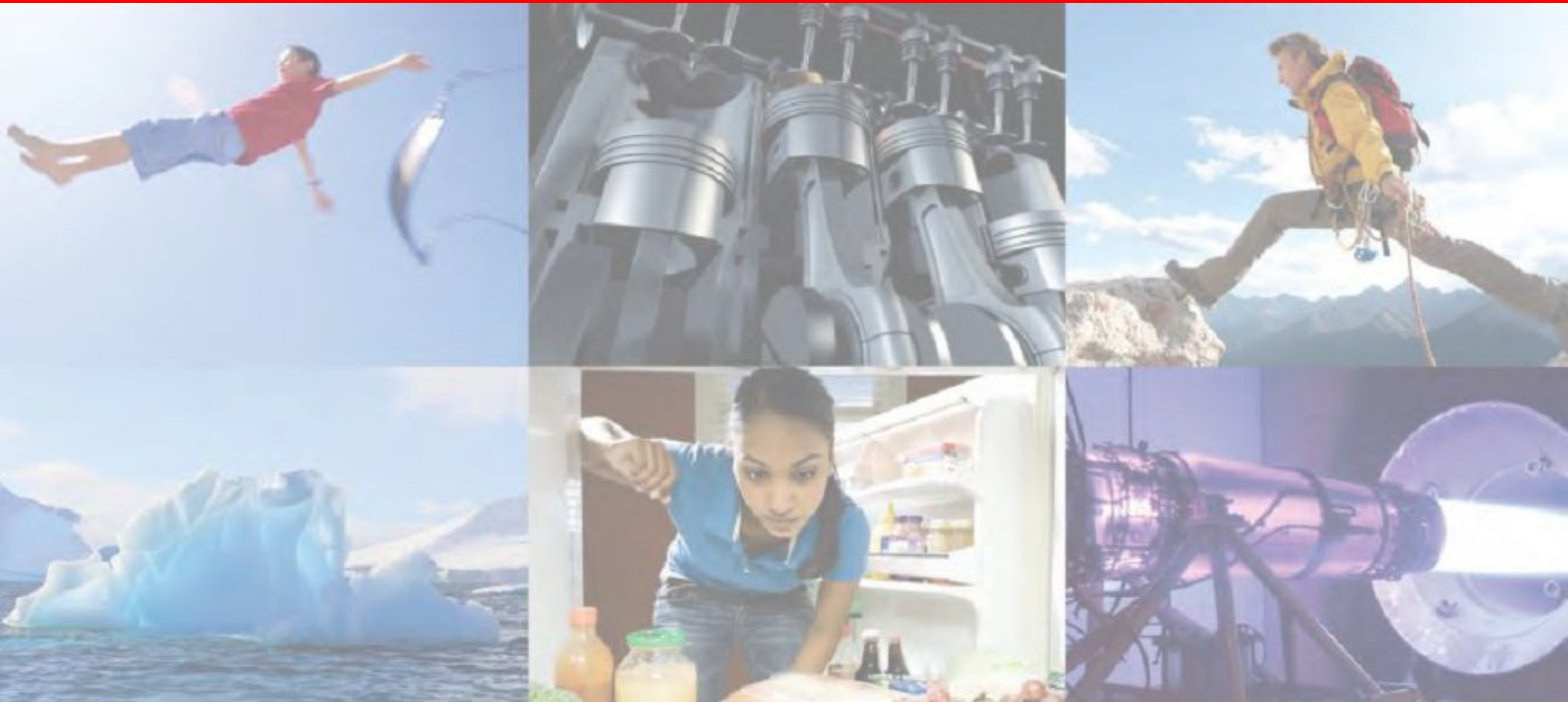


Introduction to THERMODYNAMICS

By Ertanto Vetra

Overview

- Lecture : 18 weeks (Mid Term Exam on 9^{th} week & Final Exam on 18^{th} week)

- References:
  1. Smith, J.M. & Van Ness, H.C. *Introduction to Chemical Engineering Thermodynamics 7th ed.*
  2. Moran, M.J. & Saphiro H.N. *Fundamentals of Engineering Thermodynamics 7th ed.*
  3. Other reference as needed

- This course is calculation-intensive, ALWAYS bring yourself a calculator

EVALUATION

- Homework (Individual/Group) = **15%**
  - DO it by yourself
  - Creativity is highly appreciated
  - Hand writing is accepted, but computer typed is better
- Quiz (Open/Closed Book) = **25%**
  - Closed book → Announced; Open book → Unannounced
- Mid-Term Exam = **30%**
  - Open Note (max. 2 page of duplex A4, hand written by yourself)
  - Topics from the beginning to the middle of semester
- Final Exam = **30%**
  - Open All (Book/Notes/Laptop)
  - Topics from the middle to the end of semester

Topics

Week 1-8	UTS	Week 10-17	UAS

- Introductions
- Physical Properties
- Basics of Thermodynamic
- Thermodynamic process
- Heat effect
- Laws of Thermodynamics
- Entropy
- Thermodynamic cycles

- Vapor Power System
- Gas Power System
- Refrigeration/Liquefaction
- Reaction and Combustion
- Vapor-Liquid Equilibrium

Thermodynamics

- Thermodynamics can be defined as the **science of energy**
- Thermodynamics = *therme* (heat) and *dynamis* (power) → efforts to convert heat into power
  - How to produce power from heat?
  - How to remove heat by adding power?

