Chapter 1 - Introduction and Preliminaries

Lecture 2
Sections 1.7-1.11

MEMS 0051 Introduction to Thermodynamics

Mechanical Engineering and Materials Science Department
University of Pittsburgh

Learning Objectives

1.7 Pressure

1.8 Energy

1.9 Equality of Temperatures

1.10 Zeroth Law of Thermodynamics

1.11 Temperature Scales

Summary

Student Learning Objectives

At the end of the lecture, students should be able to:

- Recognize the units of pressure
- Identify the components of energy (internal, kinetic and potential)
- Understand the difference between energy and specific energy
- Understand the equality of temperature and how it pertains to the Zeroth Law of Thermodynamics
- Be familiar with the SI temperature scales (Celsius and Kelvin)

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Summary

Pressure

- **Pressure** (P) is force, which is mass times acceleration, per unit area [N/m^2, Pa]
- We assume that pressure acts uniformly over a given area, and the pressure within a gas/liquid will act uniformly over the surfaces containing said medium
- The force produced by a pressured fluid is simply the pressure of said fluid times the area on which it is acting

$$F = P\,A$$

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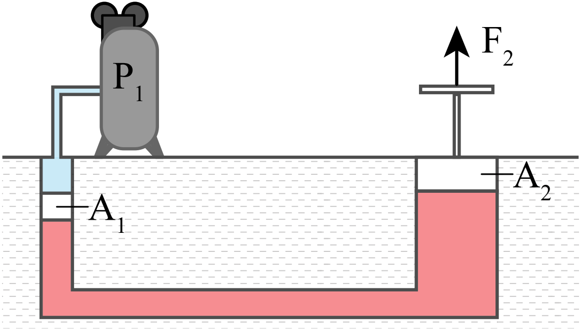
Example #1

- Consider an application of Pascal's law where an incompressible fluid (i.e. cannot be compressed) is contained between two piston-cylinder devices. Determine the force F_2 the second piston generates based upon the input force F_1.



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Example #1

- Solution:

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Energy

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Summary

- The energy of matter is broken down into three components:
    1. **Internal energy** (U) [J] - energy contained within the system, excluding the following:
    2. **Kinetic energy** (KE) [J] - energy of motion
    3. **Potential energy** (PE) [J] - energy due to external force fields

$$E = U + KE + PE$$

- The unit of energy is **Joules** [J], or [kg-m^2/s^2]=[N-m], which is equivalent to the energy transferred to an object when a force of one Newton acts on an object in the direction of its motion through a distance of one meter

Specific Energy

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- On a per mass basis, we have

$$\boxed{e = u + ke + pe = u + \frac{V^2}{2} + gz}$$

- It is noted the kinetic energy in this formulation is for translation energy, and we can modify our expression for other forms of motion (i.e. rotational)
- The energy we are interested in, in a macroscopic viewpoint, is always taken in reference to a basal value, for u is difficult to quantify
- Be consistent with units - each term on the RHS should have units of [J/kg] or [kJ/kg]

Example #2

- Say a copper block with a specific internal energy of 1 [kJ/kg] is moving horizontally across a surface with a velocity of 25 [m/s]. Determine the total specific energy.

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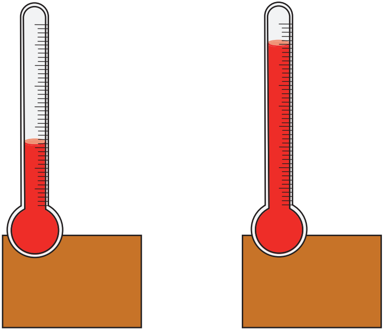
Equality of Temperature

- Consider two blocks, of the same size and material, say copper
- Say one is hot, and the other is cold, as indicated by thermometers



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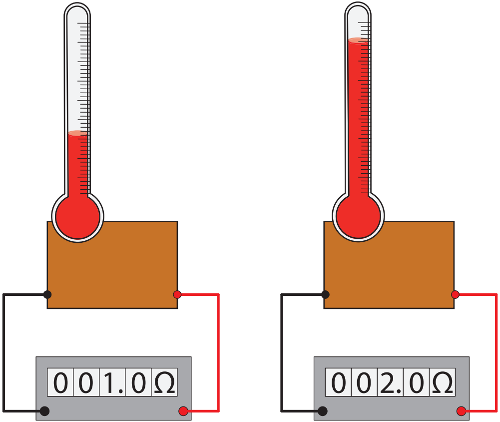
Equality of Temperature

- If we measure the electrical resistance of each block, they should differ ($\rho = \rho(T)$)



