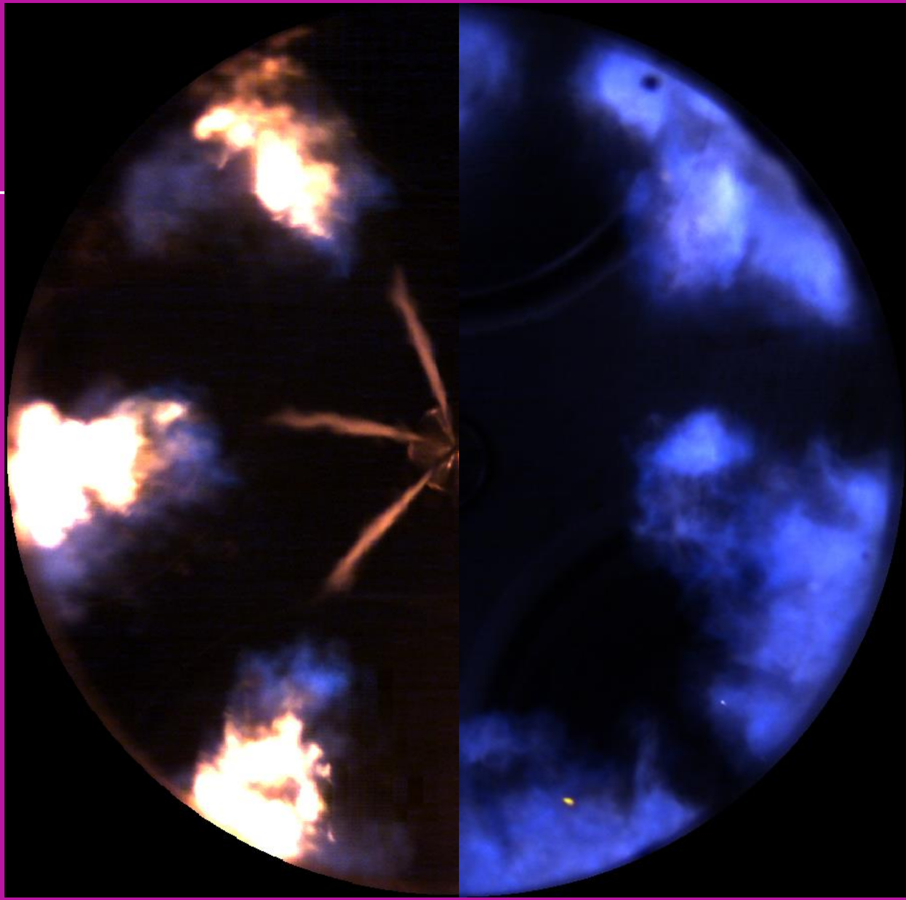
Thermodynamics

An Engineering Approach

Lecture 1: Introduction and Basic Concepts

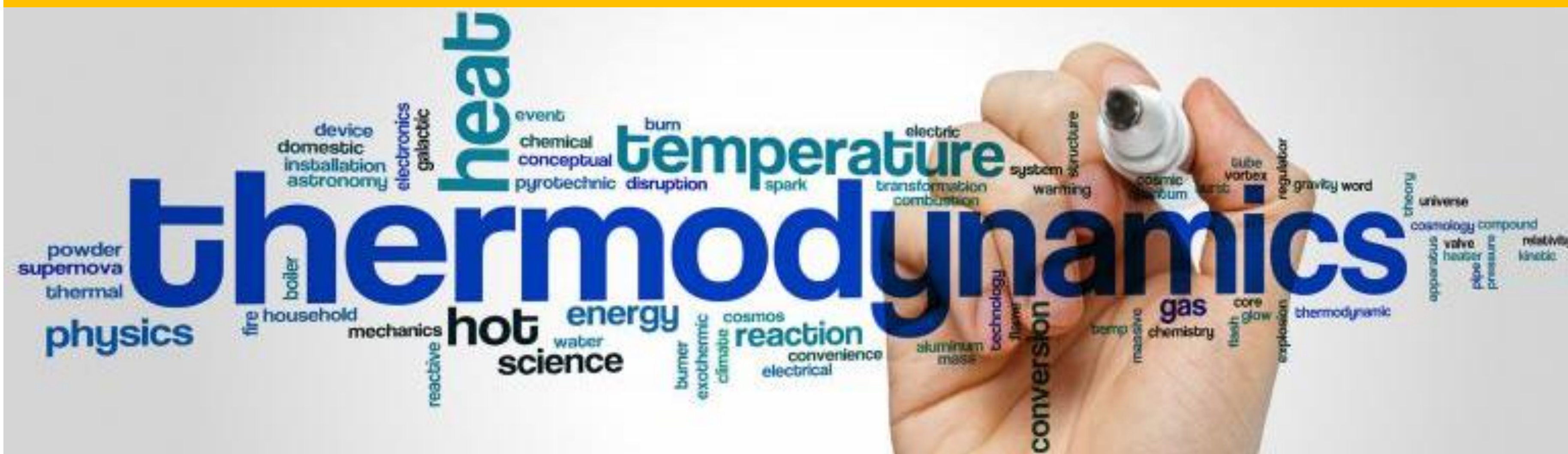
Qiang Cheng (Jonny)



Aalto University
School of Engineering

Background

- **Thermodynamics is a branch of physics that deals with heat, work, and temperature, and their relation to energy, radiation, and physical properties of matter.**
- **The behavior of these quantities is governed by the four laws of thermodynamics which convey a quantitative description using measurable macroscopic physical quantities but may be explained in terms of microscopic constituents by statistical mechanics.**
- **Thermodynamics applies to a wide variety of topics in science and engineering, especially physical chemistry, chemical engineering and mechanical engineering, but also in other complex fields such as meteorology, biology and phylosophy.**



https://online.stanford.edu/courses/matsci204-thermodynamics-and-phase-equilibria

Objective

- **To cover the basic principles of thermodynamics.**
- **To present a wealth of real-world engineering examples to give students a feel for how thermodynamics is applied in engineering practice.**
- **To develop an intuitive understanding of thermodynamics by emphasizing the physics and physical arguments that underpin the theory.**
- **To present a comprehensive and rigorous treatment of classical thermodynamics while retaining an engineering perspective.**
- **To lay the groundwork for subsequent studies in such fields as fluid mechanics, heat transfer and to prepare the students to effectively use thermodynamics in the practice of engineering.**
- **To gain a better understanding of our life and achieve a higher quality of lift!!!**