Milestones

- The first successful atmospheric steam engines in England by Thomas Savery in 1697 and Thomas Newcomen in 1712. These engines were very slow and inefficient, but they opened the way for the development of a new science
- The first and second laws of thermodynamics emerged simultaneously in the 1850s, primarily out of the works of William Rankine, Rudolph Clausius, and Lord Kelvin

Laws of Thermodynamics

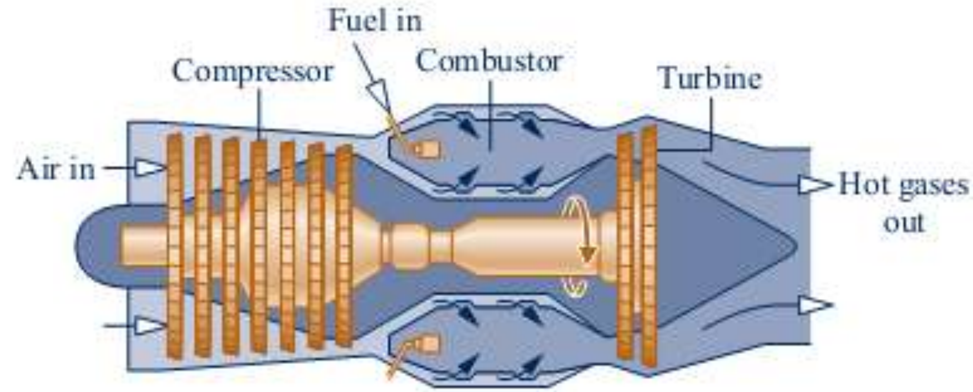
- The “Laws” of thermodynamics are not laws, but principles derived from observation that have never known to have been violated. There are theoretical underpinnings, but no rigorous proof of these laws.

Laws of Thermodynamics

0. If two systems are in thermal equilibrium with a third system, they must be in thermal equilibrium with each other.
1. Heat is a form of energy. The energy in the universe is constant
2. The entropy of any closed system not in thermal equilibrium almost always increases.
3. The entropy of a system approaches a constant value as the temperature approaches zero.

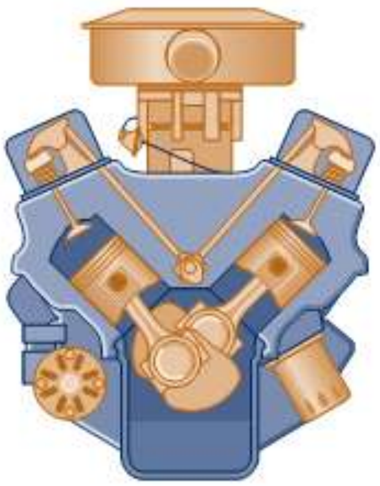
Application of Thermodynamics

- Air conditioning system
- Refrigerators
- Automotive engines
- Power generation Plant



