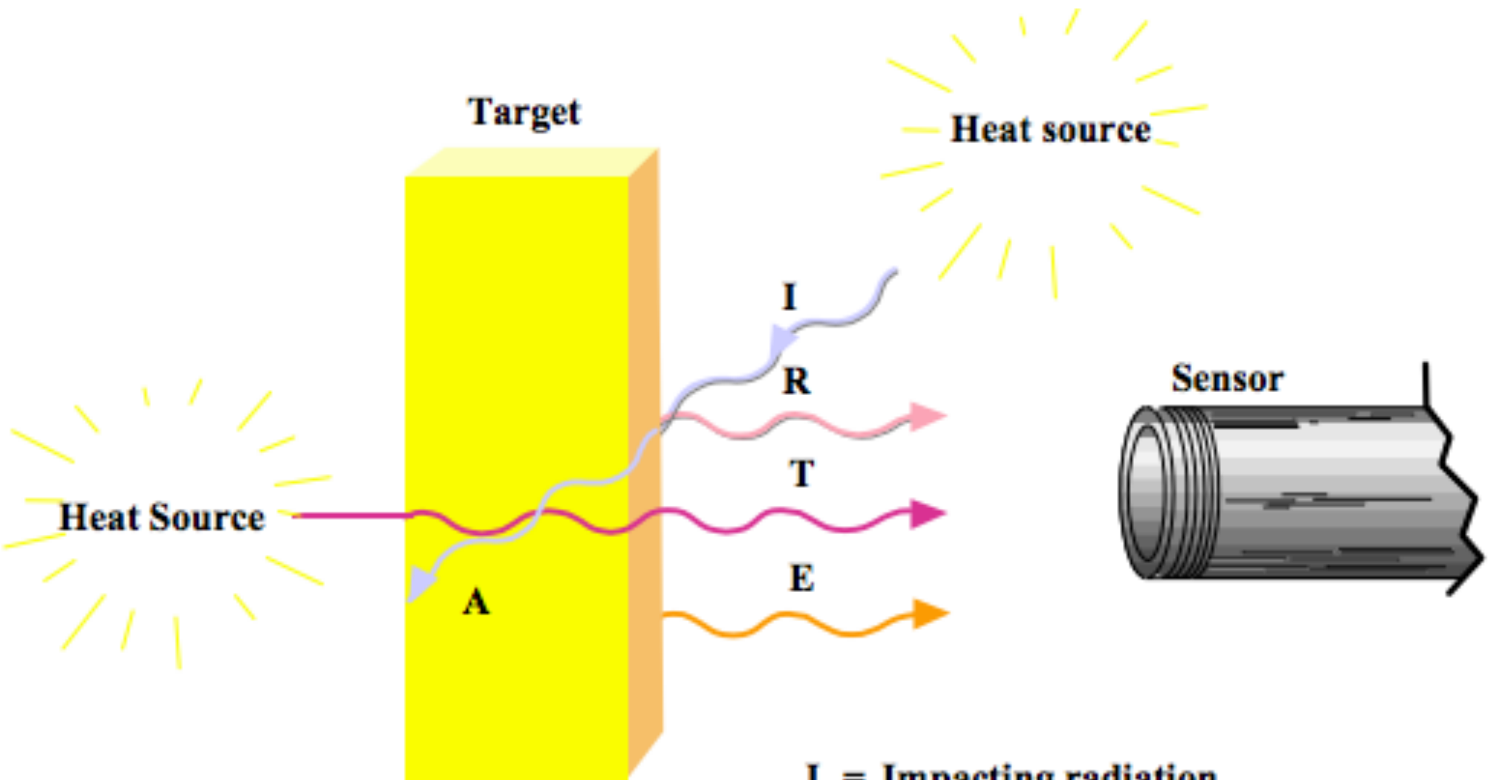
$$q_{rad} = \varepsilon \sigma T^4$$

Where ε = emissivity

σ = Stefan-Boltzmann constant = $5.67 \times 10^{-8} \frac{W}{m^2 \cdot K^4}$

T = Absolute temperature [K]

Infrared Radiation Thermometers



I = Impacting radiation
R = Reflected radiation
T = Transmitted radiation
E = Emitted radiation
A = Absorption

http://support.fluke.com/raytek-sales/Download/Asset/IR_THEORY_55514_ENG_REVB_LR.PDF

Globe temperatures

- Consider influence of surfaces and convection in the temperature calculations.

