A.E 203

CHAPTER

1

Advanced Thermodynamics

Introduction and Basic Concepts

Lecture Notes:
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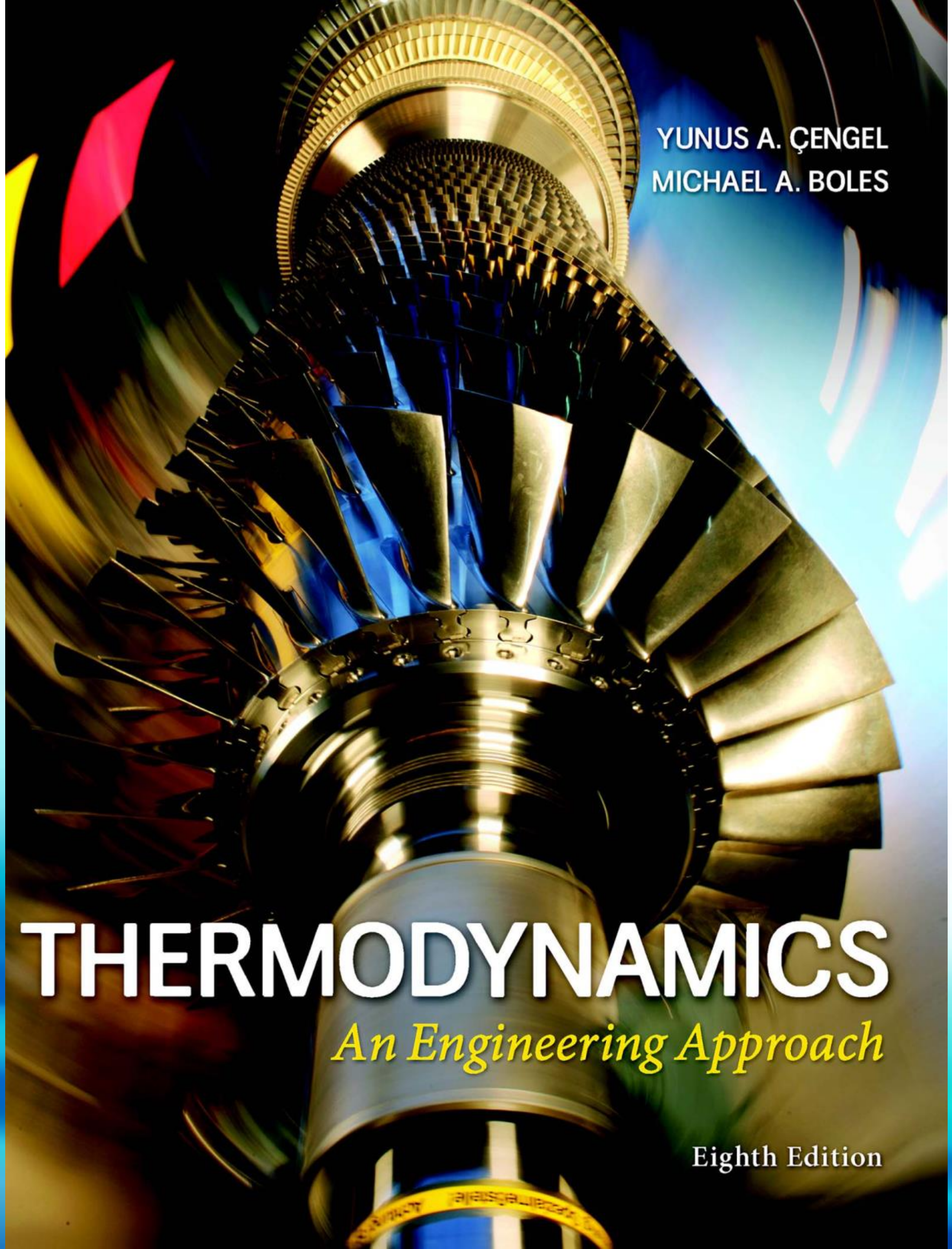
The objectives of Chapter 1 are to:

- **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.**
- **Review the metric SI and the English unit systems that will be used throughout the text.**
- **Explain the basic concepts of thermodynamics such as system, state, state postulate, equilibrium, process, and cycle.**
- **Discuss properties of a system and define density, specific gravity, and specific weight.**
- **Review concepts of temperature, temperature scales, pressure, and absolute and gage pressure.**
- **Introduce an intuitive systematic problem-solving technique.**


YUNUS A. ÇENGEL
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THERMODYNAMICS
An Engineering Approach
Eighth Edition

WHAT IS THERMODYNAMICS ?

Thermodynamics: Is the study of ***energy* and the ways in which it can be used to improve the lives of people around the world**.

The name ***thermodynamics*** stems from the Greek words *therme* (heat) and *dynamis* (power).

