Lab #1a
Temperature Measurement
Outline

• Goals of lab
• Purposes of measuring temperature
• Temperature scales
• Temperature standards
• Time constant
• Conventional temperature measuring devices
  – Liquid-in-glass
  – Bimetallic
  – Thermocouple (Configurations, types, Seebeck effect)
  – Resistance Temperature Detector (RTD)
  – Thermistor
  – Infrared thermometer
Goals of Lab

- Familiarization with
  - Different temperature measuring devices
  - Principle of operation and construction details of a thermocouple
Purpose of Measuring Temperature

• Efficiency of a process
  – Appropriate temperature for mixing/reaction

• Reduce unnecessary cost
  – By avoiding over-heating

• Safety considerations
  – Adequate microbial kill

• Quality improvement
  – Minimization of nutrient/color/flavor loss

• Monitor fluctuations in process parameters
Temperature Scales

- Celsius, Fahrenheit, Kelvin, Rankine
- °C = (°F – 32)/1.8
- °F = 32 + 1.8*(°C)
- K = °C + 273.15
- °R = (°C + 273.15)*1.8
- °R = °F + 459.67
- °R = 1.8*K

1 °C change in temp = 1 K change in temp = 1.8 °F change in temp
# Temperature Standards

*(International Temperature Scale of 1990: ITS-90)*

Calibration points between -272.5 °C and 1085 °C

<table>
<thead>
<tr>
<th>Point</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triple point of hydrogen</td>
<td>-259.3467</td>
</tr>
<tr>
<td>Triple point of water</td>
<td>0.01</td>
</tr>
<tr>
<td>Melting point of gallium</td>
<td>29.7646</td>
</tr>
<tr>
<td>Boiling point of water at 1 atm</td>
<td>100 °C (Not a std)</td>
</tr>
<tr>
<td>Freezing point of Indium</td>
<td>156.5985</td>
</tr>
<tr>
<td>Freezing point of tin</td>
<td>231.928</td>
</tr>
<tr>
<td>Freezing point of copper</td>
<td>1084.62</td>
</tr>
</tbody>
</table>
Time Constant ($\tau$)

- Time taken to reach “$1 \sim 1/e$” or 63.2% of the total temp. change in response to a step change in temp.

- $hA \ (T_\infty - T_{\text{sensor}}) = m \ c_p \ dT/dt$

- $-(T - T_\infty) / (T_i - T_\infty) = e^{-(hA \ t \ / \ m \ c_p)}$; \quad $\tau = m \ c_p / h \ A$

- The slope of the graph of $\ln [(T - T_\infty) / (T_i - T_\infty)]$ on the y-axis and time on the x-axis is “$-1/\tau$”

- It takes $\sim 5 \ \tau$ to achieve close to final reading

- Factors affecting time constant
  - Bead/tip size, conducting medium, conv. ht. transf. coef.
Measuring Temperature: Conventional Methods

- **Filled systems** -- Liquid-in-glass (Expansion $\propto$ temperature)
  - Inexpensive, accurate; fragile, no remote sensing
- **Bimetallic** (Deflection of dissimilar bonded metals $\propto$ temperature)
  - Inexpensive, rugged; low precision, no remote sensing
- **Thermocouple** (voltage across dissimilar metal junctions $\propto$ temp.)
  - Inexpensive; least sensitive among electronic type, non-linear
- **RTD** (Resistance of metal $\propto$ temperature)
  - Accurate, linear; expensive, power source, self-heating
- **Thermistor** (Resistance across semiconductor $\propto$ temperature)
  - Fast response; fragile, power source, non-linear, self-heating
- **Pyrometer** (Radiation $\propto$ temperature)
  - Wide range, remote sensing; expensive, low precision, power
Liquid in Glass (LIG) Systems

- Liquids
  - Mercury (linear)
  - Toluene, ethyl alcohol, pentane (dyeing required; also, non-linear)
- Range: -200 °C to 760 °C
- Bulb serves as reservoir for liquid
- As temp. increases, liquid expands & moves through narrow bore
  (expansion amplified by narrow bore -- < 0.5 mm diameter)
  - Expansion $\propto$ temperature
- Immersion of thermometer: Partial, total, and complete
- Space above liquid
  - Nitrogen, argon or nothing (if nothing, slight vacuum in stem)
  - Inert gas decreases tendency for liquid to volatilize
- Advantages: Inexpensive, accurate, power source not required
- Disadvantages: Fragile, safety concerns, remote sensing not possible, analog reading
Liquid-in-Glass Thermometer
Bimetallic Thermometer

- **Principle**
  - Differential expansion of thin dissimilar metals bonded together into a strip (may be coiled) actuates a pointer
  - One end is fixed; other end deflects (moves pointer)
    - Arc if metals are bonded linearly
    - Winding/unwinding if bonded in a helix/spiral

- **Metals**
  - Invar alloy (low coefficient of thermal expansion)
  - Steel, monel, brass

- **Range:** -40 °C to 2000 °C

- Increase length or decrease width to increase sensitivity

- **Advantages:** Inexpensive, rugged, power source not reqd.