$$\epsilon\sigma\left(T_{mrt}^4 - T_g^4\right) = h_c A(T_g - T_a)$$


Cole-parmer.com

- Mean Radiant Temperature (MRT):

$$T_{rmt}^4 = T_g^4 + CV^{0.5}\left(T_g - T_a\right)$$

  - T_{rmt}: *Mean Radiant Temperature in R or K*
  - T_g : *Globe temperature in R or K*
  - $C: 0.103\times10^9 (IP)\ or\ 0.247\times10^9 (SI)$
  - V : *Air velocity in fpm or* $\frac{m}{s}$
  - T_a: ambient temperature in R or K

Globe temperatures

- Globe Temperature (T_g)
  - Black-globe thermometer measures mean radiant temperature (MRT)

$$MRT = \left[(GT + 273)^4 + \frac{1,1 \cdot 10^8 \cdot v_a^{0,6}}{\varepsilon \cdot D^{0,4}} (GT - T_a) \right]^{1/4} - 273$$

where:

- MRT is the mean radiant temperature (°C);
- GT is the globe temperature (°C);
- v_a is the air velocity at the level of the globe (m/s);
- ε is the emissivity of the globe (no dimension);
- D is the diameter of the globe (m);
- T_a is air temperature (°C);

- Wet Bulb Globe Temperature (WBGT)
  - Apparent temperature used to estimate the effect temperature, humidity, wind speed, and visible and infrared radiation on humans
  - $WBGT = 0.7T_w + 0.2T_g + 0.1T_d$
    - T_w = wet bulb temperature
    - T_g = globe temperature
    - T_d = dry bulb temperature

Globe temperatures

- **Example:** Determine the operative temperature for a workstation in a room near a large window where the globa and dry bulb temperatures are measured to be 75 F and 81 F, respectively. The air velocity is estimated to 30 ft/min at the station.

Globe temperatures

- **Solution**

$$T_{rmt}^4 = T_g^4 + CV^{0.5}(T_g - T_a)$$

$$T_{rmt} = \left[T_g^4 + CV^{0.5}(T_g - T_a)\right]^{0.25}$$

$$T_{rmt} = [(81+460)^{0.25} + (0.103\times10^9)(30)^{0.5}(81-75)]^{0.25} = 546\,R = 86\,F$$

$$T_o = \frac{T_{mrt} + T_a}{2} = \frac{86+75}{2} = 80.5\,F$$

HUMIDITY MEASUREMENT

Hygrometer

- Humidity sensors, also known as hygrometers, measure humidity or psychrometric state of air

- A hygrometer can encompass:
  - Wet-bulb temperature
  - Relative humidity
  - Humidity (mixing) ratio
  - Dew point
  - Frost point