Turbojet engine

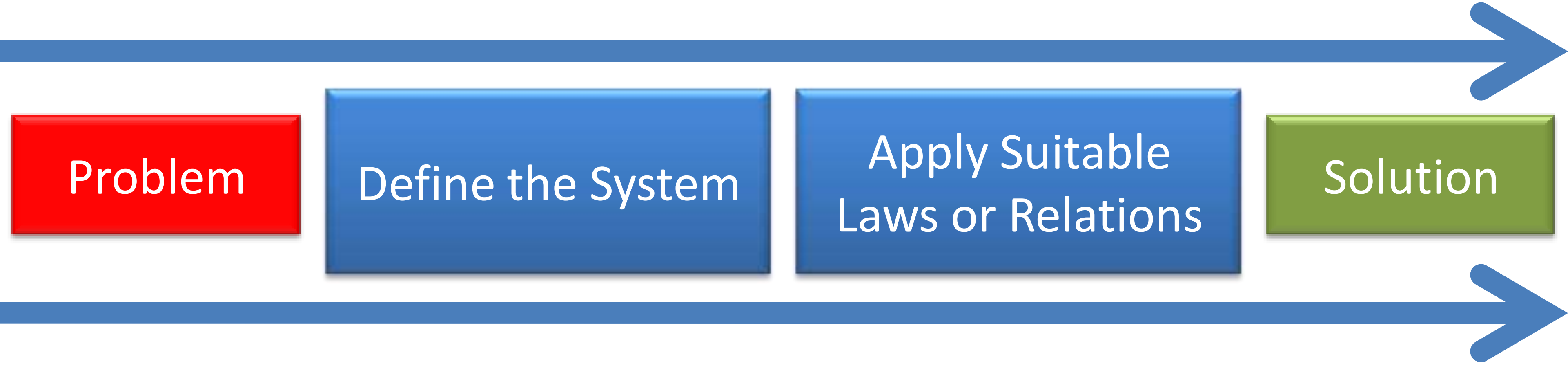
Refrigerator



Vehicle engine

Defining the System

- The key initial step in any engineering analysis is to describe precisely what is being studied



Defining the System

- The ***system*** is whatever we want to study
- Everything external to the system is considered to be part of the system's ***surroundings***
- The system is distinguished from its surroundings by a specified ***boundary***
- A system can be a ***closed system (control mass)*** or an ***open system (control volume)***

Extensive & Intensive Properties

- **Intensive properties** are those that are independent of the mass of a system, such as temperature, pressure, and density.
- **Extensive properties** are those whose values depend on the size—or extent—of the system. Total mass, total volume, and total momentum are some examples of extensive properties

Extensive & Intensive Properties

- The difference between intensive and extensive properties is like the difference between “quality” and “quantity”. For example, temperature is intensive, if one block of ice is at −10 °C then adding another identical block does not make the temperature −20 ° C, but it does mean that melting the two blocks of ice will take twice as much energy.
- Note that any extensive property can be made into an intensive property by dividing by another extensive property,

  e.g.: mass (extensive) divided by volume (extensive) is density (intensive)

Dimensions & Units

- Any physical quantity can be characterized by dimensions. The magnitudes assigned to the dimensions are called units
- There are seven base units, Other units are derived from them:

Quantity	Unit Name	Unit Simbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Thermodynamic Temperature	kelvin	K
Luminous intensity	candela	cd
Amount of Substance	mole	mol

Dimensions & Units

- SI = *Système international d'unités*
- The SI is a simple and logical system based on a **decimal** relationship between the various units
- Seconds = duration of 9,192,631,770 cycles of radiation associated with a specified transition of the cesium atom
- meter = the distance light travels in a vacuum during 1 / 299,792,458 of a second
- kilogram = the mass of a platinum/iridium cylinder kept at the International Bureau of Weights and Measures at Skvres, France
- Temperature = absolute zero and the triple point of Vienna Standard Mean Ocean Water, which is water specially prepared with a specified blend of hydrogen and oxygen isotopes
- Mole = amount of substance represented by as many elementary entities (e.g., molecules) as there are atoms in 0.012 kg of carbon-12

Dimensions & Units

SI notational scheme (1967)

- Thle degree symbol was dropped from the absolute temperature unit
- All unit names were to be written without capitalization even if they were derived from proper names
- The abbreviation of a unit was to be capitalized if the unit was derived from a proper name, e.g.: SI unit of force is *newton* **NOT** *Newton* and it is abbreviated **N**
- The full name of a unit may be pluralized, but its abbreviation cannot, e.g.: *5 m* or *5 meters* **NOT** *5 ms* or *5 meter*
- No period is to be used in unit abbreviations unless they appear at the end of a sentence

Dimensions & Units

- The English system, however, has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily (12 in = 1 ft, 1 mile = 5280 ft, 4 qt = gal, etc.), which makes it confusing and difficult to learn.
- United States being the only industrialized nation that does not mainly use the metric system in its commercial and standards activities.
- English engineering system, use units that are related to SI units by fixed conversion factors. Thus, the foot (ft) is defined as 0.3048 m, the pound mass (lb) as 0.45359237 kg, and the pound mole (lb mol) as 453.59237 mol.

Dimensions & Units

As pointed out, the SI is based on a decimal relationship between units

Table 1.1 Prefixes for SI Units

Multiple	Prefix	Symbol	Multiple	Prefix	Symbol
10^{-24}	yocto	y	10^{1}	deca	da
	zepto	z	10^{2}	hecto	n
10^{-18}	atto	a	10^{3}	kilo	k
10^{-15}	femto	f	10^{6}	mega	M
10^{-12}	pico	p	10^{9}	giga	G
	nano	n	10^{12}	tera	T
	micro	μ	10^{15}	peta	P
10^{-3}	milli	m	10^{18}	exa	E
	centi	c	10^{21}	zetta	Z
10^{-1}	deci	d	10^{24}	yotta	Y

