Measurement of Temperature & Heat Flux

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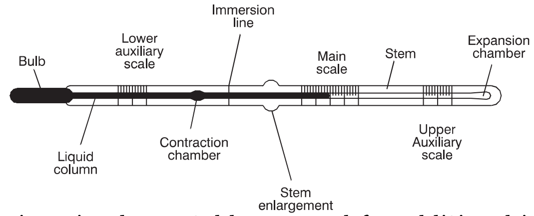
ME 361: Instrumentation and Measuremen

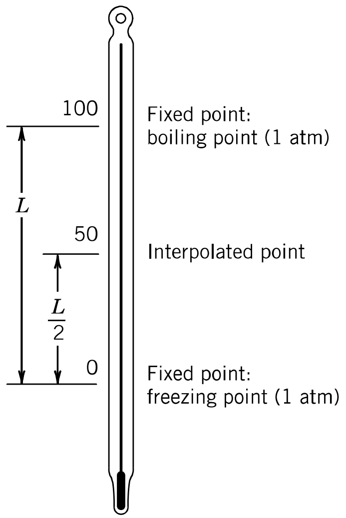
http://zahurul.buet.ac.bd/ME361/

Liquid-in-glass Thermometer

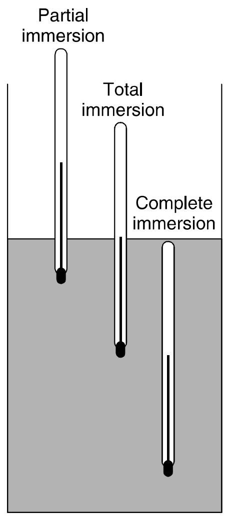


T832

- Inexpensive, simple, portable, no need for additional indicator.
- High heat capacity $\Longrightarrow$ time lag exists.
- Not suitable for distant reading.
- Not suitable for surface temperature measurement.
- Alcohol is limited to low-temperature measurements. Its high coefficient of expansion makes it more sensitive.
- Mercury cannot be used below its freezing point of -37.8°C. Its upper limit is usually 315°C, but it may be extended to 540°C by filling gas filling above the mercury.