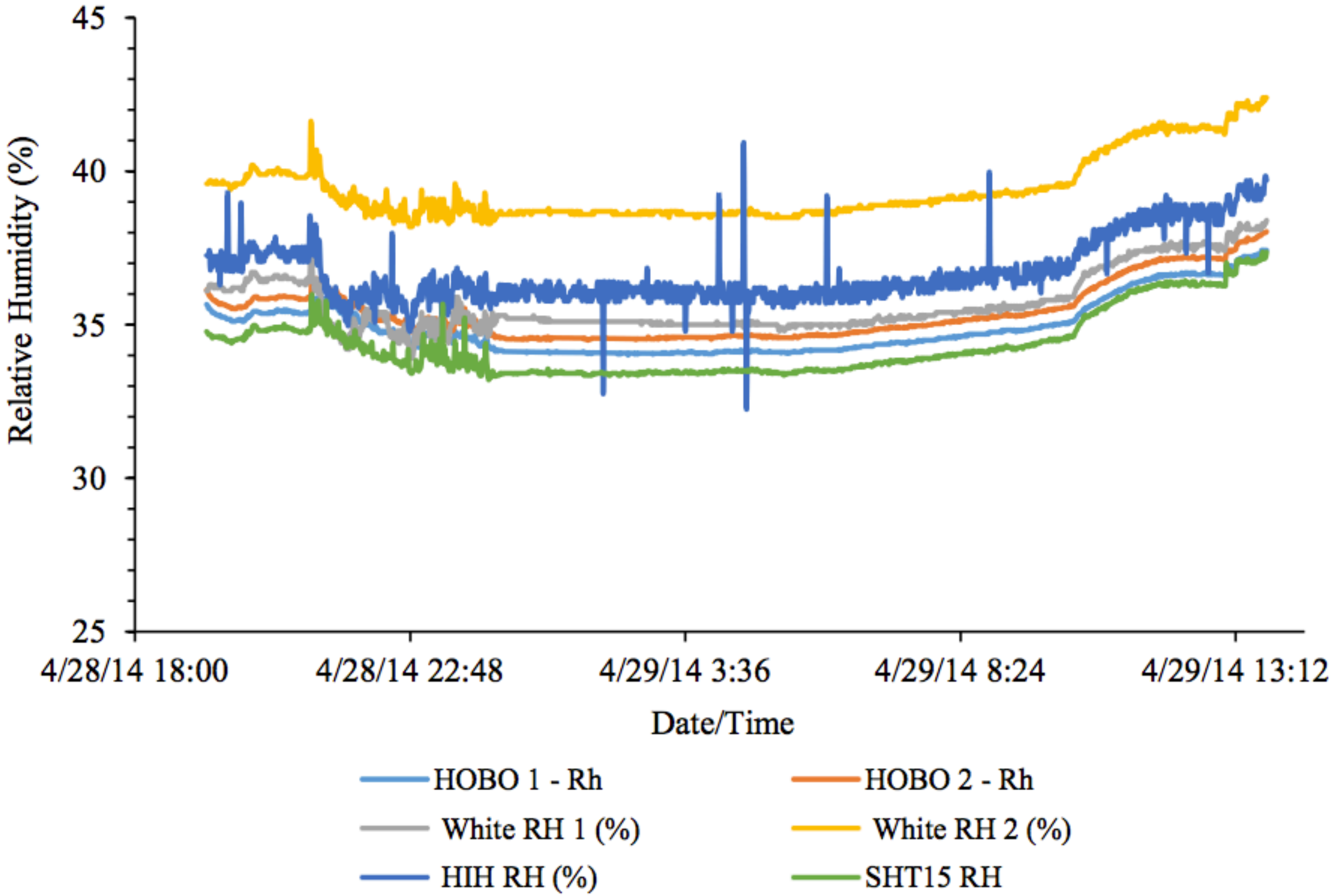
Humidity Sensors

Type of Sensor	Sensor Category	Method of Operation	Approximate Range	Some Uses	Approximate Accuracy
Psychrometer	Evaporative cooling	Temperature measurement of wet bulb	32 to 180°F	Measurement, standard	±3 to 7% rh
Adiabatic saturation psychrometer	Evaporative cooling	Temperature measurement of thermodynamic wet bulb	40 to 85°F	Measurement, standard	±0.2 to 2% rh
Chilled mirror	Dew point	Optical determination of moisture formation	−110 to 200°F dp	Measurement, control, meteorology	±0.4 to 4°F
Heated saturated salt solution	Water vapor pressure	Vapor pressure depression in salt solution	−20 to 160°F dp	Measurement, control, meteorology	±3°F
Hair	Mechanical	Dimensional change	5 to 100% rh	Measurement, control	±5% rh
Nylon	Mechanical	Dimensional change	5 to 100% rh	Measurement, control	±5% rh
Dacron thread	Mechanical	Dimensional change	5 to 100% rh	Measurement	±7% rh
Goldbeater's skin	Mechanical	Dimensional change	5 to 100% rh	Measurement	±7% rh
Cellulosic materials	Mechanical	Dimensional change	5 to 100% rh	Measurement, control	±5% rh
Carbon	Mechanical	Dimensional change	5 to 100% rh	Measurement	±5% rh
Dunmore type	Electrical	Impedance	7 to 98% rh at 40 to 140°F	Measurement, control	±1.5% rh
Polymer film electronic hygrometer	Electrical	Impedance or capacitance	10 to 100% rh		±2 to 3% rh
Ion exchange resin	Electrical	Impedance or capacitance	10 to 100% rh at −40 to 190°F	Measurement, control	±5% rh
Porous ceramic	Electrical	Impedance or capacitance	Up to 400°F	Measurement, control	±1 to 1.5% rh
Aluminum oxide	Electrical	Capacitance	5 to 100% rh	Measurement, control	±3% rh
	Electrical	Capacitance	−110 to 140°F dp	Trace moisture measurement, control	±2°F dp
Electrolytic hygrometer	Electrolytic cell	Electrolyzes due to adsorbed moisture	1 to 1000 ppm	Measurement	
Infrared laser diode	Electrical	Optical diodes	0.1 to 100 ppm	Trace moisture measurement	±0.1 ppm
Surface acoustic wave	Electrical	SAW attenuation	85 to 98% rh	Measurement, control	±1% rh
Piezoelectric	Mass sensitive	Mass changes due to adsorbed moisture	−100 to 0°F	Trace moisture measurement, control	±2 to 10°F dp
Radiation absorption	Moisture absorption	Moisture absorption of UV or IR radiation	0 to 180°F dp	Measurement, control, meteorology	±4°F dp, ±5% rh
Gravimetric	Direct measurement of mixing ratio	Comparison of sample gas with dry airstream	120 to 20,000 ppm mixing ratio	Primary standard, research and laboratory	±0.13% of reading
Color change	Physical	Color changes	10 to 80% rh	Warning device	±10% rh