Thermodynamics ***is the study of the various processes that change energy from one form into another (such as converting heat into work) and uses variables such as temperature, volume, and pressure.***

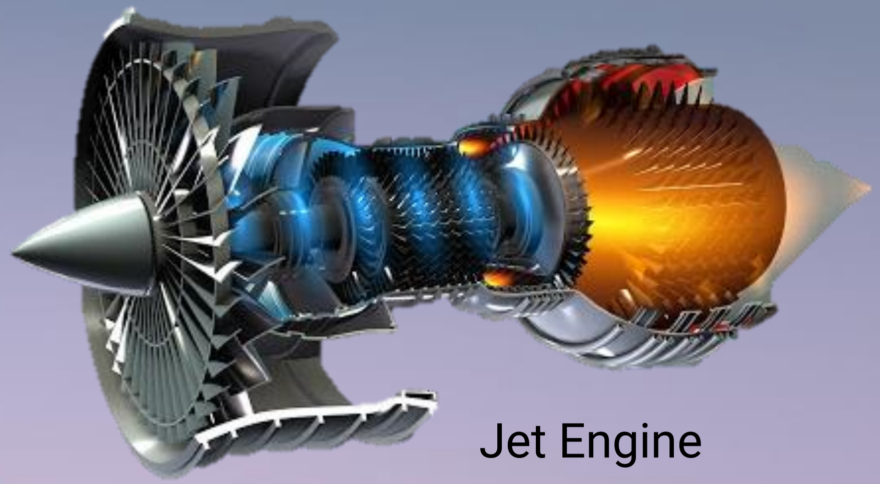
Thermodynamics ***deals with the laws that govern the transformation of energy from one form to another.***

WHY IS THERMODYNAMICS IMPORTANT TODAY?

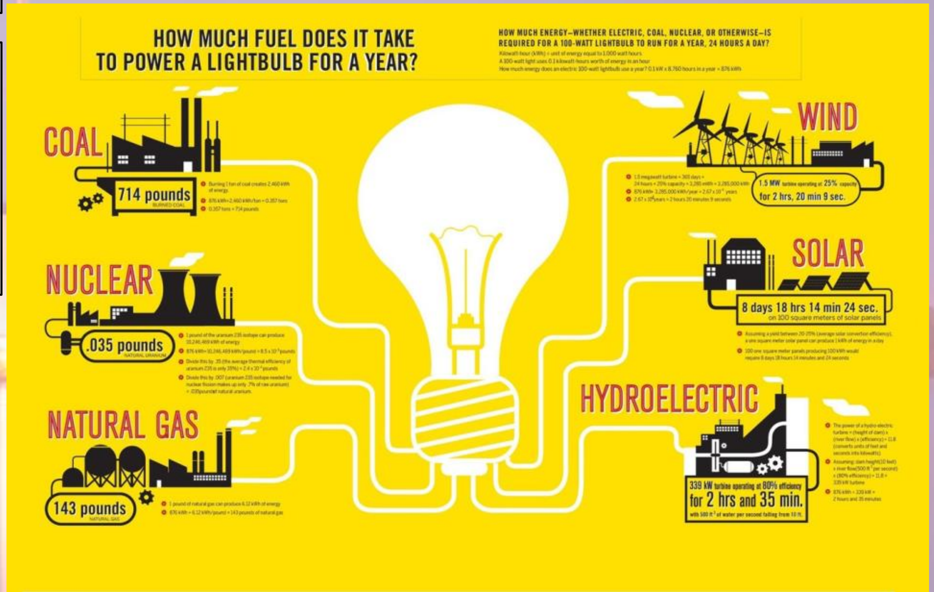
The people of the world consume 1.06 cubic miles* of oil each year as an energy source for a wide variety of uses such as the engines shown in Figure.

Coal, gas, and nuclear energy provide additional energy, equivalent to another 1.57 mi^3 of oil, making our total use of exhaustible energy sources equal to 2.63 mi^3 of oil every year.

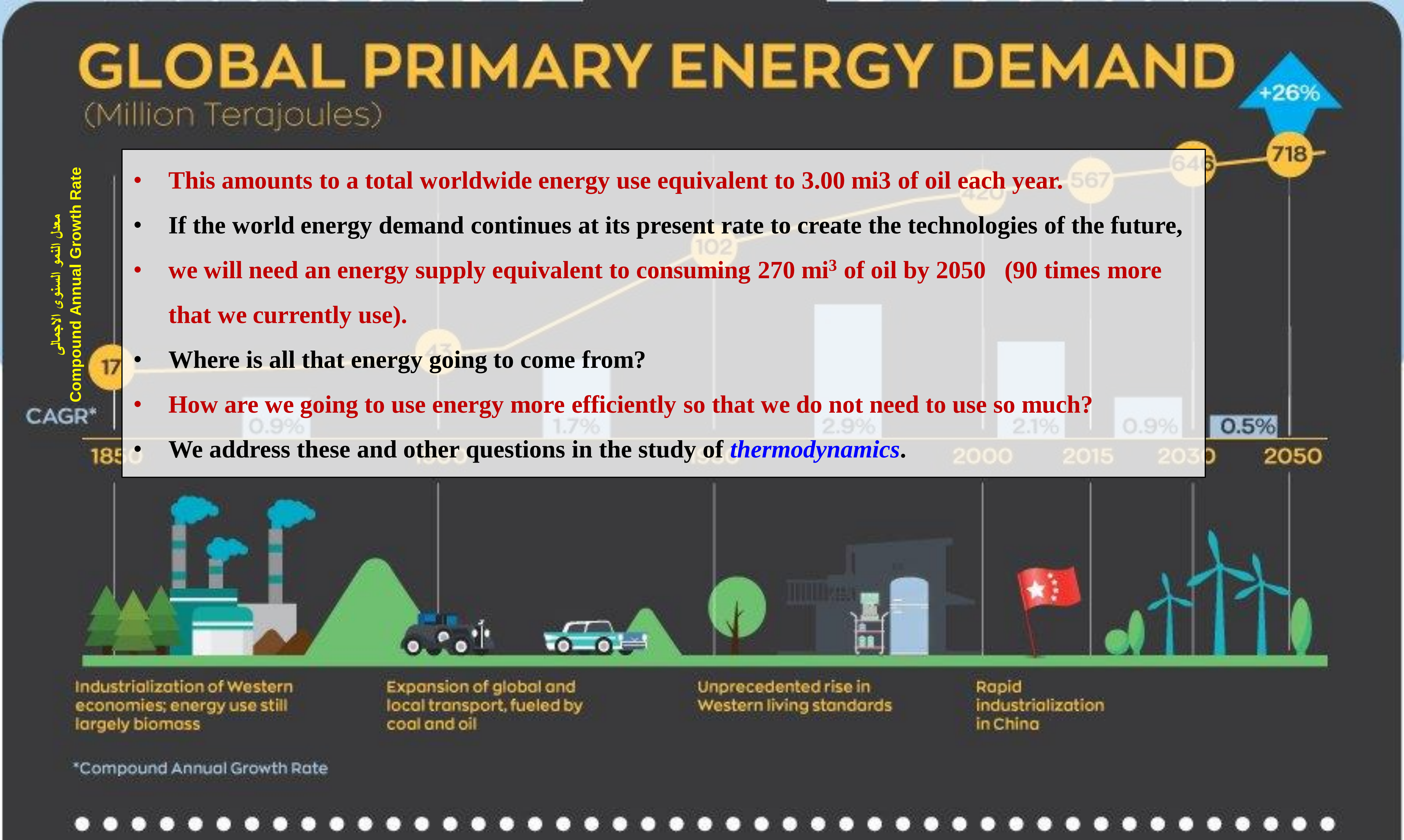
We also use renewable energy from solar, biomass, wind and hydroelectric, in amounts that are equivalent to an additional 0.37 mi3 of oil each year.