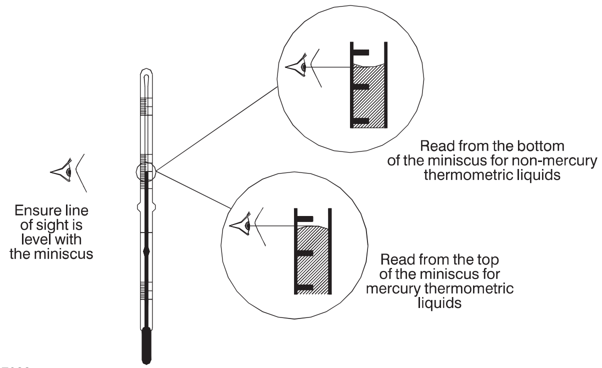


T806

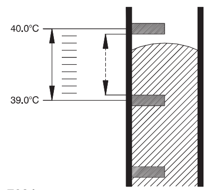


T808

Reading in Liquid-in-Glass Thermometer

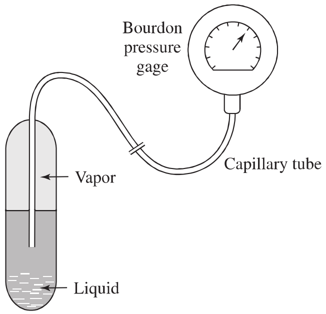


T833



T834

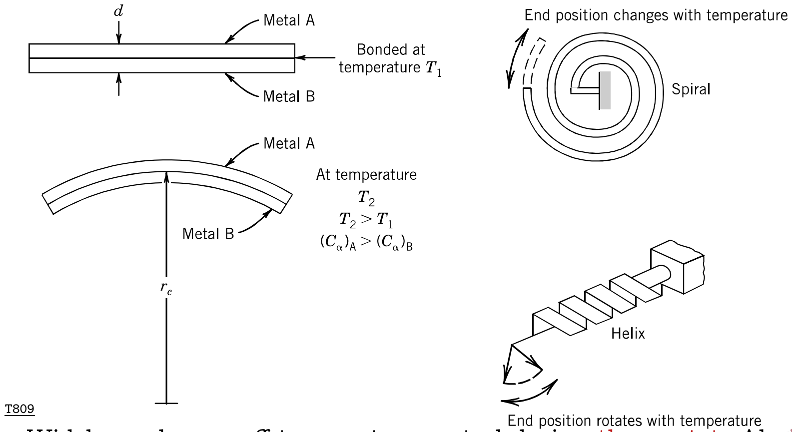
Fluid-expansion Thermometer



T828

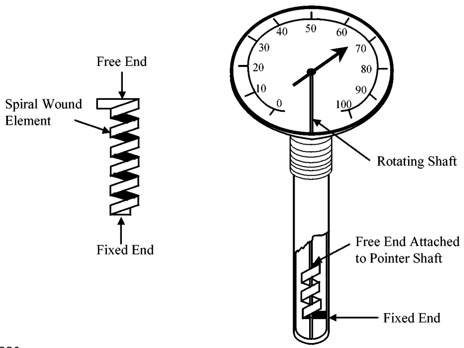
- Economical, versatile, and widely used devices for industrial applications.
- Long capillary tubes (60 m) may be used.
- Low cost, stable operation, and accurate within ± 1°C.

Bimetallic Strip Thermometer



T809

○ Widely used as on-off temperature-control device, thermostat. Also used for measuring ambient and oven temperatures.



T830

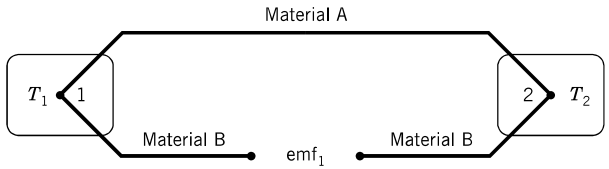
T831

- Low cost, negligible maintenance & longer stable operation.
- Good resistance to mechanical shock.
- Close linearity within temperature range (-30 → 550°C).
- Compact, low thermal inertia and reduced lag.
- Accuracy 1-2% of the scale range.

Thermoelectric Effect

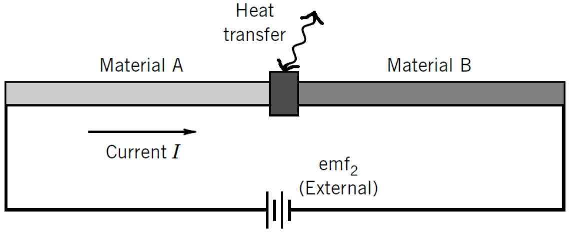
The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa via a thermocouple. The term "thermoelectric effect" encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect. Usually, Peltier and Thomson emfs are negligible in the circuit.

1. Seebeck Effect: refers to the generation of a voltage potential, or emf, in an open thermocouple circuit due to a difference in temperature between junctions in the circuit.



T810

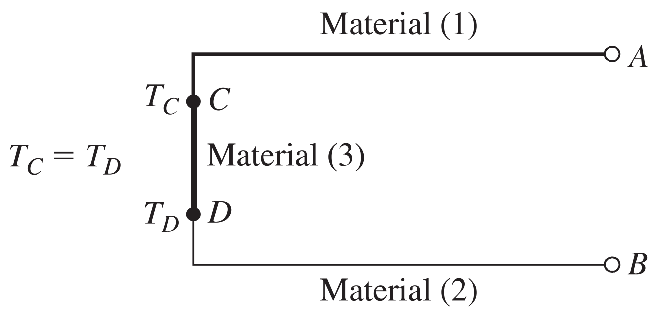
2. Peltier Effect: refers to the effect whereby heat is given out or absorbed when an electric current passes across a junction between two materials.