Notes:

1. This table does not include all available technology for humidity measurement.
2. Approximate range for device types listed is based on surveys of device manufacturers.
3. Approximate accuracy is based on manufacturers' data.
4. Presently, NIST only certifies instruments with operating ranges within −103 to 212°F dew point.

Does this stuff really matter?



Akram Ali, IIT M.S. thesis 2015

Psychrometers

- A psychrometer contains a pair of matched electrical or mechanical temperature sensors:
  - While one of them kept wet with a moistened wick
  - Air blows over the sensor
  - Evaporation occurs

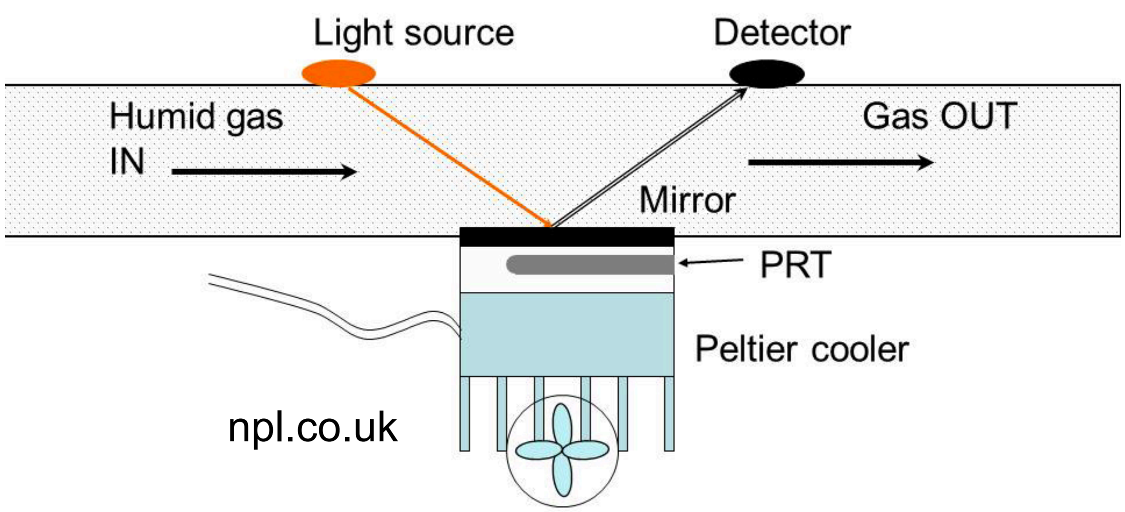
Carolina.com

- Different types of psychrometers are:
  - Sling psychrometer:
    - Consists of two thermometers mounted side by side
    - A handle for whirling the device through the air
  - Ventilated or aspirated psychrometer:
    - Thermometers remain stationary
    - A small fan, blower, or syringe moves air across the thermometer bulbs

Th-friedrichs.com

Dew-Point Hygrometers

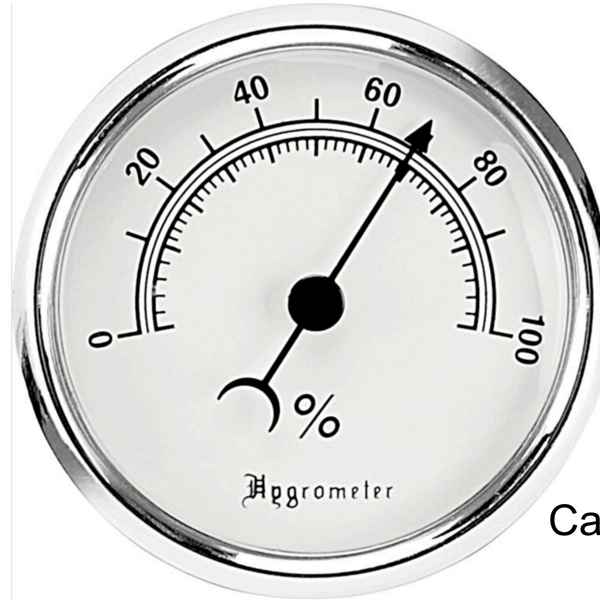
- **Condensation (chilled-mirror) Dew-Point Hygrometers:**
  - Accurate and reliable instrument
  - Wide humidity range
  - Complexity and cost (compared to the psychrometer)
  - A surface is cooled (thermoelectrically, mechanically, or chemically)
    - Until dew or frost begins to condense out
    - Maintained electronically in vapor-pressure equilibrium
    - Detected by optical, electrical, or nuclear techniques