Jet Engine



* One cubic mile of oil is equal to 1.1 trillion gallons and contains 160 quadrillion (160×10^{15}) kilojoules of energy.



Compound Annual Growth Rate
معدل النمو السنوى الاجمالى

- This amounts to a total worldwide energy use equivalent to 3.00 mi3 of oil each year.
- If the world energy demand continues at its present rate to create the technologies of the future,
- we will need an energy supply equivalent to consuming 270 mi^3 of oil by 2050 (90 times more that we currently use).
- Where is all that energy going to come from?
- How are we going to use energy more efficiently so that we do not need to use so much?
- We address these and other questions in the study of ***thermodynamics***.

Energy Sources

The main energy sources come from the use of diverse natural resources

CEIDEN LANENT Foro Nuclear

SOLAR
Obtained from sun radiation

WIND
Generated from the use of wind force

HYDRAULIC
Extracted from the force of currents and water jumps

GEOTHERMAL
Comes from the natural heat inside the Earth

TIDAL
Produced by the movement of tides

NUCLEAR
Released by atom nuclei via fission and fusion processes

CARBON
Obtained from the combustion of vegetable remains accumulated and transformed throughout time

PETROLEUM
Uses the fuel resulting from the mixture of organic compounds, mainly hydrocarbons

NATURAL GAS
Gaseous fuel that comes from geological formations

BIOMASS
Obtained from organic compounds through natural processes

Energy Challenges

What alternatives exist to provide the power that we need?

Which one of these alternatives is actually best?

Hydrogen-powered fuel cells, biomass, nuclear power plants, solar and wind energy systems have all been mentioned in the popular media as potential solutions.

What role can each of them play in terms of displacing our current energy supplies?

These are huge questions. The solution to our energy problem will likely be one of the biggest challenges facing our species this century. In one sense this is alarming, but it is also very exciting.

ENGINEERING CONTEXT

- Although aspects of **thermodynamics** have been studied since ancient times, the formal study of **thermodynamics** began in the early ***nineteenth century*** through consideration of *the capacity of hot objects to produce work*.

- Thermodynamics now provides essential concepts and methods for addressing ***critical twenty-first-century*** issues, such as using **fossil fuels more effectively, fostering renewable energy technologies, and developing more fuel-efficient means of transportation.**
- **Greenhouse gas emissions and air and water pollution.**
- Thermodynamics is both a branch **of science and an engineering** specialty.
- The scientist is normally interested in gaining a fundamental **understanding of the physical and chemical behavior of fixed quantities of matter** at rest and uses the principles of thermodynamics to relate the properties of matter.
- Engineers are generally interested in studying ***systems*** and how they interact with their ***surroundings.*** *To facilitate this, thermodynamics has been extended* to the study of systems through which matter flows, including **bioengineering and biomedical systems**.

$F = P_{atm} A$
A = surface area of sphere = $4\pi r^2$
r= 61 cm= 0.6 m
$F = 53$ tons

Application Areas of Thermodynamics

Refrigerator

Boats

Aircraft and spacecraft

Power plants

All activities in nature involve some interaction between energy and matter; thus, it is hard to imagine an area that does not relate to thermodynamics in some manner.

Application Areas of Thermodynamics

Human body

Cars

Wind turbines

Food processing

A piping network in an industrial facility.

THERMODYNAMICS AND ENERGY

- **Conservation of energy principle**: During an interaction, energy can change from one form to another but the total amount of energy remains constant.
- Energy cannot be created or destroyed.
- **The first law of thermodynamics**: An expression of the conservation of energy principle.
- The first law asserts that *energy* is a thermodynamic property.
- We cannot see, smell, taste, hear or feel energy. We can measure it, but only indirectly.