T811

3. Thomson Effect: If a temperature gradient exists along either or both of the materials, the junction emf may undergo an additional slight alteration.

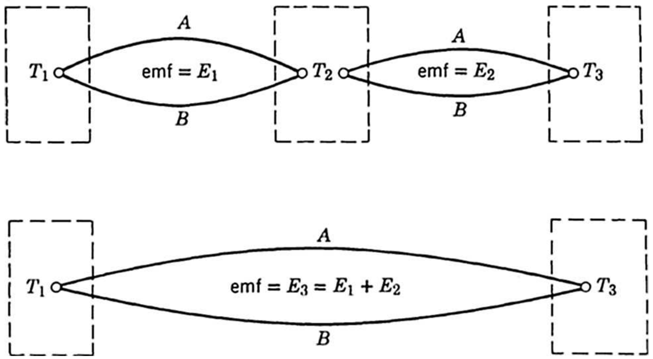
Law of Intermediate Material



T824

The thermocouple is unaffected by the presence of the inserted material maintained at same temperature and any local hot spot

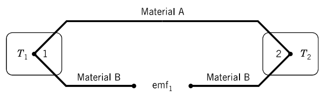
Law of Intermediate Temperatures



T825

The circuit develops an emf of E_1 between temperatures T_1 and T_2; and develops an emf of E_2 between temperatures T_2 and T_3. The law of intermediate temperatures states that this same circuit will develop an emf of $E_3 = E_1 + E_2$ when operating between temperatures T_1 and T_3.

Thermocouple Temperature Measurement Circuits



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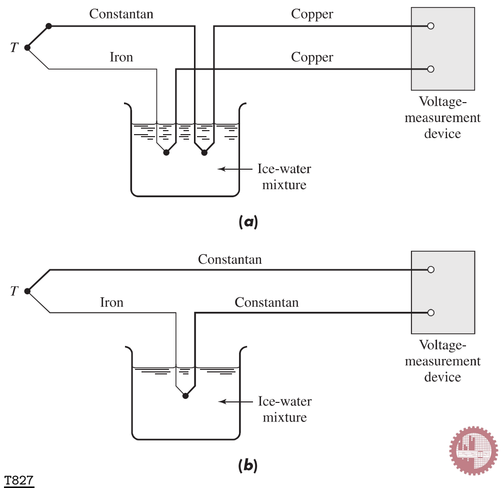
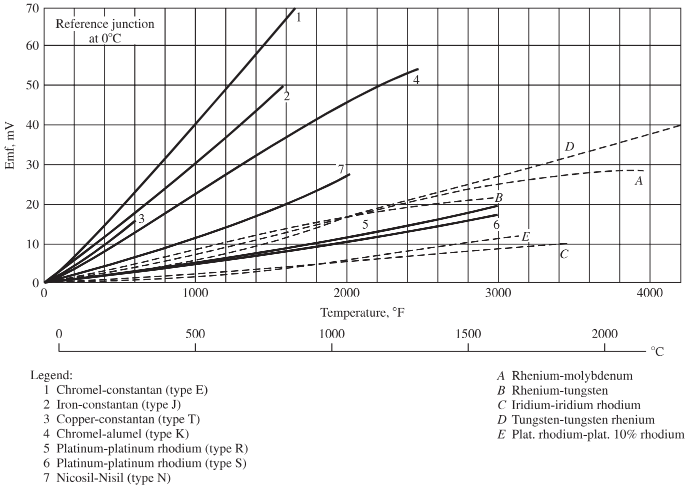


T827

EMF temperature relations for thermocouple materials



T812

Thermocouple Designations

Type	Material Combination: Positive	Material Combination: Negative	Applications
E	Chromel(+)	Constantan(−)	Highest sensitivity (<1000°C)
J	Iron(+)	Constantan(−)	Nonoxidizing environment (<760°C)
K	Chromel(+)	Alumel(−)	High temperature (<1372°C)
S	Platinum/ 10% rhodium	Platinum(−)	Long-term stability high temperature (<1768°C)
T	Copper(+)	Constantan(−)	Reducing or vacuum environments (<400°C)