npl.co.uk

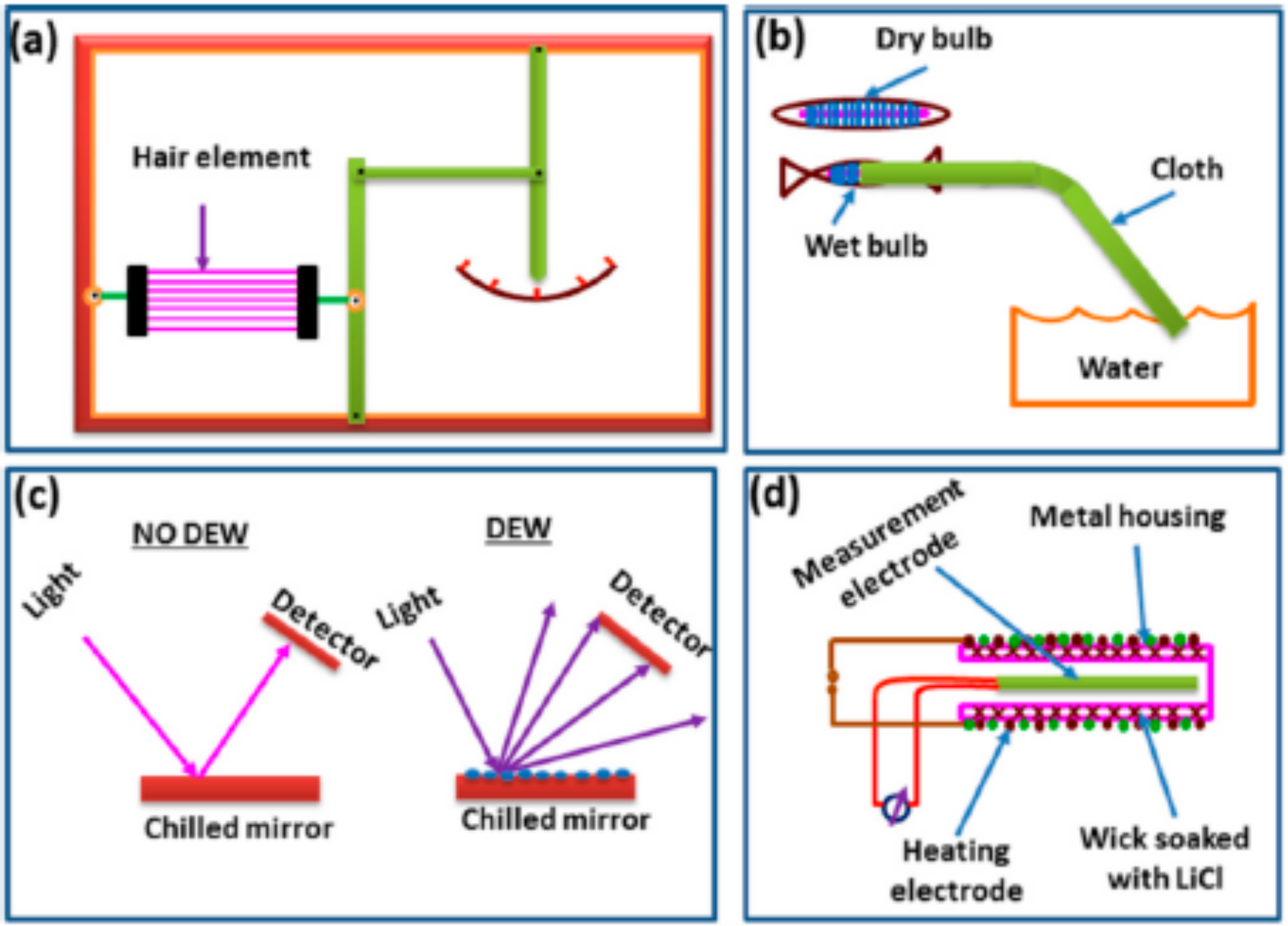
Dew-Point Hygrometers

- **Mechanical Hygrometers:**
  - Rely on organic materials:
    - Human hair
    - Nylon
    - Dacron
    - Animal membrane
    - Wood
    - Paper
  - Unreliable below 32°F
  - Inadequate for monitoring a changing process
  - Can be affected significantly by exposure to extremes of humidity
  - Require initial calibration and frequent recalibration
  - Useful for reading relative humidity directly
  - Simpler and less expensive than most other types