Philosophy and Goals

- **In this course you will be introduced to properties of matter (Temperature, Pressure, Enthalpy, Specific Volume, Entropy, etc.) and governing laws which can be used to describe the behavior of matter and its interaction with the surrounding environment.**
- **You will learn how to identify systems and to use thermodynamic analysis to describe the behavior of the system in terms of properties and processes.**
- **Understanding how to apply these concepts is a powerful tool for the engineer, enabling the evaluation of material states (phases) under different conditions and the maximum efficiency achievable with various power cycles.**
- **After completing this course, you should be able to define and describe properties and processes used in thermodynamic analysis and the governing laws.**
- **In addition, you should be able to apply control volume analysis and thermodynamic principles to solve problems involving power and refrigeration cycles.**
- **Communicates directly to the minds of tomorrow's engineers in a simple yet precise manner.**
- **Leads students toward a clear understanding and firm grasp of the basic principles of thermodynamics.**
- **Encourages creative thinking and development of a deeper understanding and intuitive feel for thermodynamics.**

Other Materials and Sources

- MITOPENCOURSEWARE:

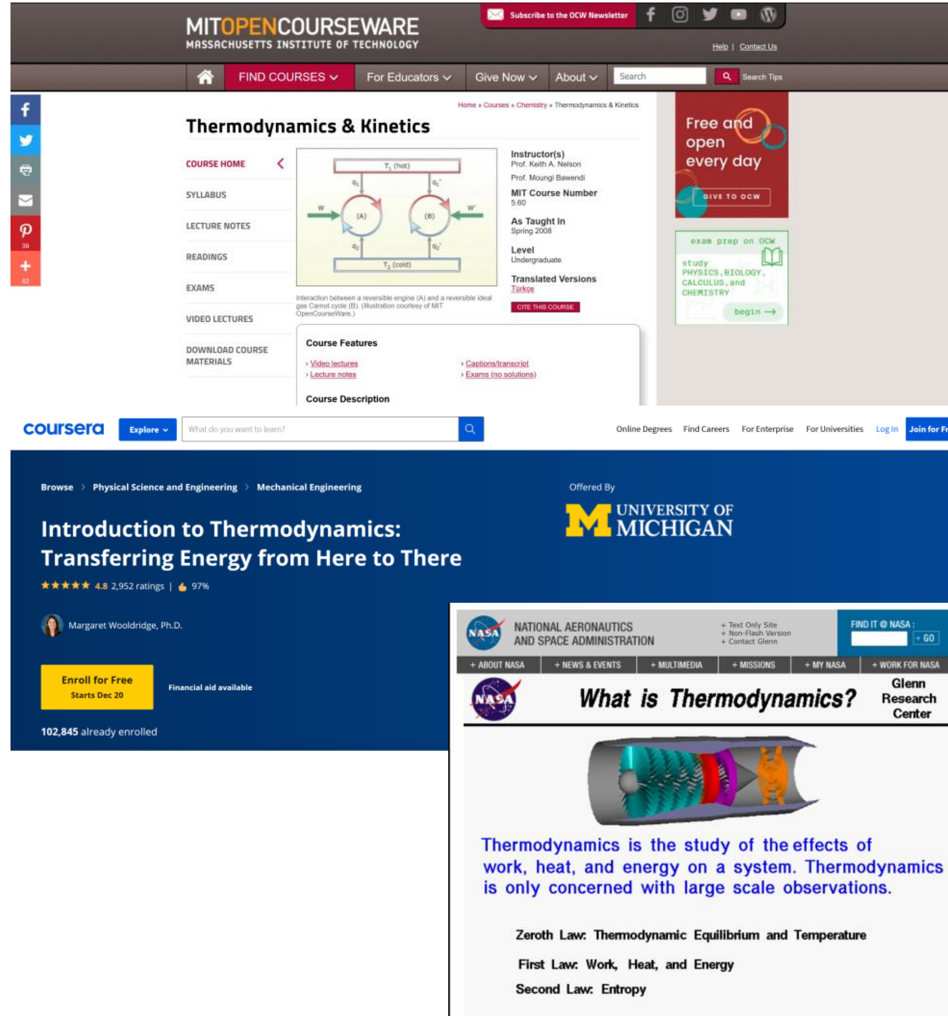
  https://ocw.mit.edu/courses/chemistry/5-60-thermodynamics-kinetics-spring-2008/video-lectures/

- NASA

  https://www.grc.nasa.gov/www/k-12/airplane/thermo.html

- University of Michigan

  https://www.coursera.org/learn/thermodynamics-intro



Aalto University
School of Engineering

Problem-solving technique

- **Step 1: Problem Statement**
- **Step 2: Schematic**
- **Step 3: Assumptions and Approximations**
- **Step 4: Physical Laws**
- **Step 5: Properties**
- **Step 6: Calculations**
- **Step 7: Reasoning, Verification, Conclusion and Discussion**