Unity Conversion Ratios

- All non-primary units (secondary units) can be formed by combinations of primary units. Force units, for example, can be expressed as:

$$N = kg \frac{m}{s^2} \quad \text{and} \quad lbf = 32.174\ lbm \frac{ft}{s^2}$$

- They can also be expressed more conveniently as unity conversion ratios as:

$$\frac{N}{kg \cdot m/s^2} = 1 \quad \text{and} \quad \frac{lbf}{32.174\ lbm \cdot ft/s^2} = 1$$

- Unity conversion ratios are identically equal to 1 and are unitless, and thus such ratios (or their inverses) can be inserted conveniently into any calculation to properly convert units
- Students are encouraged to always use unity conversion ratios such as those given here when converting units

Exercise (1)

- Using unity conversion ratios, show that 1.00 lbm weights 1.00 lbf on earth

Force

- Force = (mass) (acceleration)
- In English system it is considered as a primary dimension and is assigned a non-derived unit, while in SI, it is a non-primary dimension
- In SI, force unit = newton (N)
  - the force required to accelerate a mass of 1 kg at a rate of 1 m/s^2
- In English unit = pound-force (lbf)
  - the force required to accelerate a mass of 32.174 lbm (1 slug) at a rate of 1 ft/s^2
- Weight is also a kind of force where the acceleration is gravity; W= m.g

Exercise (2)

An astronauts weighs 730 N in Houston, Texas, where the local acceleration of gravity is $g=9.792\ m.s^{-2}$. What are the astronauts mass and weight on the moon, where $g = 1.67\ m.s^{-2}$?

Work

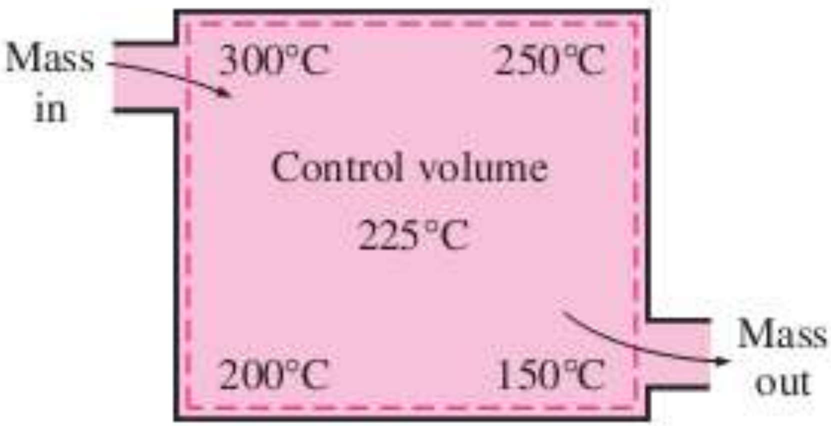
- Form of energy
- Defined as force times distance, thus it has the unit "newton-meter (N.m)" which is called a joule (J); 1 J = 1 N.m
- In English system, the unit is Btu (British thermal unit) = the energy required to raise the temperature of 1 lbm of water at 68°F by 1°F
- In metric system, the amount of energy needed to raise the temperature of 1 g of water at 14.5°C by 1°C is defined as 1 calorie (cal), and 1 cal = 4.1868 J
- The magnitudes of the kilojoule and Btu are almost identical (1 Btu = 1.0551 kJ)

Properties, State, Processes and cycles

- **Properties** = macroscopic characteristic of a system, e.g.: mass, volume, energy
- **State** = Condition of a system as described by its properties
- **Process** = any change that a system undergoes from one state to another
- **Path** = the series of states through which a system passes during a process
- A System is said to undergone a **cycle** if it returns to its initial process, e.g.: refrigeration cycle, Carnot cycle

Steady State Process

- Steady = no change of properties over time
- The opposite is Unsteady / Transient
- Uniform = no change with location over a specified region



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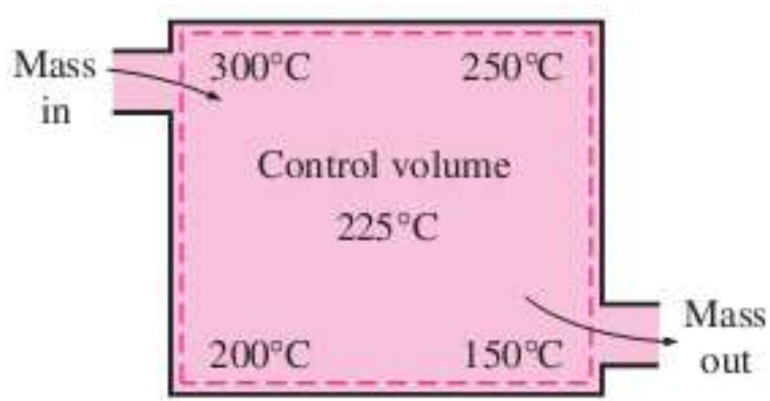