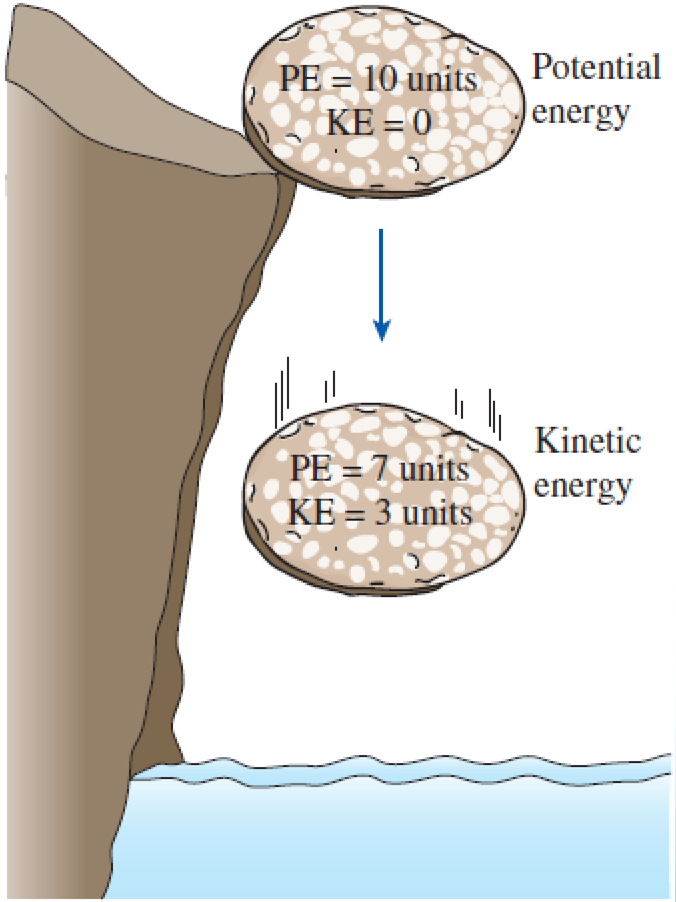


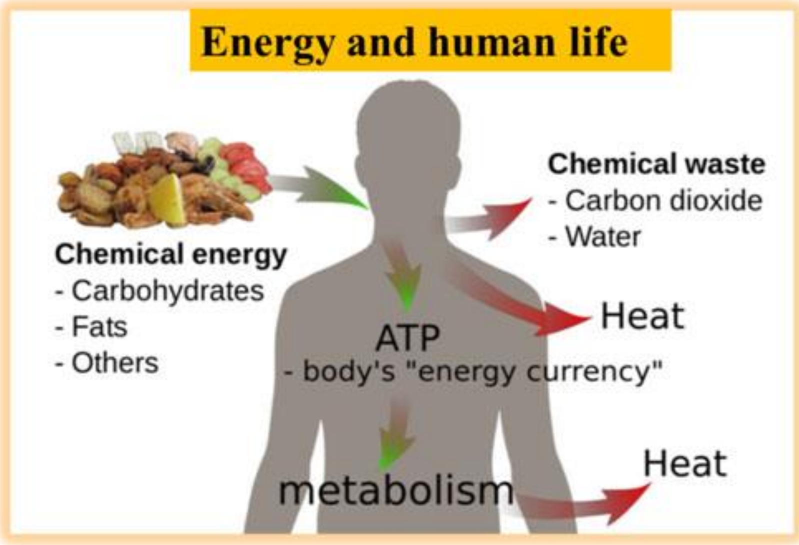
FIGURE 1–1
Energy cannot be created or destroyed; it can only change forms (the first law).

- **The conservation of energy principle** also forms the backbone of the diet industry:

- A person who has a greater energy input (food) than energy output (exercise) will gain weight (store energy in the form of fat), and a person who has a smaller energy input than output will lose weight (Fig. 1–2).

- The change in the energy content of a body or any other system is equal to the difference between the energy input and the energy output, and the energy balance is expressed as

$$E_{in} - E_{out} = \Delta E.$$



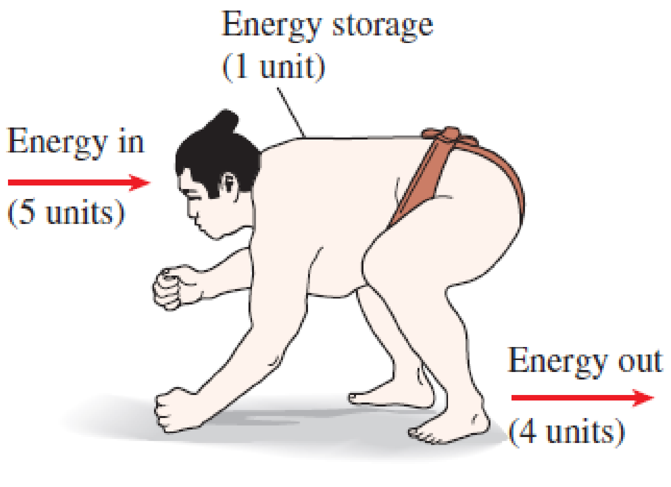


FIGURE 1–2
Conservation of energy principle for the human body.