Engineering Software Packages

MATLAB

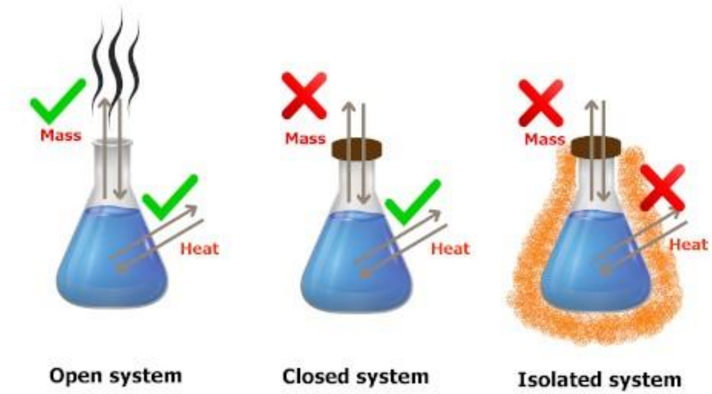
python™

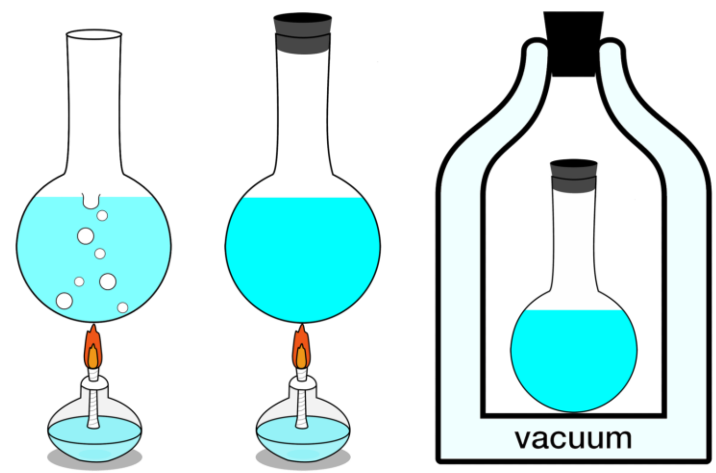
Wolfram Mathematica 10

Lecture 1: Introduction and Basic Concepts

Learning Outcomes

- Identify the unique vocabulary associated with thermodynamics through the precise definition of basic concepts to form a sound foundation for the development of the principles of thermodynamics.
- Identify SI and English Engineering units, including units for specific volume, pressure, and temperature. Describe the relationship among the Kelvin, Rankine, Celsius, and Fahrenheit temperature scales. Apply appropriate unit conversion factors during calculations.
- Discuss properties of a system and define density, specific gravity, and specific weight.
- Explain several fundamental concepts used throughout the book, including closed system, control volume, boundary and surroundings, property, state, process, the distinction between extensive and intensive properties, and equilibrium.
- Introduce an intuitive systematic problem-solving technique.



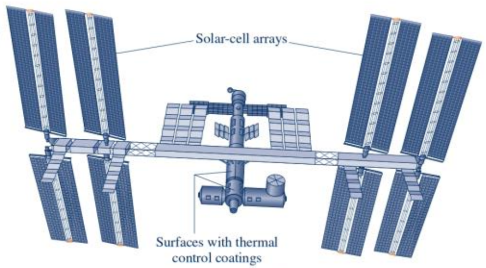


Aalto University
School of Engineering

Using Thermodynamics

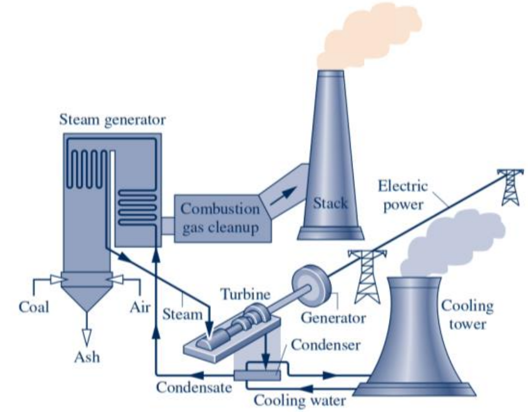
Selected Areas of Application of Engineering Thermodynamics

- Aircraft and rocket propulsion
- Alternative energy systems
  - Fuel cells
  - Geothermal systems
  - Magnetohydrodynamic (MHD) converters
  - Ocean thermal, wave, and tidal power generation
  - Solar-activated heating, cooling, and power generation
  - Thermoelectric and thermionic devices
  - Wind turbines
- Automobile engines
- Bioengineering applications
- Biomedical applications
- Combustion systems
- Compressors, pumps
- Cooling of electronic equipment
- Cryogenic systems, gas separation, and liquefaction
- Fossil and nuclear-fueled power stations
- Heating, ventilating, and air-conditioning systems
  - Absorption refrigeration and heat pumps
  - Vapor-compression refrigeration and heat pumps
- Steam and gas turbines
  - Power production
  - Propulsion

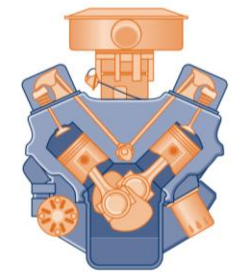


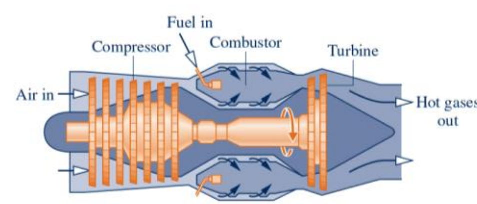
International Space Station


Refrigerator

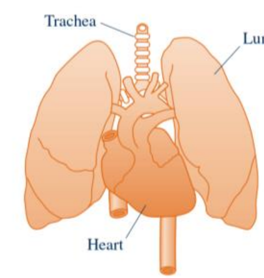


Electrical power plant


Vehicle engine



Turbojet engine



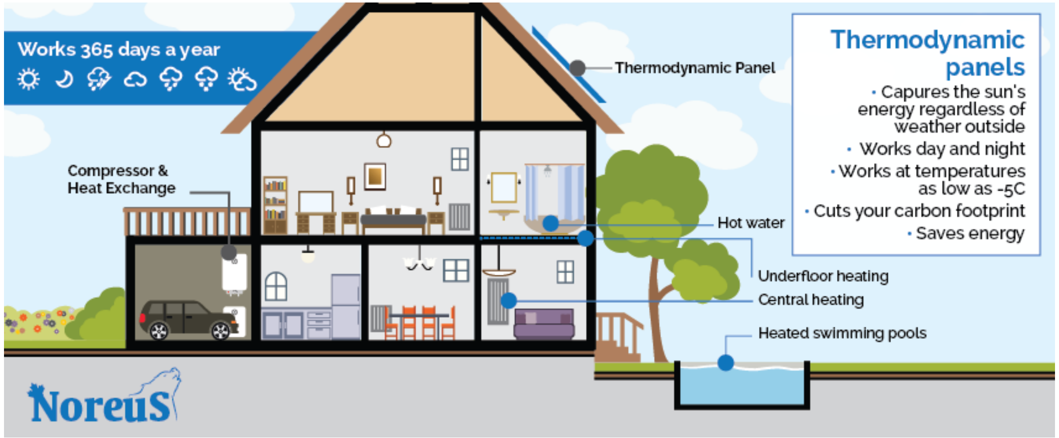
Biomedical applications

Aalto University
School of Engineering

Using Thermodynamics

Predictions of Life in 2050

At home
- Homes are constructed better to reduce heating and cooling needs.
- Homes have systems for electronically monitoring and regulating energy use.
- Appliances and heating and air-conditioning systems are more energy-efficient.
- Use of solar energy for space and water heating is common.
- More food is produced locally.