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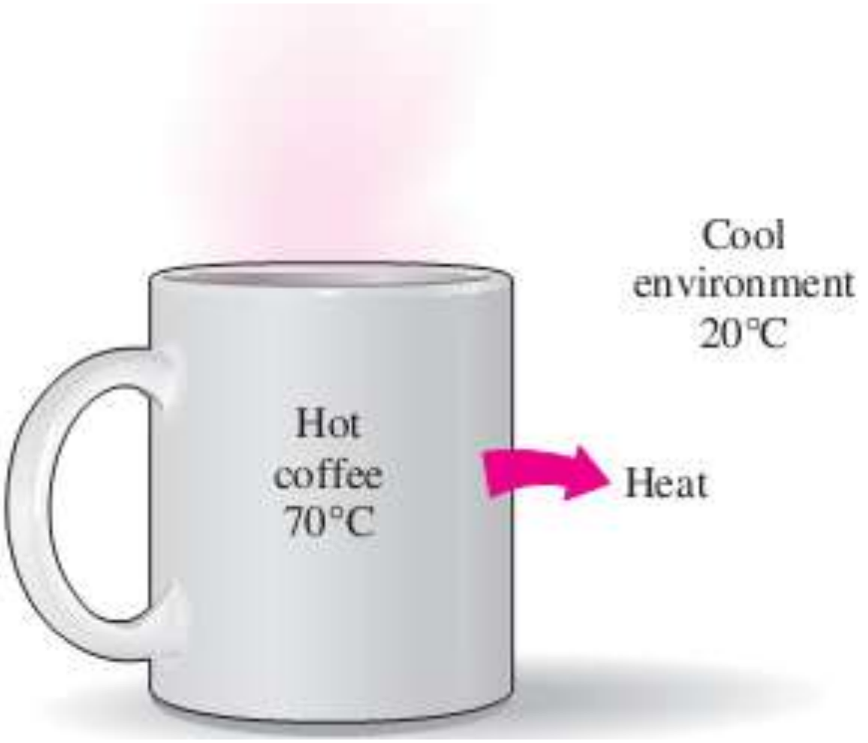
Thermal equilibrium



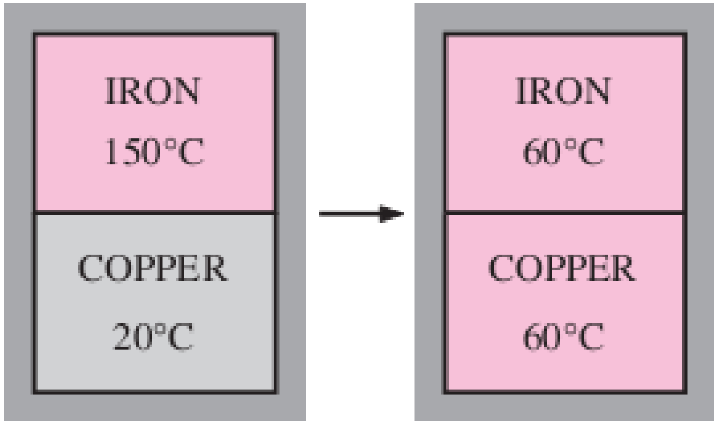


FIGURE 1–31

Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.

The equality of temperature is the only requirement for thermal equilibrium

Zeroth law of Thermodynamics

- If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other
- The zeroth law was first formulated and labeled by R. H. Fowler in 1931
- As the name suggests, its value as a fundamental physical principle was recognized more than half a century after the formulation of the first and the second laws of thermodynamics.
- It was named the zeroth law since it should have preceded the first and the second laws of thermodynamics.

Temperature

- The temperature scales used in the SI is the Celsius scale (formerly called the centigrade scale; in 1948 it was renamed after the Swedish astronomer A. Celsius, 1702–1744)
- In the English system is the Fahrenheit scale(named after the German instrument maker G. Fahrenheit, 1686–1736)
- **Thermodynamics temperature scale** : the absolute measure of temperature. its *null* or zero point, absolute zero, is the temperature at which the particle constituents of matter have minimal motion and can become no colder (kelvin in SI and rankine in English)