Cabelas.com

Dew-Point Hygrometers



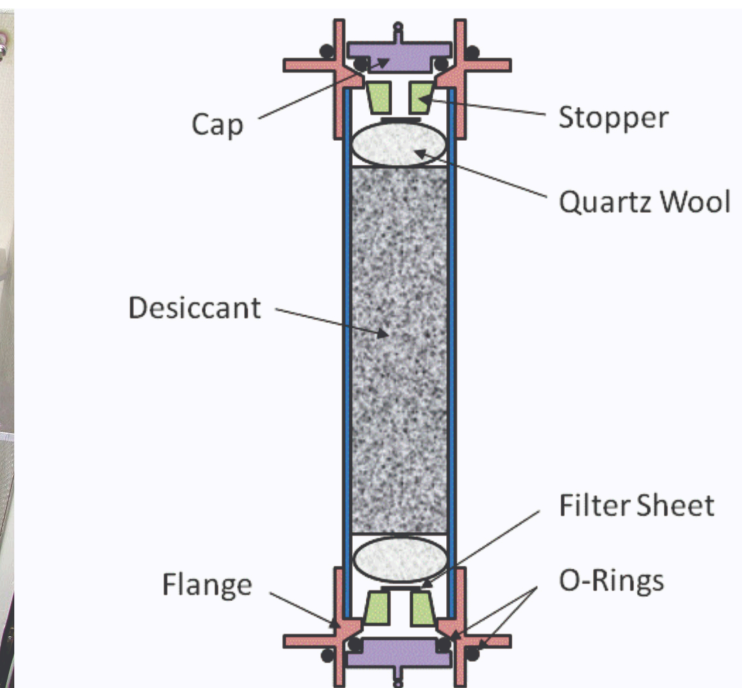
Tripathy et al., *Sensors* 2014, *14*(9)

Spectroscopic "Radiation absorption" Hygrometers

- Operate on the principle:
  - Selective absorption of radiation is a function of frequency for different media
  - Water vapor absorbs infrared radiation at 2 to 3 μm wavelengths
  - Ultraviolet radiation centered about the Lyman-alpha line at 0.122 μm
- Measure extremely quickly
- Provide response times of 0.1 to 1 s
- Can be used where a noncontact application is required
- Are high cost and relatively large size

Gravimetric Hygrometers

- Measure humidity by extracting/finding mass of water vapor in a known quantity or atmosphere.
- Use desiccant materials:
  - Precise work: Powerful desiccants, such as phosphorous pentoxide
  - Other purposes: Calcium chloride or silica gel



CLASS ACTIVITY

Group Formation

- Assign students into groups

- Main tasks:
  1. Calibration and deployment of HOBO U12 data loggers
     - Use them to measure/log T/RH in the main office
     - Periodic comparisons to sling psychrometer and WGBT
     - Estimate response time (create a change)

  2. Calibration and deployment of thermocouples (with LabJack DAQ)
     - Use them to measure room air conditioner cooling performance in the classroom

HOBO U12

- Understand how to launch the HOBO U12 with different configurations
- Launch several HOBO U12 for measurements with 10 second intervals
- Co-locate them for several minutes for calibration
- Estimate response time

- Review the provided HOBO U12 specification
- Install them in your designated room
- Download the data
- Stop HOBO reading to save battery

HOBO U12

HOBO® U12 Logger

Multi-channel energy & environmental monitoring

HOBO U12 data loggers provide flexibility for monitoring up to 4 channels of energy and environmental data with a single, compact logger. They provide 12-bit resolution measurements for detecting greater variability in recorded data, direct USB connectivity for convenient, fast data offload, and a 43K measurement capacity.