- Thermodynamics is equally central to adjacent disciplines such as chemistry, mechanical engineering, and information theory.
- ***Engineering thermodynamics*** is at the root of the discipline, which was first established as a theoretical foundation to understand the *operation and efficiency of heat engines*.

- ***Chemical thermodynamics*** uses concepts such as equilibrium to predict how chemical reactions unfold.
- In recent decades, concepts from **statistical thermodynamics**, particularly entropy, have been applied to ***information theory*** leading to applications such as cryptography.

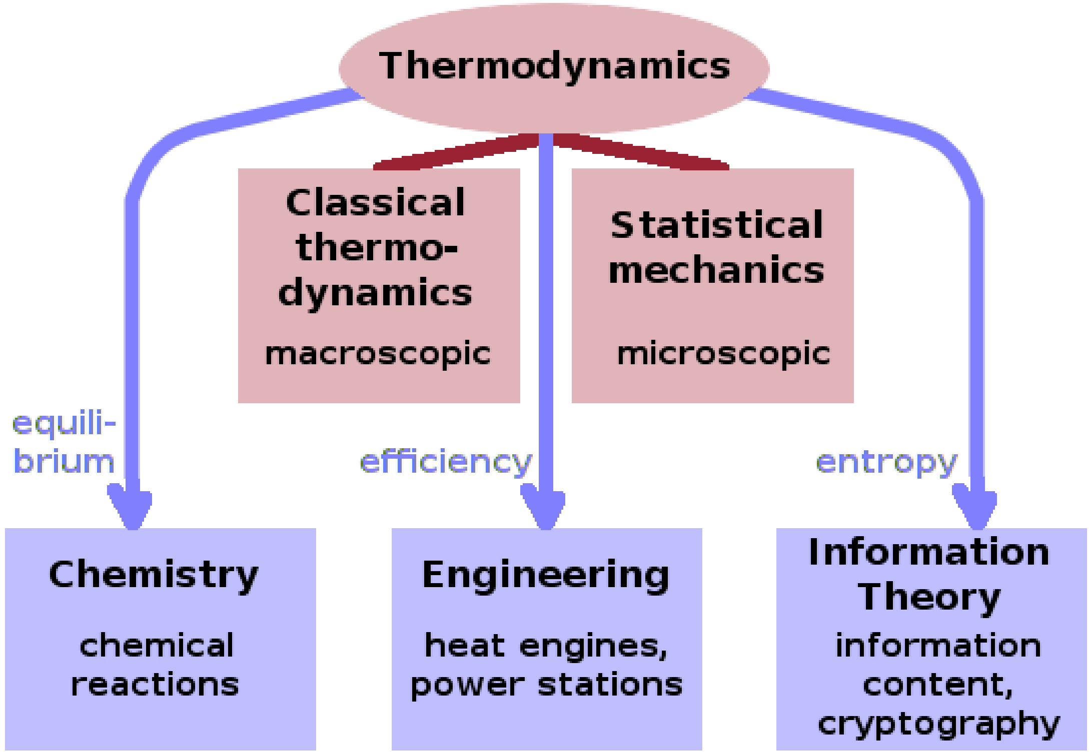
Classical thermodynamics:

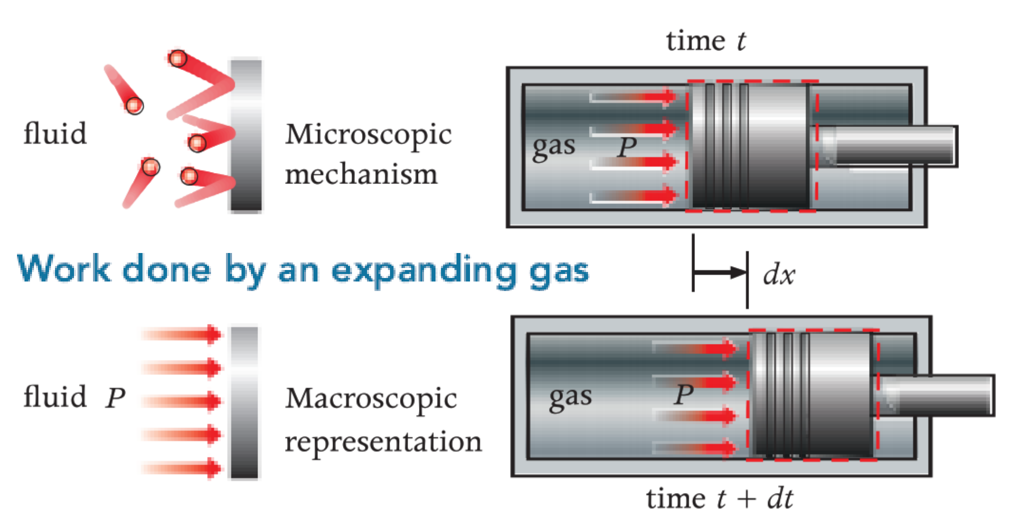
A macroscopic approach to the study of thermodynamics that does not require a knowledge of the behavior of individual particles.