Temperature relations

$$T(\text{K}) = T(^\circ\text{C}) + 273.15 \qquad T(\text{R}) = T(^\circ\text{F}) + 459.67$$

$$T(\text{R}) = 1.8T(\text{K})$$

$$T(^\circ\text{F}) = 1.8T(^\circ\text{C}) + 32$$

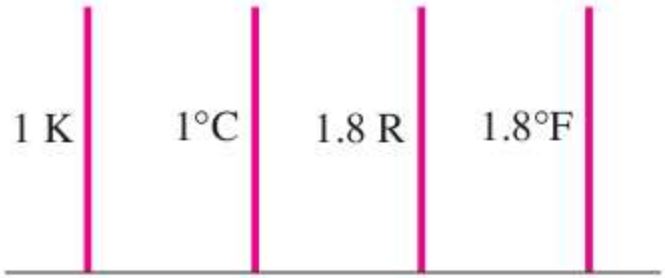


FIGURE 1–35

Comparison of magnitudes of various temperature units.

$$\Delta T(\text{K}) = \Delta T(^\circ\text{C})$$

$$\Delta T(\text{R}) = \Delta T(^\circ\text{F})$$

Pressure

- Defined as : a normal force exerted by a fluid per unit area
- It has the units of newtons per square meter (N/m^2) or pascal (Pa) ; 1 Pa = 1 N/m^2

$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa}$$

$$1 \text{ atm} = 101{,}325 \text{ Pa} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$$

$$1 \text{ kgf/cm}^2 = 9.807 \text{ N/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2 = 9.807 \times 10^4 \text{ Pa}$$

$$= 0.9807 \text{ bar}$$

$$= 0.9679 \text{ atm}$$

Absolute/Gage/Vacuum Pressure

- The actual pressure at a given position is called the **absolute pressure**
- Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere, and so they indicate the difference between the absolute pressure and the local atmospheric pressure. This difference is called the **gage pressure**
- Pressures below atmospheric pressure are called **vacuum pressures**
- In thermodynamic relations and tables, **absolute pressure** is almost always used.

$$P_{gage} = P_{abs} - P_{atm} \qquad P_{vac} = P_{atm} - P_{abs}$$

Pressure variation with height

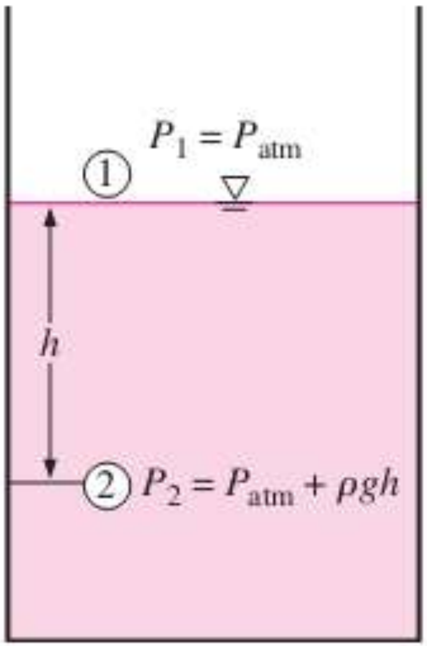


FIGURE 1–42

Pressure in a liquid at rest increases linearly with distance from the free surface.

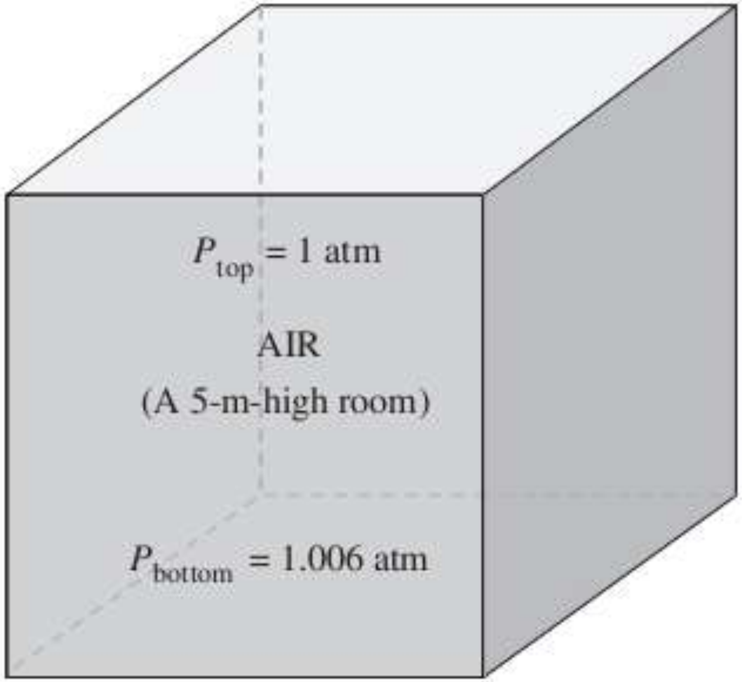
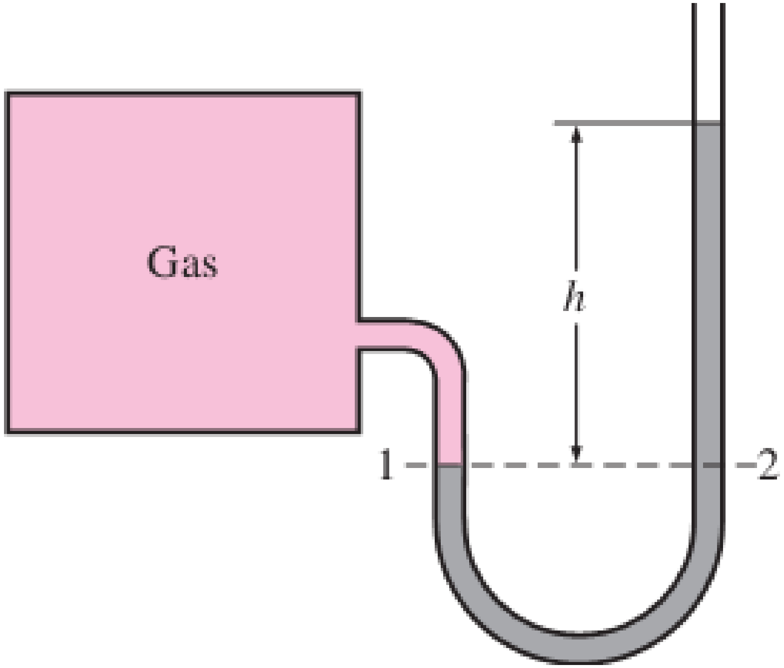