Supported Measurements: Temperature, Relative Humidity, Dew Point, 4-20mA, AC Current, AC Voltage, Air Velocity, Carbon Dioxide, Compressed Air Flow, DC Current, DC Voltage, Gauge Pressure, Kilowatts, Light Intensity, Volatile Organic Compound (some sensors sold separately)

Key Advantages:

- Records up to 4 channels
- Your choice of three models, with flexible measurement options
- Programmable as well as push-button start
- Compatible with a broad range of external sensors

HOBO U12

Part number	U12-012 (Temp/RH/Light/Ext)	U12-013 (Temp/RH/2 Ext)
Memory	43,000 measurements	
Sampling rate	1 second to 18 hours, user-selectable	
Battery life	1 year typical, user-replaceable, CR2032	
	Temperature	
Max range	-20° to 70°C (-4° to 158°F)	
Accuracy	± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F)	
Resolution (12-bit)	0.03°C @ 25°C (0.05°F @ 77°F)	
	Relative Humidity	
Measurement range	5% to 95% RH (non-condensing)	
Accuracy	±2.5% from 10%RH to 90%RH typical to a maximum of ±3.5% including hysteresis at 25˚C (77˚F); below 10%RH and above 90%RH ±5% typical	
Resolution (10-bit)	0.05%RH	
	Light Intensity	
	Designed for general purpose indoor measurement of relative light levels	
Range	1 to 3000 footcandles (lumens/ft2) typical 0-32,300 lumens/m2	
	External Input	
Range	0 to 2.5 VDC	
Accuracy	± 2 mV, ± 2.5% of absolute reading	
Resolution	0.6 mV	
CE compliant	Yes	

LabJack U6 with Type K thermocouples

https://labjack.com/support/app-notes/thermocouples/u6

TP-50

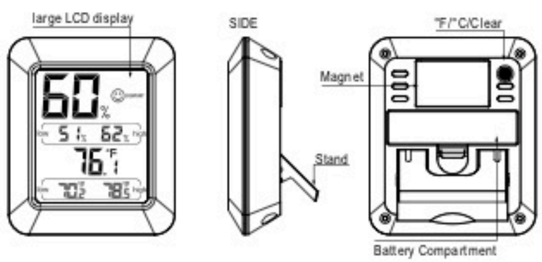
- Review the provided monitor specification

TP-50

EN V20160720 EN FR

ThermoPro

INDOOR HUMIDITY AND TEMPERATURE MONITOR INSTRUCTION MANUAL
Model No. TP-50



1. Display: Displays the current humidity and temperature, and record maximum and minimum humidity/temperature.
2. °C/°F/Clear Button: Press once to change the temperature display to either °C or °F. Press and hold for 2 seconds to clear the record maximum and minimum humidity/ temperature readings.
3. Battery Compartment: Holds one 1 AAA battery to power the unit.
4. Comfort Level: 3 icons: DRY, COMFORT, WET.
   If humidity is below 50%: Dry.
   If humidity is between 50% to 70% AND temperature is between 68°F-79°F (20°C-26°C): Comfort.
   If humidity is above 70%: Wet.
   Elsewise: No icon.
5. Totally wireless tabletop and magnet-mountable design.

BEFORE FIRST USE

1. Insert or Replace Battery: Insert one AAA battery with correct polarity (+) and (-) as indicated.
2. Do not immerse product in water.
3. The humidity and temperature monitor is now ready to use.

CARE OF YOUR HUMIDITY/TEMEPRATURE MONITOR

- Do not leave exposed to extreme high or low temperatures since this may cause damage to electronic parts and plastics.
- Remove battery if planning to store for more than four months.

Specifications

1. Temperature range: -58 °F ~ 158°F (-50 °C ~ 70 °C).
2. Humidity range: 10% ~ 99%.
3. Comfort display: DRY, COMFORT, WET.
4. Temperature display unit: °C °F selectable.
5. Temperature Resolution: 0.1 °C/°F.
6. Humidity Resolution: 1%.
7. Refresh rate: 10 seconds.
8. Power supply: 1 X AAA 1.5V.

EXTECH HT30

- Familiarize with the sensor
- Read data for the class (for several minutes)

- Review the provided specification
- Read data (all 4 variables) every minute during your experiment

EXTECH HT30

Wet Bulb Globe Temperature (WBGT)		0°C to 50°C (32°F to 122°F)
WBGT Accuracy		Calculated from measured parameters
TG Black Globe Temperature range		0 to 80°C (32°F to 176°F)
TG Accuracy	Indoor	±2°C (4°F)
	Outdoor	±3°C (5.5°F)
TA Air Temperature range		0°C to 50°C (32°F to 122°F)
TA Accuracy		±1°C (1.8°F)
Relative Humidity (RH)		0 to 100%RH
RH Accuracy		±3% (at 25°C, 10 to 95%RH)
Resolution		0.1°F/°C; 0.1%RH
Operating Temperature		0°C to 50°C (32°F to 122°F)
Operating Humidity		Max. 80% RH
Power Supply		Two AAA batteries
Battery Life		Approx 1000 hours
Dimensions		Meter: 254 x 48.7 x 29.4mm (10x1.9x1.1") Black Ball: 40mm, 35mm (1.57 Dia., 1.37H)
Weight		136g (4.8oz)
Optional Accessories		PC software and cable (407752)