Transportation
- Plug-in hybrid vehicles and all-electric vehicles dominate.
- Hybrid vehicles mainly use biofuels.
- Use of public transportation within and between cities is common.
- An expanded passenger railway system is widely used.

Lifestyle
- Efficient energy-use practices are utilized throughout society.
- Recycling is widely practiced, including recycling of water.
- Distance learning is common at most educational levels.
- Telecommuting and teleconferencing are the norm.
- The Internet is predominately used for consumer and business commerce.

Power generation
- Electricity plays a greater role throughout society.
- Wind, solar, and other renewable technologies contribute significant share of the nation's electricity needs.
- A mix of conventional fossil-fueled and nuclear power plants provides a smaller, but still significant, share of the nation's electricity needs.
- A smart and secure national power transmission grid is in place.

Aalto University
School of Engineering

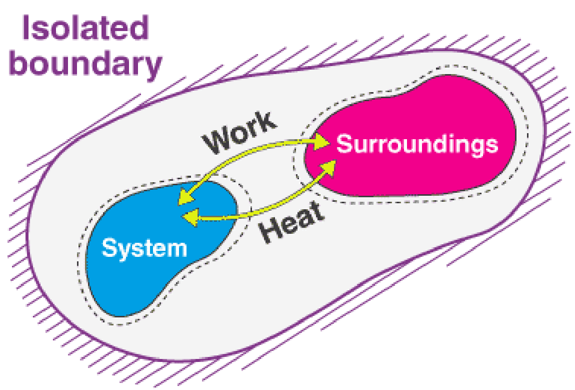
Defining Systems

System

In thermodynamics the term *system* is used to identify the subject of the analysis. Once the system is defined and the relevant interactions with other systems are identified, one or more physical laws or relations are applied.

surroundings
boundary

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, which may be at rest or in motion.



System boundary

A boundary is a closed surface surrounding a system through which energy and mass may enter or leave the system.

Surroundings

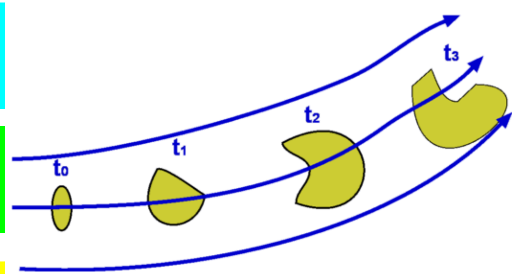
Everything that interacts with the system

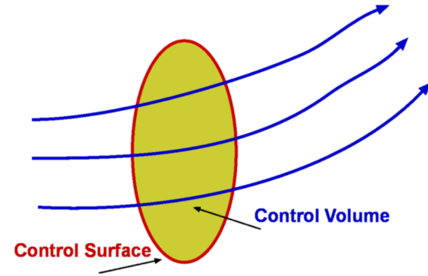
System

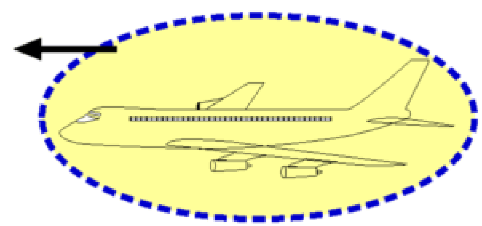
A system is a region containing energy and/or matter that is separated from its surroundings by arbitrarily imposed walls or boundaries

System and Control Volumes

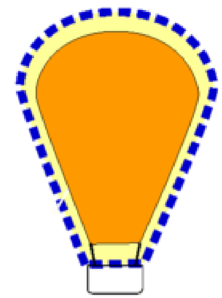
- A system is defined as a quantity of matter or a region in space chosen for study.
- The mass or region outside the system is called the surroundings.
- The real or imaginary surface that separates the system from its surroundings is called the boundary. The boundary of a system can be fixed or movable.
- Note that the boundary is the contact surface shared by both the system and the surroundings. Mathematically speaking, the boundary has zero thickness, and thus it can neither contain any mass nor occupy any volume in space.







A moving Control Volume around a moving Aeroplane.



A collapsible Control Volume around a balloon.