FIGURE 1–41

In a room filled with a gas, the variation of pressure with height is negligible.

Manometer



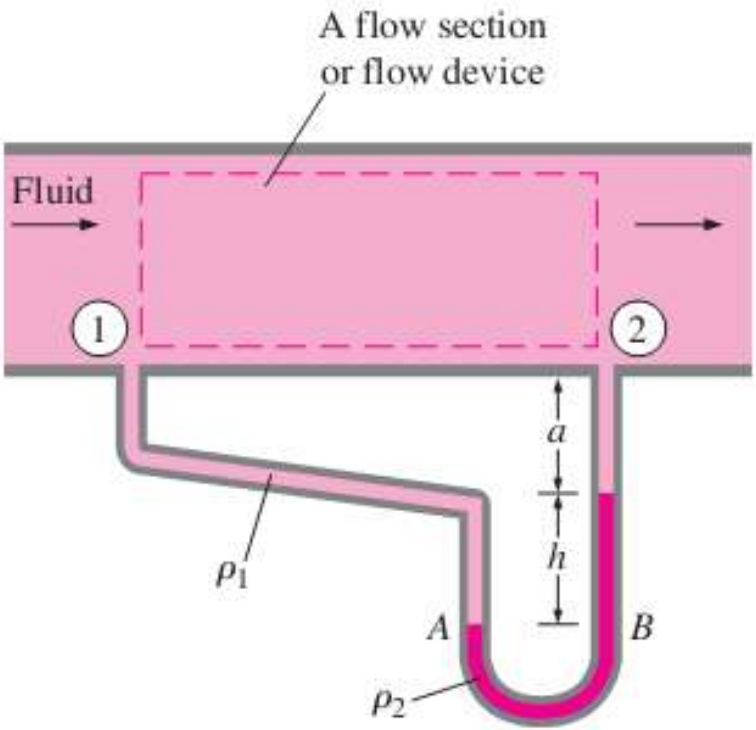


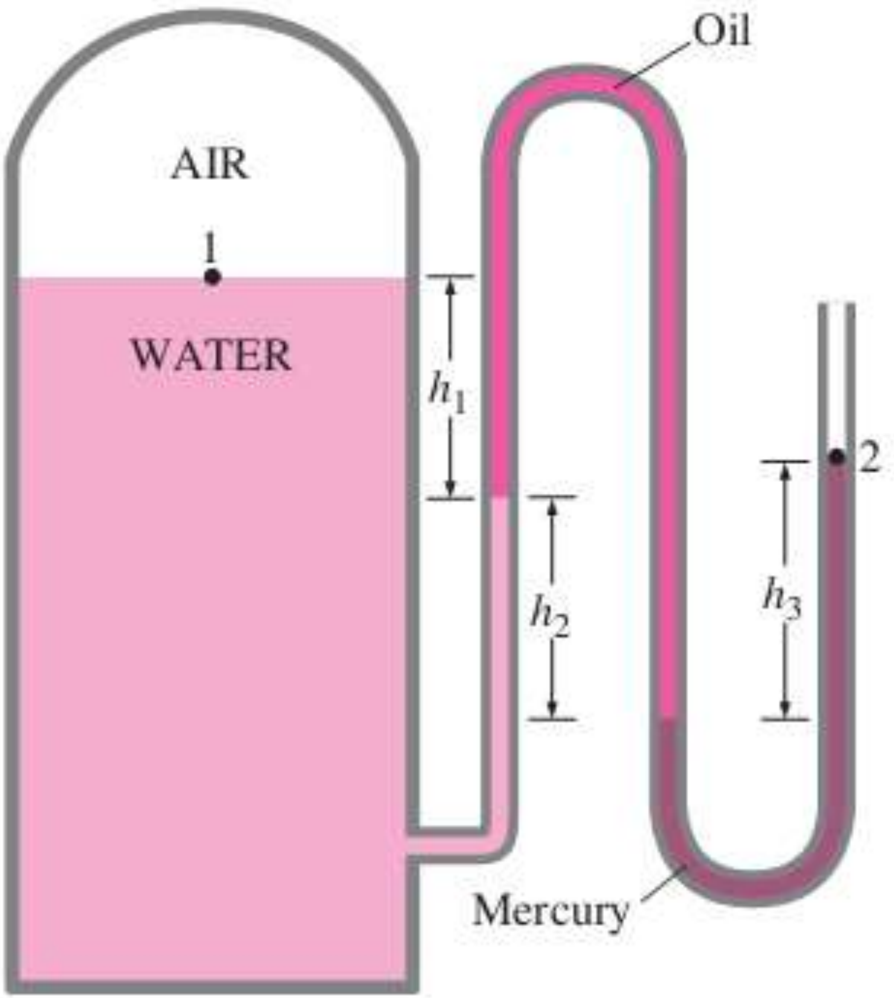
FIGURE 1–48

Measuring the pressure drop across a flow section or a flow device by a differential manometer.

Exercise (3)

At 300.15 K the reading on a manometer filled with mercury (density = 13,530 $kg.m^{-3}$) is 60.5 cm. The local acceleration of gravity is 9.784 m.s-2. To what pressure does this weight of mercury correspond?

Exercise (4)



The water in a tank is pressurized by air, and the pressure is measured by a multi-fluid manometer as shown in left figure.

The tank is located on a mountain at an altitude of 1400 m where the atmospheric pressure is 85.6 kPa.

Determine the air pressure in the tank if h_1= 0.1 m, h_2= 0.2 m, and h_3= 0.35 m. Take the densities of water, oil, and mercury to be 1000 kg/m^3, 850 kg/m^3, and 13,600 kg/m^3, respectively.

Homework

1. It is known that the value of R (universal gas constant) is 8,314 J/mol.K. Convert the constants in the following unit (Show your conversion steps):
   1. hp.hr/lbmol. °R
   2. btu/lbmol °R
   3. m^3 bar/kmol.K
   4. ft^3. lb/in^2/lbmol. °R