- **Disadvantages:** Low precision, remote sensing not possible
Bimetallic Thermometer
Thermocouple

• Principle: Contact between dissimilar metals produces a voltage proportional to temperature (Seebeck effect)
  – Peltier effect (current in circuit of dissimilar metals produces voltage – thermoelectric cooler)
• Range: -200 °C to 2300 °C
• Types: T (blue), K (yellow), E (purple), J (black), N, C, M
  – Platinum or Platinum-Rhodium alloy (B, R, S)
    • Stable, less sensitive, high temperature applications, more expensive
  – Type T (Copper-Constantan): -200 °C to 350 °C; 43 μV/°C
• Advantages: Inexpensive, rugged, wide temperature range
• Disadvantages: Least sensitive amongst electronic types, non-linear response, low voltage
Types of Thermocouples
## Thermocouple Types

<table>
<thead>
<tr>
<th>ANSI/ASTM</th>
<th>Symbol Single</th>
<th>Generic Names</th>
<th>Color Coding</th>
<th>Overall Jacket Extension Grade Wire</th>
<th>Magnetic Yes/No</th>
<th>Environment (Bare Wire)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T</strong></td>
<td>TP TN</td>
<td>Copper</td>
<td>Blue</td>
<td>Blue</td>
<td>X</td>
<td>Mild Oxidizing, Reducing. Vacuum or Inert. Good where moisture is present.</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>EP EN</td>
<td>Chromel®</td>
<td>Purple</td>
<td>Purple</td>
<td>X</td>
<td>Oxidizing or Inert. Limited use in Vacuum or Reducing</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>KP KN</td>
<td>Chromel, Nominal</td>
<td>Yellow</td>
<td>Yellow</td>
<td>X</td>
<td>Clean Oxidizing and Inert. Limited use in Vacuum or Reducing</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>NP NN</td>
<td>Nicrosil®, Nominal</td>
<td>Orange</td>
<td>Orange</td>
<td>X</td>
<td>Clean Oxidizing and Inert. Limited use in Vacuum or Reducing</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>SP SN</td>
<td>Platinum 10% Rhodium Pure Platinum</td>
<td>Black</td>
<td>Green</td>
<td>X</td>
<td>Oxidizing or Inert Atmospheres. Do not insert in metal tubes. Beware of contamination.</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>RP RN</td>
<td>Platinum 13% Rhodium Pure Platinum</td>
<td>Black</td>
<td>Green</td>
<td>X</td>
<td>Oxidizing or Inert Atmospheres. Do not insert in metal tubes. Beware of contamination.</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>BP BN</td>
<td>Platinum 30% Rhodium Platinum 6% Rhodium</td>
<td>Gray</td>
<td>Gray</td>
<td>X</td>
<td>Oxidizing or Inert Atmospheres. Do not insert in metal tubes. Beware of contamination.</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>P N</td>
<td>Tungsten 5% Rhenium Tungsten 26% Rhenium</td>
<td>Green</td>
<td>Red</td>
<td>X</td>
<td>Vacuum, Inert, Hydrogen Atmospheres. Beware of Embrittlement.</td>
</tr>
</tbody>
</table>
Thermocouple Configurations

- Ungrounded
- Grounded
- Exposed

Diagram showing the components of thermocouples:
- Insulation
- Sheath
- Conductors
Thermocouple Principle (Seebeck Effect)
Resistance Temperature Detector (RTD)

- Principle: Resistance of metal = f(Temperature)
- Types: Carbon resistors, film thermometers, wire-wound thermometers, coil element
- Most common: Platinum-based (3-wire setup)
  - Also called, PRTs (Platinum Resistance Thermometers)
  - Pt-100 (100 ohms at 0 °C; 0.385 ohms/°C)
  - Other metals: Iron, copper
- Range: -250 °C to 650 °C
- Advantages: Accurate, stable, linear
- Disadvantages: Expensive, requires a power source, self-heating
RTD
Thermistor

• Principle: Resistance across semiconductor is proportional to its temperature

• Two types
  – Positive temperature coefficient (PTC)
    • Most are of “switching” type
      – Resistance increases rapidly above Curie temperature
      – Polycrystalline ceramic containing barium titanate (BaTiO₃)
  – Negative temperature coefficient (NTC)

• Range: -195 °C to 450 °C

• Advantages: Fast response, high output

• Disadvantages: Fragile, requires a power source, non-linear, low range, self-heating
Infrared Thermometer

• Principle: Radiation (emissivity) proportional to temperature of object
  – Lens focuses infrared energy onto detector
  – This energy is converted into an electrical signal
  – Signal is converted to temperature

• Distance to spot ratio (D:S)
  – 12:1 => If object is 12” away, temp. is averaged across 1” diameter

• Range: -40 °C to 3000 °C

• Infrared camera: Several IR thermometers measuring temp. at many points across large area

• Advantages: Wide temp. range, use for moving objects

• Disadvantages: Expensive, low precision, requires power source, reflective materials are a problem
Infrared Thermometer

- 150ms faster sampling time
- 1% accuracy
- 50:1 distance to spot size
- Dual laser pointers

Distance (D) to Spot size(S)
D:S=50:1(8869)

0.5 in spot @ 25 in
13mm spot @ 650mm (Unit: mm)