T815

Standard Thermocouple Compositions

Type	Wire: Positive	Wire: Negative	Expected Systematic Uncertainty'
S	Platinum	Platinum/10% rhodium	±1.5°C or 0.25%
R	Platinum	Platinum/13% rhodium	±1.5°C
B	Platinum/30% rhodium	Platinum/6% rhodium	±0.5%
T	Copper	Constantan	±1.0°C or 0.75%
J	Iron	Constantan	±2.2°C or 0.75%
K	Chromel	Alumel	±2.2°C or 0.75%
E	Chromel	Constantan	±1.7°C or 0.5%

Alloy Designations

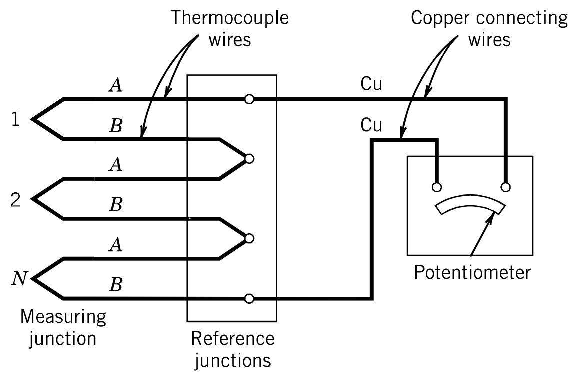
Constantan: 55% copper with 45% nickel

Chromel: 90% nickel with 10% chromium

Alumel: 94% nickel with 3% manganese, 2% aluminum, and 1% silicon

T816

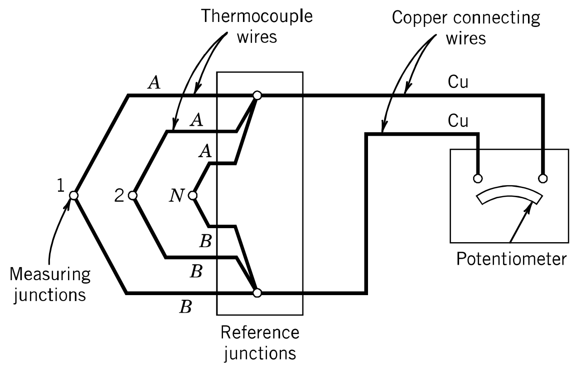
Thermopile Arrangement



T817

Thermopile, a multiple-junction thermocouple circuit, is used to amplify the output of the circuit.

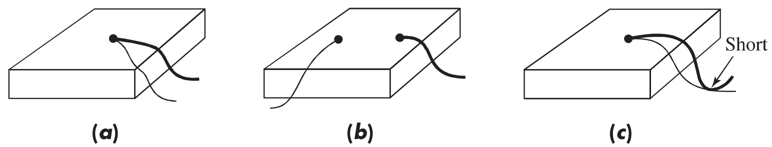
Thermocouples Arranged in Parallel



T818

When a spatially averaged temperature is desired, multiple thermocouple junctions arranged in parallel are used.

Installation of thermocouples on a metal plate

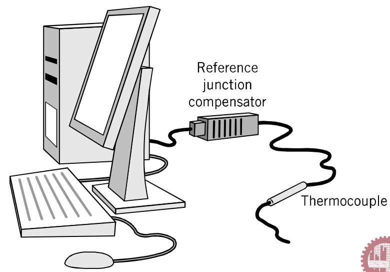


T813

- (a): Only junction bead contacts plate: Thermocouple indicates the temperature of the junction point.
- (b): contact at two points: the emf of the thermocouple will be indicative of the average of the temperatures of these two points.
- (c): contact at bead and along wires: temperature indicated by the thermocouple will be that temperature at the shorted electric contact.