Equality of Temperature

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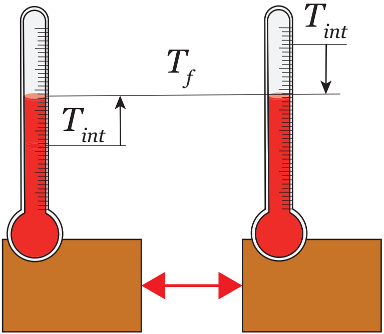
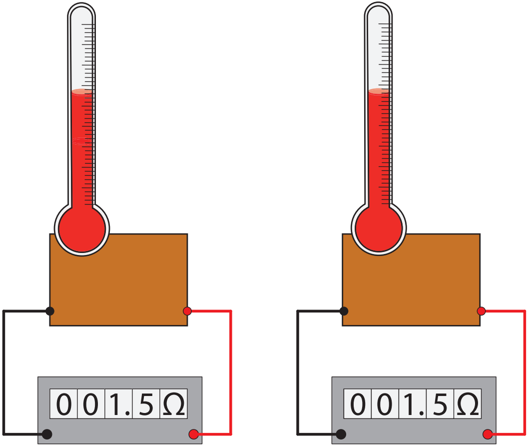
Summary

- Now if the blocks are put in thermal communication, we observe the temperature of the hot block decreases and that of the cold block increases (no perceivable change as $t \rightarrow \infty$)



Equality of Temperature

- If we measure the electrical resistivity of each block, they will be identical



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Equality of Temperature

- Therefore, two bodies have **equality of temperature** if, when they are in thermal communication, have no change in any observable property (electrical resistivity, density, etc.)

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Zeroth Law of Thermodynamics

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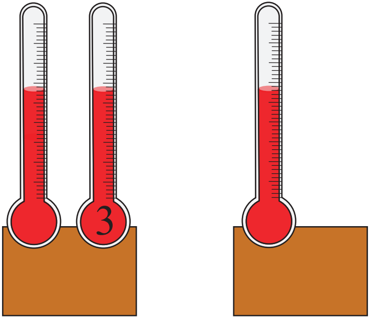
Summary

- Consider our two blocks again, and a third thermometer
- Let the third thermometer be in contact with one block until equality of temperature is established



Zeroth Law of Thermodynamics

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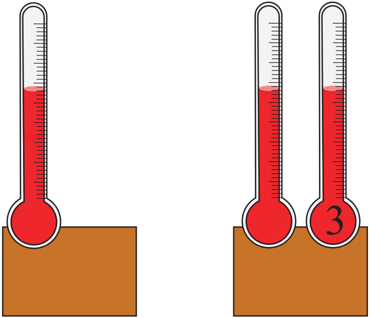
- Then, we take the third thermometer and place it in contact with the second block until equality of temperature is established



Zeroth Law of Thermodynamics

- If there is no discernible change in the mercury level of the third thermometer, we say the two blocks are in thermal equilibrium with the given thermometer
- The **Zeroth Law of Thermodynamics** states when two bodies have equality of temperature with a third, they must have equality of temperature with each other

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Summary

- Although the zeroth law establishes equality of temperature between three bodies, what happens when we have multiple temperature measurement devices?
- We have to introduce a temperature scale that is used as a standard
- We use the SI unit system for the **Celsius scale** °C, which is based upon the triple point of water (0.01 °C) and the steam point (100.00 °C)
- The absolute temperature scale, the **Kelvin scale** [K] or **thermodynamic scale of temperature**, provides a scale where temperature cannot go below 0 [K] (actually, it can)

$$\mathrm{K} = {}^\circ\mathrm{C} + 273.15$$

Example #3

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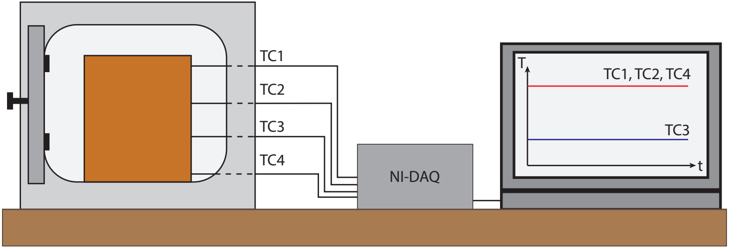
Summary

- Four thermocouples (TC1, TC2, etc.) are placed in thermal communication with a copper block, which is being heated in an oven. The voltage output of the thermocouples is recorded by a DAQ, that allows a computer to log the temperature versus time. What can we say about the thermocouples? What can we say about the block in terms of thermal equilibrium?



Student Learning Objectives

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Summary

At the end of the lecture, students should be able to:

- Recognize the units of pressure
  - Pressure has units of Pascals, [Pa], which is a Newton per square-meter
- Identify the components of energy (internal, kinetic and potential)
  - Energy E is the sum of Internal, U, Kinetic, KE and Potential, PE, energies.
- Understand the difference between energy and specific energy
  - Specific energy is energy on a per-unit mass basis

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Summary

- Understand the equality of temperature and how it pertains to the Zeroth Law of Thermodynamics
  - The equality of temperature states that two bodies are in thermal equilibrium if there are no discernible differences of measure temperature, or another temperature-dependent intensive property. If two bodies have equality of temperature with a third body, they have equality of temperature with each other, i.e. the Zeroth Law of Thermodynamics
- Be familiar with the SI temperature scales (Celsius and Kelvin)
  - Temperature is measure in Celsius, °C, or Kelvin, [K]

Suggested Problems

- 1.17, 1.43, 1.44, 1.45, 1.49, 1.84, 1.85

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