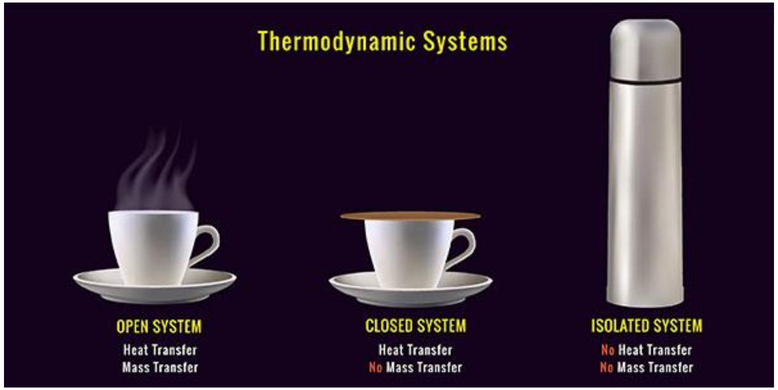
Closed System

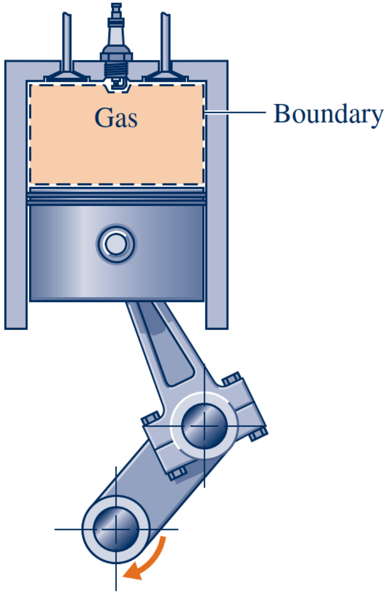
Closed Systems

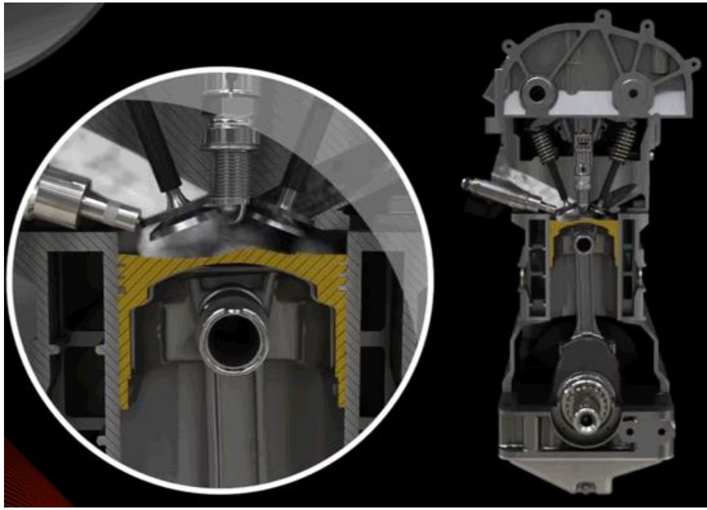
A closed system is defined when a particular quantity of matter is under study. There can be no transfer of mass across its boundary.

Isolated Systems

A special type of closed system that does not interact in any way with its surroundings is called an isolated system.



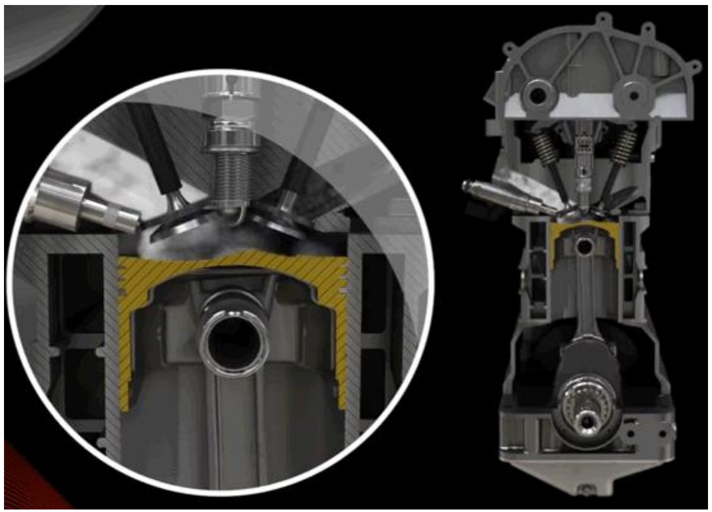


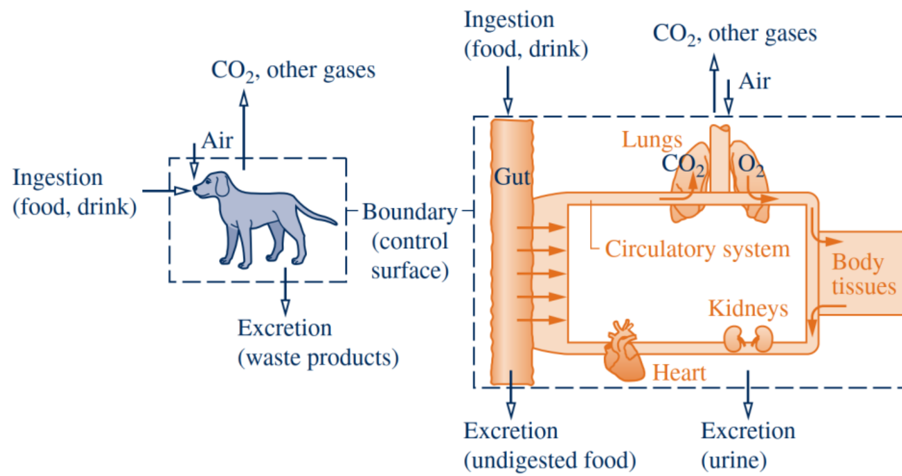


Control Volume Systems

Control Volumes

Mass and heat both cross the boundary of a system





(a) (b)

The system boundary should be delineated carefully before proceeding with any thermodynamic analysis. However, the same physical phenomena often can be analyzed in terms of alternative choices of the system, boundary, and surroundings. The choice of a particular boundary defining a particular system depends heavily on the convenience it allows in the subsequent analysis.

Describing Systems and Their Behavior

- Engineers are interested in studying systems and how they interact with their surroundings.
- Systems can be studied from a macroscopic or a microscopic point of view.

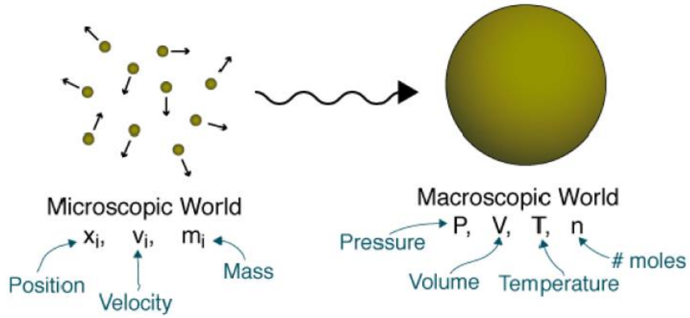
Macroscopic and Microscopic Views of Thermodynamics

Macroscopic Views

The macroscopic approach to thermodynamics is concerned with the gross or overall behavior. This is sometimes called classical thermodynamics.

Microscopic Views

The microscopic approach to thermodynamics, known as statistical thermodynamics, is concerned directly with the structure of matter. The objective of statistical thermodynamics is to characterize by statistical means the average behavior of the particles making up a system of interest and relate this information to the observed macroscopic behavior of the system.



Aalto University
School of Engineering

Property, State, and Process

property	A ***property*** is a macroscopic characteristic of a system such as mass, volume, energy, pressure, and temperature to which a numerical value can be assigned at a given time without knowledge of the previous behavior (history) of the system.
state	The word ***state*** refers to the condition of a system as described by its properties.
process	When any of the properties of a system changes, the state changes and the system is said to undergo a ***process***. A system is said to be at steady state if none of its properties changes with time.
extensive properties	A property is called ***extensive*** if its value for an overall system is the sum of its values for the parts into which the system is divided. Mass, volume, energy, and several other properties introduced later are extensive.
intensive properties	***Intensive*** properties are not additive in the sense previously considered. Their values are independent of the size or extent of a system and may vary from place to place within the system at any moment.
equilibrium	Classical thermodynamics places primary emphasis on equilibrium states and changes from one equilibrium state to another.