2. An instrument to measure the acceleration of gravity on Mars is constructed of a spring from which is suspended a mass of 0.40 kg. At a place on earth where the local acceleration of gravity is 9.81 m.s-2, the spring extends 1.08 cm. When the instrument package is landed on Mars, it radios the information that the spring is extended 0.40 cm. What is the Martian acceleration of gravity?
3. Perpetual motion is a hypothetical machines that produce more work or energy than they consume
4. (Bonus) Using only a 4-minute and 7-minute hourglass, describe the fastest way to measure 9 minutes? Illustrate your answer (be creative)

Homework (1)

- R = 8.314 J/mol K

  = 0.00078048 hp.hr/lbmol. °R

  = 1.9859 btu/lbmol °R

  = 0.083145 m^3 bar/kmol.K

  = 10.732 (ft^3. lb/in^2)/lbmol. °R

1 mol	=0.002205	lbmol
1 J	=3.73E-07	hp.h
1 K	=1.8	R
1 hp.h	=2544.43	Btu
1 J	=1.00E-05	m3.bar
1 mol	=1.00E-03	kmol
1 m3	=35.3147	ft3
1 bar	=14.5038	lb/in2

Homework (2)

- Weight = Spring Force

  $m.g = k.\,x$

  m, and k is constant regardless of the gravity, so:

  $g \sim k$

  $g_{mars} = g_{earth} \, (x_{mars} / x_{earth})$

  $g_{mars} = 9.81 \text{ m/s2} * (0.40 \text{ cm}/ 1.08 \text{ cm})$

  $= 3.63 \text{ m/s2}$

Homework (3)

- In any closed system, you cannot create new energy (first law of thermodynamics)
- You always lose a little energy (second law of thermodynamics)
- Therefore a machine cannot make more energy than it uses or even enough to keep itself operating.

Homework (4)

4-minute
hourglass

7-minute
hourglass