EXTECH HT30

<u>HT30 WBGT calculations:</u>

WBGT = Wet bulb Globe temperature
WB = Wet bulb temperature (Calculated from temperature and Humidity)
TG = Globe temperature
TA = Air temperature

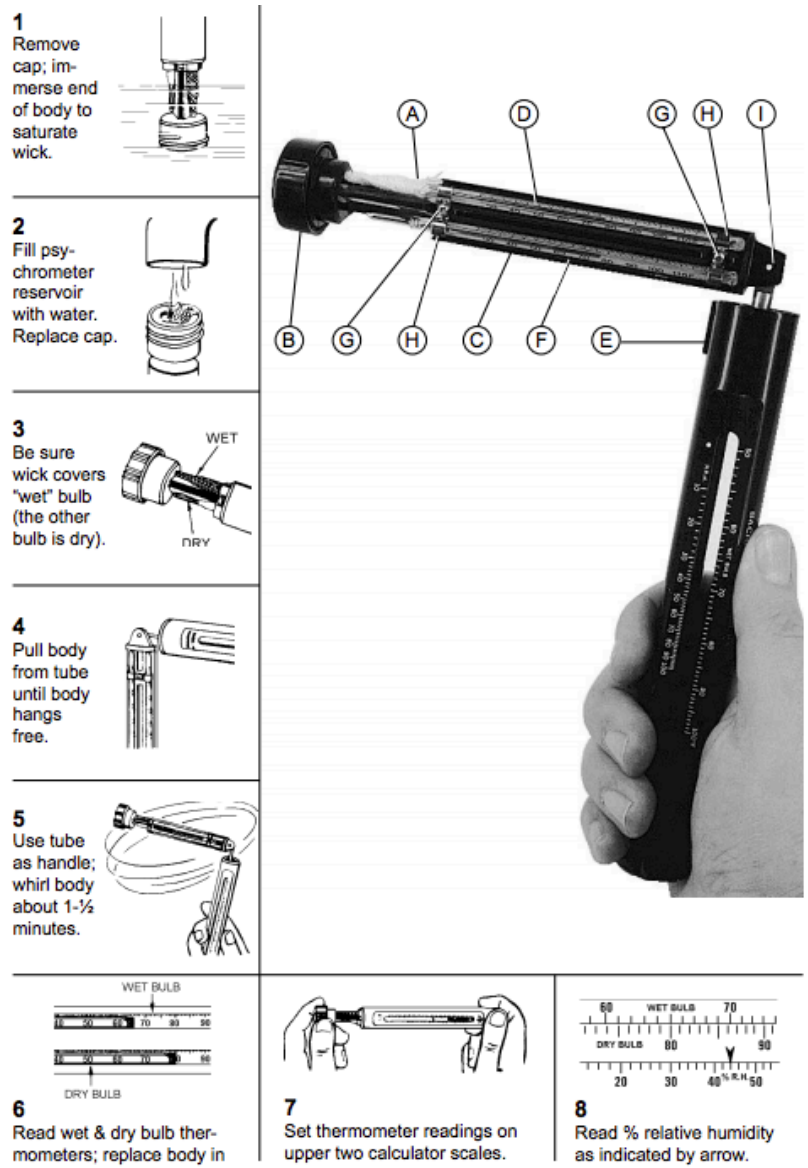
OUT of the Sun (Indoors)

WBGT = 0.7xWB + 0.3xTG

IN full Sun (Outdoors)

WBGT = 0.7xWB + 0.2xTG + 0.1xTA

Sling Psychrometer 12-9015



Sling Psychrometer 12-9015

- Understand how to work with sling psychrometer and read data

- Read data (all three variables) periodically during your measurements

Reporting Results

- Report the measurements in an Excel file similar to below:

Date/ Time	HOBO U12		Thermocouple temperature	T RH Monitor		WBGT Reading				Psychrometer
	T (F)	RH (%)	T (F)	T (F)	RH (%)	WBGT	TA	TG	RH	

Reporting Results

- Plot the results in a graph
- Briefly summarize your findings
- Which measurement is more accurate than the others?