Accordingly, several types of equilibrium must exist individually to fulfill the condition of complete equilibrium; among these are ***mechanical, thermal, phase, and chemical equilibrium***.

Property, State, and Process

property

A ***property*** is a macroscopic characteristic of a system such as mass, volume, energy, pressure, and temperature to which a numerical value can be assigned at a given time without knowledge of the previous behavior (history) of the system.

state

The word ***state*** refers to the condition of a system as describ

process

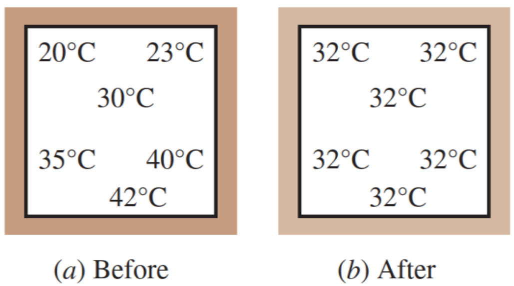
When any of the properties of a system changes, the state c is said to undergo a ***process***. A system is said to be at stead properties changes with time

extensive properties

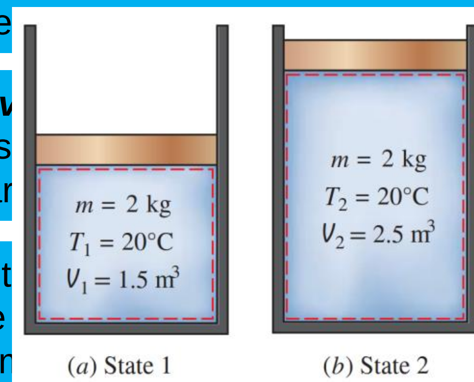
iv st s he ar

intensive properties

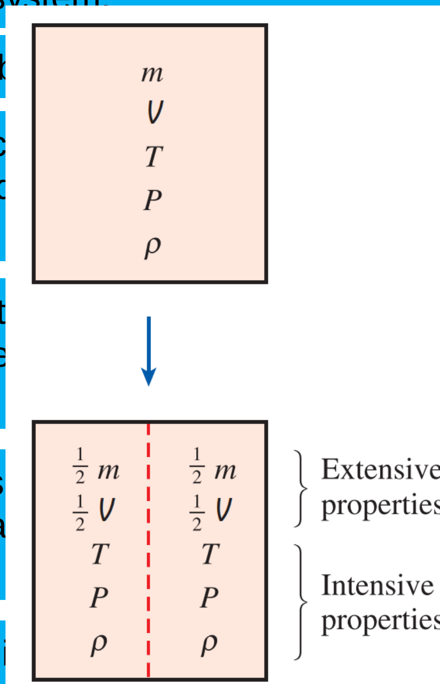
ot s are independent of the size a within the system at any mon



(*a*) Before (*b*) After



(*a*) State 1 (*b*) State 2



equilibrium

Classical thermodynamics places primary emphasis on equi from one equilibrium state to another.

Aalto University
School of Engineering

Accordingly, several types of equilibrium must exist individually to fulfill the condition of complete equilibrium; among these are ***mechanical, thermal, phase, and chemical equilibrium***.

Importance of the Dimensions and Units

units

A ***unit*** is any specified amount of a quantity by comparison with which any other quantity of the same kind is measured.

Primary dimensions

Because physical quantities are related by definitions and laws, a relatively small number of physical quantities suffice to conceive of and measure all others. These are called ***primary dimensions***.

Primary dimensions

Because physical quantities are related by definitions and laws, a relatively small number of physical quantities suffice to conceive of and measure all others. These are called ***primary dimensions***.

- Any physical quantity can be characterized by dimensions. The magnitudes assigned to the dimensions are called units.

The seven fundamental (or primary) dimensions and their units in SI

Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

Importance of the Dimensions and Units

- Despite strong efforts in the scientific and engineering community to unify the world with a single unit system, two sets of units are still in common use today: the English system, which is also known as the United States Customary System (USCS), and the metric SI (from Le Système International d'Unités), which is also known as the International System. The SI is a simple and logical system based on a decimal relationship between the various units, and it is being used for scientific and engineering work in most of the industrialized nations, including England.

Units for Mass, Length, Time, and Force

	SI		English	
Quantity	Unit	Symbol	Unit	Symbol
mass	kilogram	kg	pound mass	lb
length	meter	m	foot	ft
time	second	s	second	s
force	newton (= 1 kg · m/s^2)	N	pound force (= 32.1740 lb · ft/s^2)	lbf

Since it is frequently necessary to work with extremely large or small values when using the SI unit system, a set of standard prefixes is provided in Table 1.4 to simplify matters.

SI Unit Prefixes

Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Specific Volume

Three measurable intensive properties that are particularly important in engineering thermodynamics are ***specific volume, pressure, and temperature***.

***continuum* hypothesis**

From the macroscopic perspective, the description of matter is simplified by considering it to be distributed continuously throughout a region.

When substances can be treated as continua, it is possible to speak of their intensive thermodynamic properties "at a point." Thus, at any instant the density at a point is defined as

$$\rho = \lim_{V \to V'} \left(\frac{m}{V} \right)$$

The density, or local mass per unit volume, is an intensive property that may vary from point to point within a system. Thus, the mass associated with a particular volume V is determined in principle by integration

$$m = \int_V \rho dV$$

specific volume

The specific volume is defined as the reciprocal of the density, 1/ρ. It is the volume per unit mass. Like density, specific volume is an intensive property and may vary from point to point.