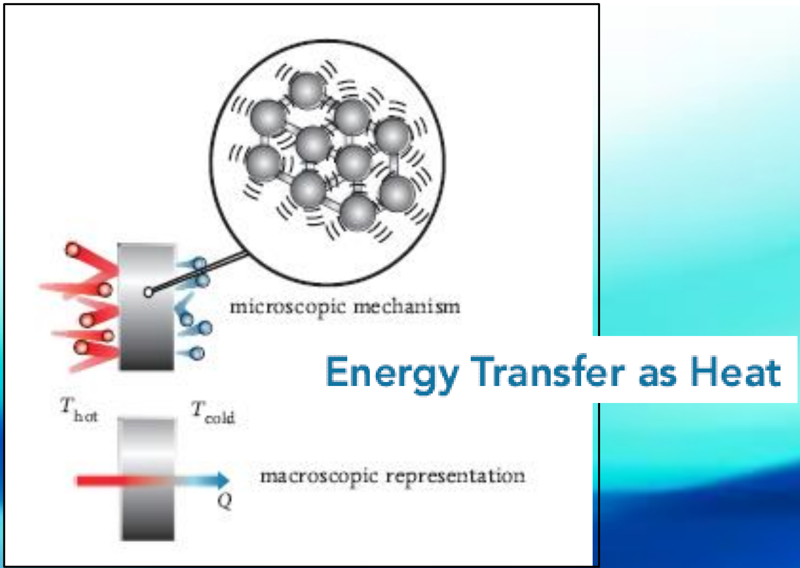
- It provides a direct and easy way to the solution of engineering problems and it is used in this text.

Statistical thermodynamics:

- A microscopic approach, based on the average behavior of large groups of individual particles.
- It is used in this text only in the supporting role.







IMPORTANCE OF DIMENSIONS AND UNITS

- Any physical quantity can be characterized by **dimensions**.
- The magnitudes assigned to the dimensions are called **units**.
- Some basic dimensions such as mass *m*, length *L*, time *t*, and temperature *T* are selected as **primary** or **fundamental dimensions**, while others such as velocity *V*, energy *E*, and volume *V* are expressed in terms of the primary dimensions and are called **secondary dimensions**, or **derived dimensions**.

- **Metric SI system**: A simple and logical system based on a decimal relationship between the various units.
- **English system**: It has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily.

TABLE 1–1

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)

TABLE 1–2

Standard prefixes in SI units

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

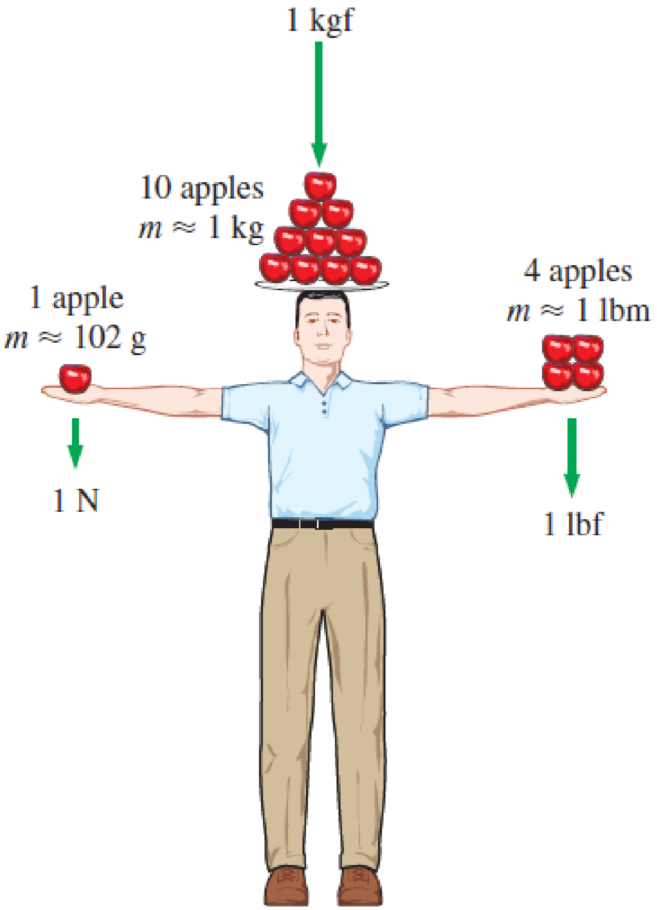


FIGURE 1–8
The relative magnitudes of the force units newton (N), kilogram-force (kgf), and pound-force (lbf).

- The mass of a body remains the same regardless of its location in the universe.
- Its weight, however, changes with a change in gravitational acceleration.
- A body weighs less on top of a mountain since g decreases with altitude.
- On the surface of the moon, an astronaut weighs about onesixth (1/6 of the Earth's) of what she or he normally weighs on earth