Thermocouple Based System

T829



T819

Resistance Thermometry

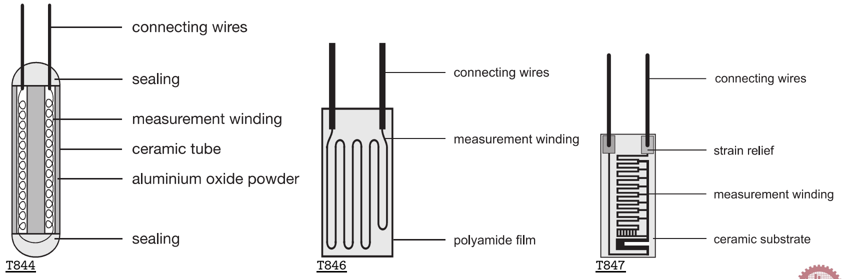
The essential elements required in precise resistance thermometry are a resistor properly mounted & protected, a means for measuring its resistance, and a relation between resistance and temperature.

$$R = \begin{cases} R_o(1 + aT + bT^2) & \cdots \text{ RTD} \\ R_o \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_o}\right)\right] & \cdots \text{ Thermistor} \end{cases}$$

R = resistance at temperature T
R_0 = resistance at reference temperature T_0
a, b = experimentally determined constants
β = experimentally determined constant.

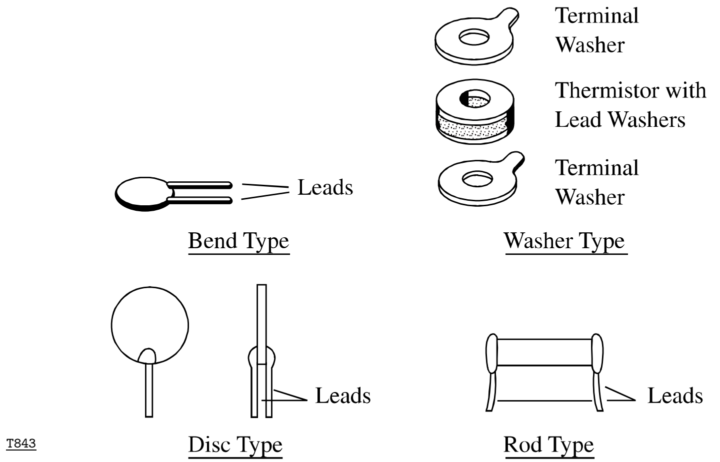
Resistance Temperature Detector (RTD)

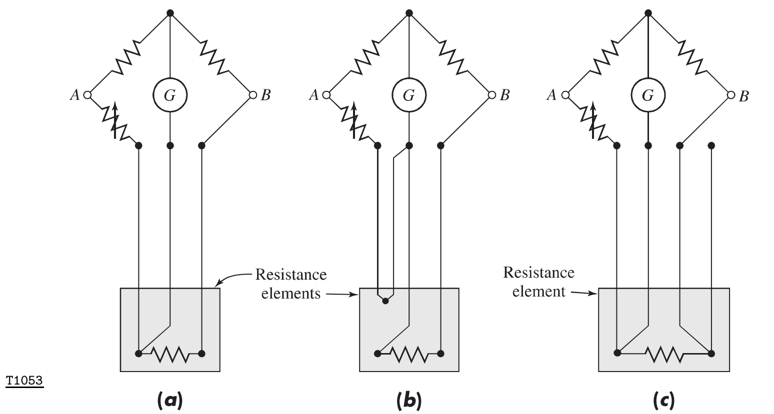
- Platinum RTD is used as an interpolation standard from oxygen point (-182.96°C) to the antimony point (630.74°C)
- In general, RTDs may be used for temperatures ranging from cryogenic to approximately 650°C. By properly measurement, uncertainty in temperature measurement as low as ±0.005°C.



wire-wound ceramic sensor *wire-wound foil sensor* *thin-film sensor*

Thermistor Packaging Examples

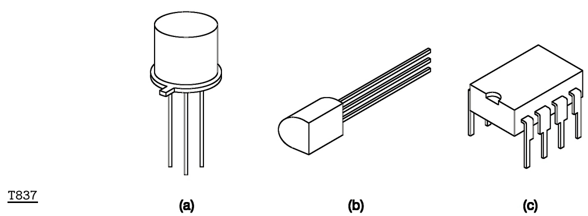




Methods of correcting for lead resistance with electrical-resistance thermometer. (a) Siemen's three-lead arrangement; (b) Callender four-lead arrangement; (c) floating-potential arrangement. Power connections made at A and B.