$$\upsilon = 1/\rho$$

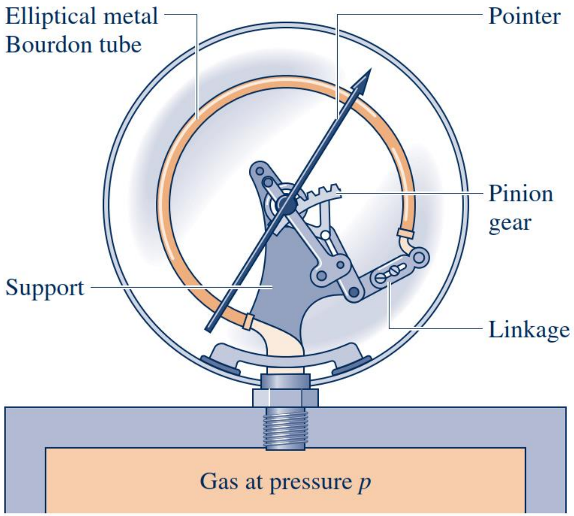
molar basis

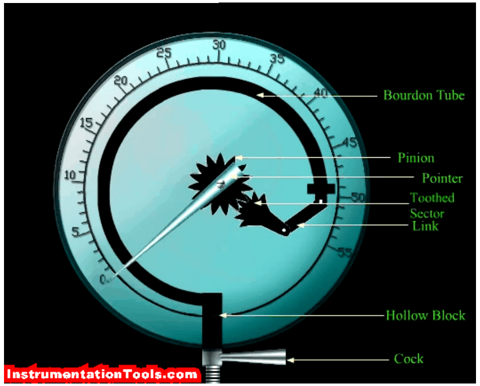
In certain applications it is convenient to express properties such as specific volume on a molar basis rather than on a mass basis.

$$\bar{\upsilon} = M\upsilon$$

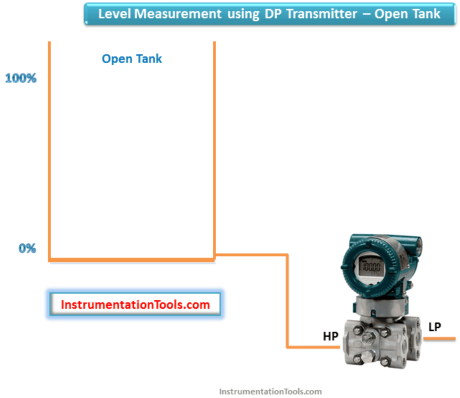
Pressure

Mechanical Pressure Measurements

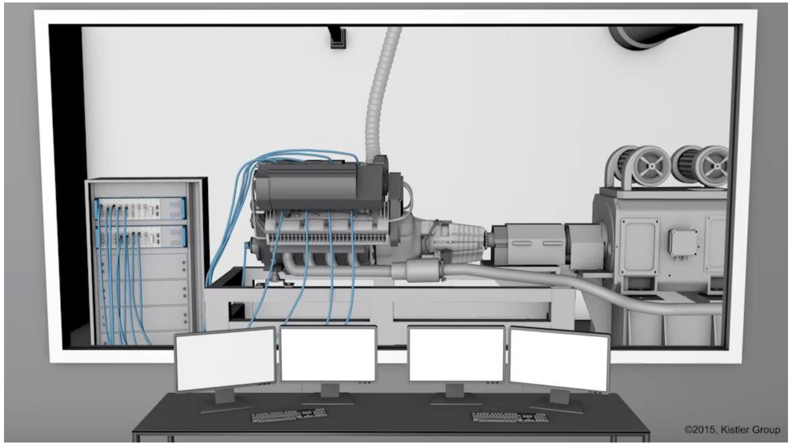




Electronical Pressure sensor



Piezoelectric Pressure sensor



Aalto University
School of Engineering

Pressure

Pressure

The pressure, *p*, at the specified point is defined as the limit

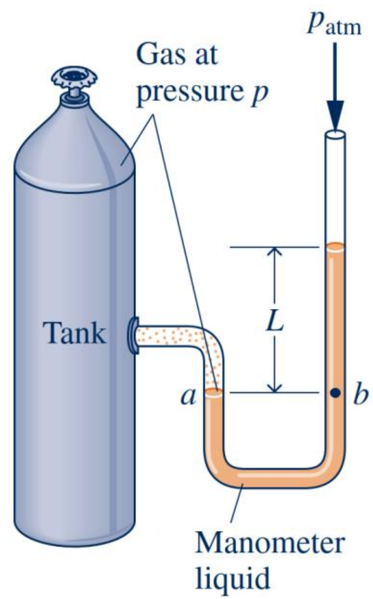
$$p = \lim_{A \to A'} \left(\frac{F_{normal}}{A} \right)$$

absolute pressure

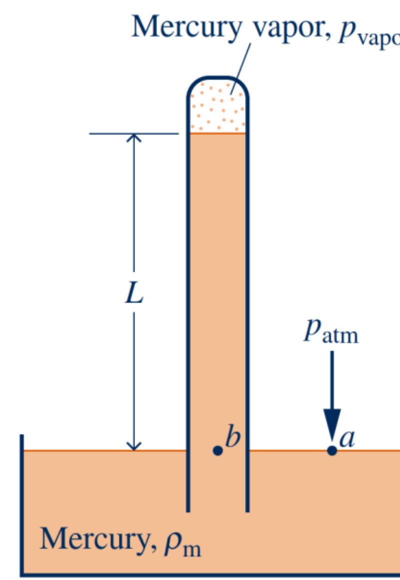
pressure with respect to the zero pressure of a complete vacuum. The lowest possible value of absolute pressure is zero.

Pressure Measurement

Manometers and barometers



Manometers



barometers

$$p = p_{atm} + \rho g L$$

Temperature

A definition of temperature in terms of concepts that are independently defined or accepted as primitive is difficult to give. However, it is possible to arrive at an objective understanding of equality of temperature by using the fact that when the temperature of an object changes, other properties also change.

thermal (heat) interaction

To illustrate this, consider two copper blocks, and suppose that our senses tell us that one is warmer than the other. If the blocks were brought into contact and isolated from their surroundings, they would interact in a way that can be described as a ***thermal (heat) interaction***.

thermal equilibrium

When all changes in such observable properties cease, the interaction is at an end. The two blocks are then in thermal equilibrium.

temperature

Temperature is a physical quantity that expresses hot and cold. It is the manifestation of thermal energy, present in all matter, which is the source of the occurrence of heat, a flow of energy, when a body is in contact with another that is colder or hotter.

zeroth law of thermodynamics

It is a matter of experience that when two objects are in thermal equilibrium with a third object, they are in thermal equilibrium with one another. This statement, which is sometimes called the zeroth law of thermodynamics, is tacitly assumed in every measurement of temperature.

Temperature

thermometric property

Any object with at least one measurable property that changes as its temperature changes can be used as a thermometer. Such a property is called a thermometric property. The particular substance that exhibits changes in the thermometric property is known as a thermometric substance.