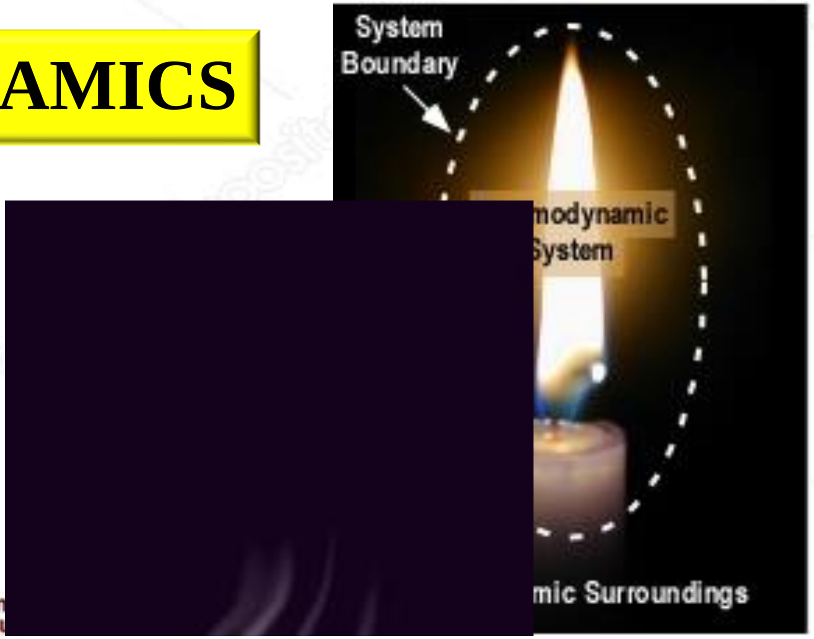
$$W = mg \quad \text{(N)}$$

W weight
m mass
g gravitational acceleration

FIGURE 1–9
A body weighing 150 lbf on earth will weigh only 25 lbf on the moon.

The term **weight is often incorrectly used to express mass, particularly** by the "weight watchers." Unlike mass, weight *W* is a *force. It is **the gravitational** **force*** applied to a body, and its magnitude is determined from Newton's second law,

THE LANGUAGE OF THERMODYNAMICS



This section deals with a series of definitions and technical terms fundamental to understanding the language of thermodynamics.

Thermodynamics: The science and technology that deal with the laws that govern the transformation of energy from one form to another

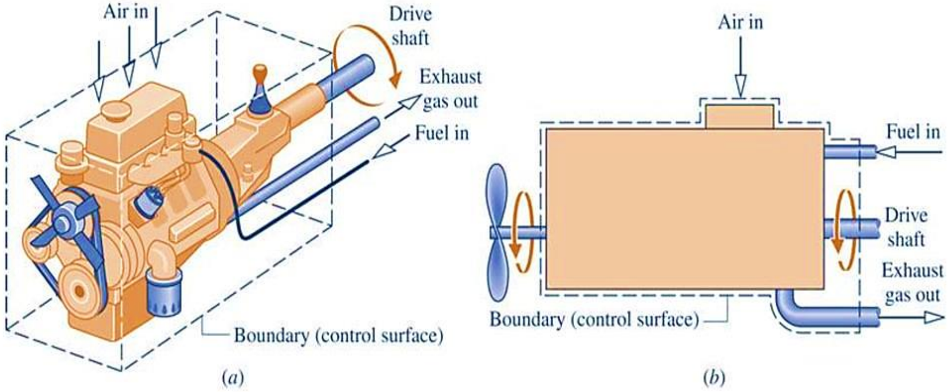
Thermodynamic system: A volume containing the item chosen for thermodynamic analysis

System boundary: The surface of a thermodynamic system

Isolated system: Any system in which neither mass nor energy crosses the system boundary

Closed system: Any system in which mass does not cross the system boundary, but energy may cross the system boundary

Open system: Any system in which both mass and energy may cross the system boundary