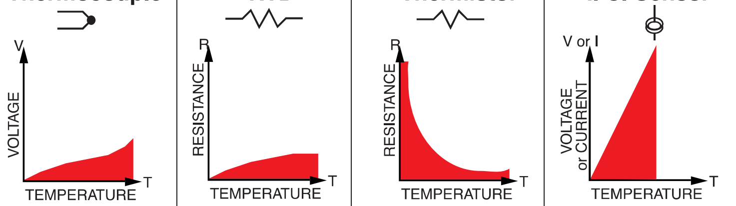
IC Temperature Sensor

- A recent innovation is the ic temperature transducer.
- Available in both voltage & current sensitive configurations. Generally output is linearly proportional to the absolute temperature.
- Used widely in on/off or alarm point control.



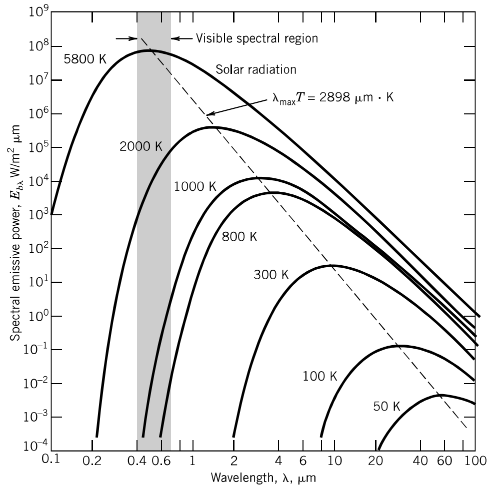
Typical semiconductor temperature sensor packaging. (a) TO99 can. (b) TO-92 plastic moulding. (c) DIP plug

	Thermocouple	RTD	Thermistor	I. C. Sensor
Advantages	☐ Self-powered ☐ Simple ☐ Rugged ☐ Inexpensive ☐ Wide variety ☐ Wide temperature range	☐ Most stable ☐ Most accurate ☐ More linear than thermocouple	☐ High output ☐ Fast ☐ Two-wire ohms measurement	☐ Most linear ☐ Highest output ☐ Inexpensive
Disadvantages	☐ Non-linear ☐ Low voltage ☐ Reference required ☐ Least stable ☐ Least sensitive	☐ Expensive ☐ Current source required ☐ Small Δ R ☐ Low absolute resistance ☐ Self-heating	☐ Non-linear ☐ Limited temperature range ☐ Fragile ☐ Current source required ☐ Self-heating	☐ T<200°C ☐ Power supply required ☐ Slow ☐ Self-heating ☐ Limited configurations