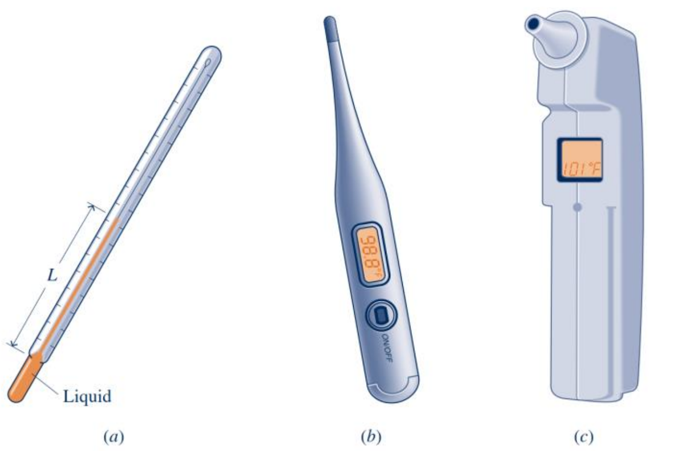
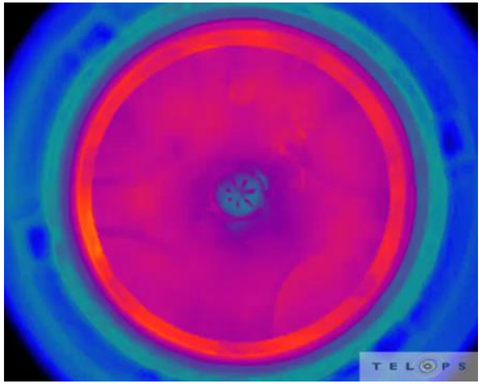


Fig. 1.13 Thermometers. (*a*) Liquid-in-glass. (*b*) Electrical-resistance. (*c*) Infrared-sensing ear thermometer.



Aalto University
School of Engineering

Temperature Scales

Kelvin scale

The Kelvin scale is an absolute thermodynamic temperature scale that provides a continuous definition of temperature, valid over all ranges of temperature. The unit of temperature on the Kelvin scale is the kelvin (K). The kelvin is the SI base unit for temperature.

Rankine scale

By definition, the Rankine scale, the unit of which is the degree rankine (8R), is proportional to the Kelvin temperature according to

$$T(°\mathrm{R}) = 1.8T(\mathrm{K})$$

Celsius scale

The Celsius temperature scale uses the unit degree Celsius (oC), which has the same magnitude as the kelvin. Thus, temperature differences are identical on both scales.

$$T(°\mathrm{C}) = T(\mathrm{K}) - 273.15$$

Fahrenheit scale

A degree of the same size as that on the Rankine scale is used in the Fahrenheit scale, but the zero point is shifted according to the relation

$$T(°\mathrm{F}) = T(°\mathrm{R}) - 459.67$$

$$T(°\mathrm{F}) = 1.8T(°\mathrm{C}) + 32$$

Methodology for Solving Thermodynamics Problems

❶ Known: State briefly in your own words what is known. This requires that you read the problem carefully and think about it.

❷ Find: State concisely in your own words what is to be determined.

❸ Schematic and Given Data: Draw a sketch of the system to be considered. Label the diagram with relevant information from the problem statement. Record all property values you are given or anticipate may be required for subsequent calculations. Sketch appropriate property diagrams, locating key state points and indicating, if possible, the processes executed by the system.

❹ Engineering Model: To form a record of how you model the problem, list all simplifying assumptions and idealizations made to reduce it to one that is manageable. Sometimes this information also can be noted on the sketches of the previous step. The development of an appropriate model is a key aspect of successful problem solving.

❺ Analysis: Using your assumptions and idealizations, reduce the appropriate governing equations and relationships to forms that will produce the desired results.

Example

Using the Solution Methodology and System Concepts

A wind turbine–electric generator is mounted atop a tower. As wind blows steadily across the turbine blades, electricity is generated. The electrical output of the generator is fed to a storage battery.

(a) Considering only the wind turbine–electric generator as the system, identify locations on the system boundary where the system interacts with the surroundings. Describe changes occurring within the system with time.

(b) Repeat for a system that includes only the storage battery.

SOLUTION

Known: A wind turbine–electric generator provides electricity to a storage battery.

Find: For a system consisting of (a) the wind turbine–electric generator, (b) the storage battery, identify locations where the system interacts with its surroundings, and describe changes occurring within the system with time.

Schematic and Given Data:

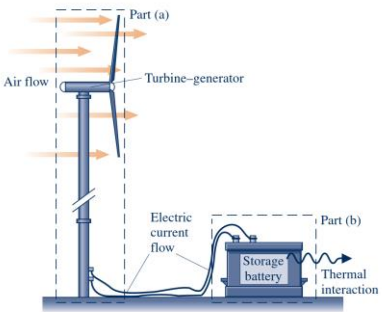


Fig. E1.1

Engineering Model:

1. In part (a), the system is the control volume shown by the dashed line on the figure.
2. In part (b), the system is the closed system shown by the dashed line on the figure.
3. The wind is steady.

steady wind, the turbine–generator is likely to reach steady-state operation, where the rotational speed of the blades is constant and a steady electric current is generated.

1 **(b)** In this case, the battery is studied as a closed system. The principal interaction between the system and its surroundings is the electric current passing into the battery through the wires. As noted in part (a), this interaction is not considered a mass transfer. As the battery is charged and chemical reactions occur within it, the temperature of the battery surface may become somewhat elevated and a thermal interaction might occur between the battery and its surroundings. This interaction is likely to be of secondary importance. Also, as the battery is charged, the state within changes with time. The battery is not at steady state.

1 Using terms familiar from a previous physics course, the system of part (a) involves the *conversion* of kinetic energy to electricity, whereas the system of part (b) involves energy *storage* within the battery.

Skills Developed

Ability to...

- ❑ apply the problem-solving methodology used in this book.
- ❑ define a control volume and identify interactions on its boundary.
- ❑ define a closed system and identify interactions on its boundary.
- ❑ distinguish steady-state operation from nonsteady operation.

Quick Quiz May an overall system consisting of the turbine–generator and battery be considered as operating at steady state? Explain. **Ans.** No. A system is at steady state only if *none* of its properties changes with time.