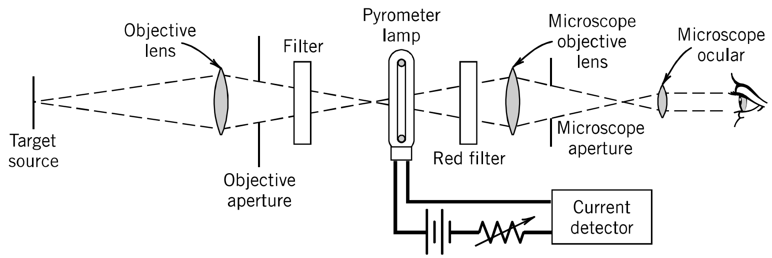
T838

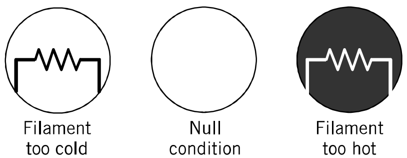
Blackbody Radiation



T820

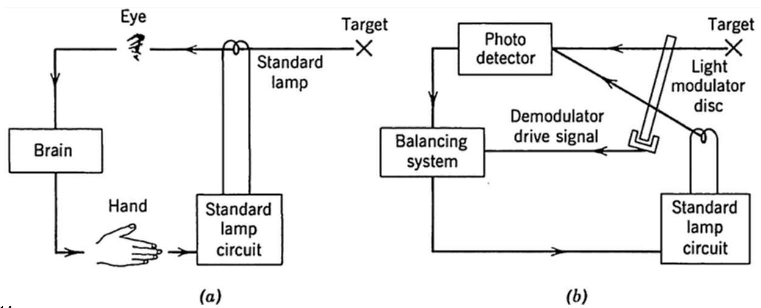
Optical Pyrometer





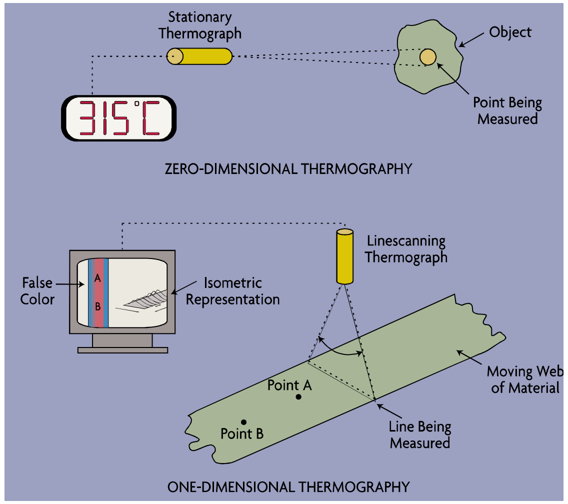
Appearance of lamp filament in eyepiece of optical pyrometer.

T823



T814

Operational Diagrams. (a) manually operated optical pyrometer. (b) Automatic optical pyrometer.



T826

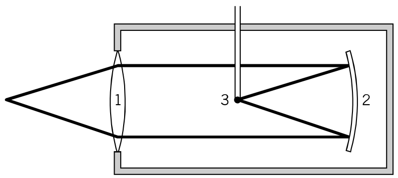
Linescanning & Thermography

T841

T842

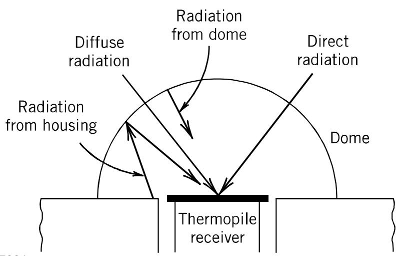
IR thermometer & Thermography

Radiation Detectors (Radiometers)



T835

Radiometer: (1) lens, (2) focusing mirror, (3) thermopile or thermistor.



T821

Pyranometer: solar radiation meter.

Standard Fixed Point Temperatures (ITS-90)

	Temperature[a]	
Defining Suite	K	°C
Triple point of hydrogen	13.8033	−259.3467
Liquid–vapor equilibrium for hydrogen at 25/76 atm	≈17	≈−256.15
Liquid–vapor equilibrium for hydrogen at 1 atm	≈20.3	≈−252.87
Triple point of neon	24.5561	−248.5939
Triple point of oxygen	54.3584	−218.7916
Triple point of argon	83.8058	−189.3442
Triple point of water	273.16	0.01
Solid–liquid equilibrium for gallium at 1 atm	302.9146	29.7646
Solid–liquid equilibrium for tin at 1 atm	505.078	231.928
Solid–liquid equilibrium for zinc at 1 atm	692.677	419.527
Solid–liquid equilibrium for silver at 1 atm	1234.93	961.78
Solid–liquid equilibrium for gold at 1 atm	1337.33	1064.18
Solid–liquid equilibrium for copper at 1 atm	1357.77	1084.62

T807