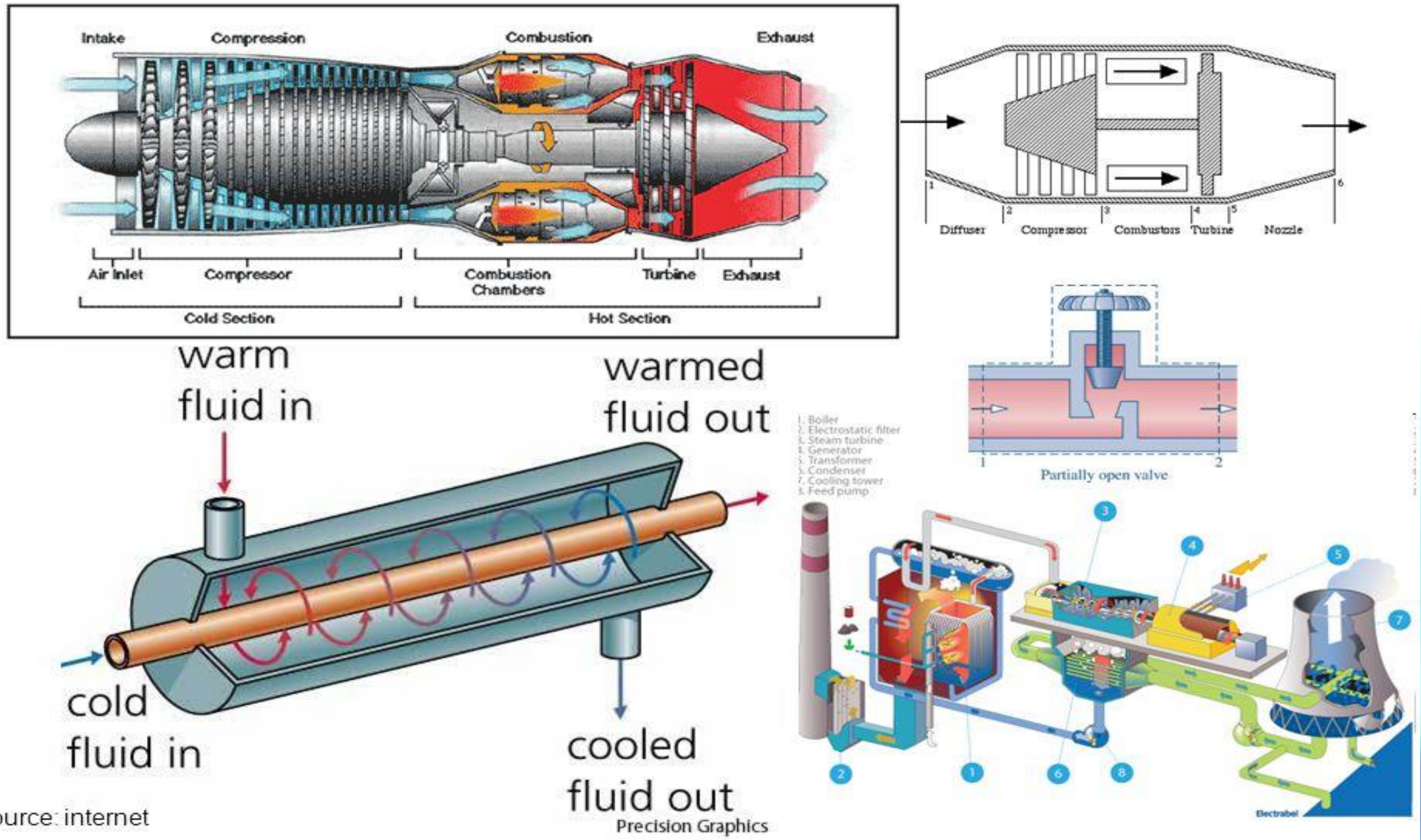
OPEN SYSTEM
Heat Transfer
Mass Transfer

THE LANGUAGE OF THERMODYNAMICS

- An open system, or a control volume, as it is often called, is a properly selected region in space.

- It usually encloses a device that involves *mass flow* such as a compressor, turbine, or nozzle.
- Flow through these devices is best studied by selecting the region within the device as the *control volume*.
- Both mass and energy can *cross the boundary of a control volume*.

Examples of open systems



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THE LANGUAGE OF THERMODYNAMICS

- **Property**

► A macroscopic characteristic of a system to which a numerical value can be assigned at a given time without knowledge of the previous behavior of the system.

- ► **Mass**
- ► **Volume**
- ► **Energy**
- ► **Pressure**
- ► **Temperature**
- ► **Enthalpy**
- ► **Internal energy**

TABLE A-22

Ideal Gas Properties of Air

T(K), h and u(kJ/kg), s° (kJ/kg · K)

T	h	u	s°	when $\Delta s = 0$[1] p_r	v_r	T	h	u	s°	when $\Delta s = 0$ p_r	v_r
200	199.97	142.56	1.29559	0.3363	1707.	450	451.80	322.62	2.11161	5.775	223.6
210	209.97	149.69	1.34444	0.3987	1512.	460	462.02	329.97	2.13407	6.245	211.4
220	219.97	156.82	1.39105	0.4690	1346.	470	472.24	337.32	2.15604	6.742	200.1
230	230.02	164.00	1.43557	0.5477	1205.	480	482.49	344.70	2.17760	7.268	189.5
240	240.02	171.13	1.47824	0.6355	1084.	490	492.74	352.08	2.19876	7.824	179.7
250	250.05	178.28	1.51917	0.7329	979.	500	503.02	359.49	2.21952	8.411	170.6
260	260.09	185.45	1.55848	0.8405	887.8	510	513.32	366.92	2.23993	9.031	162.1
270	270.11	192.60	1.59634	0.9590	808.0	520	523.63	374.36	2.25997	9.684	154.1
280	280.13	199.75	1.63279	1.0889	738.0	530	533.98	381.84	2.27967	10.37	146.7
285	285.14	203.33	1.65055	1.1584	706.1	540	544.35	389.34	2.29906	11.10	139.7
290	290.16	206.91	1.66802	1.2311	676.1	550	554.74	396.86	2.31809	11.86	133.1
295	295.17	210.49	1.68515	1.3068	647.9	560	565.17	404.42	2.33685	12.66	127.0
300	300.19	214.07	1.70203	1.3860	621.2	570	575.59	411.97	2.35531	13.50	121.2
305	305.22	217.67	1.71865	1.4686	596.0	580	586.04	419.55	2.37348	14.38	115.7
310	310.24	221.25	1.73498	1.5546	572.3	590	596.52	427.15	2.39140	15.31	110.6
315	315.27	224.85	1.75106	1.6442	549.8	600	607.02	434.78	2.40902	16.28	105.8
320	320.29	228.42	1.76690	1.7375	528.6	610	617.53	442.42	2.42644	17.30	101.2
325	325.31	232.02	1.78249	1.8345	508.4	620	628.07	450.09	2.44356	18.36	96.92
330	330.34	235.61	1.79783	1.9352	489.4	630	638.63	457.78	2.46048	19.84	92.84
340	340.42	242.82	1.82790	2.149	454.1	640	649.22	465.50	2.47716	20.64	88.99
350	350.49	250.02	1.85708	2.379	422.2	650	659.84	473.25	2.49364	21.86	85.34
360	360.58	257.24	1.88543	2.626	393.4	660	670.47	481.01	2.50985	23.13	81.89
370	370.67	264.46	1.91313	2.892	367.2	670	681.14	488.81	2.52589	24.46	78.61
380	380.77	271.69	1.94001	3.176	343.4	680	691.82	496.62	2.54175	25.85	75.50
390	390.88	278.93	1.96633	3.481	321.5	690	702.52	504.45	2.55731	27.29	72.56
400	400.98	286.16	1.99194	3.806	301.6	700	713.27	512.33	2.57277	28.80	69.76
410	411.12	293.43	2.01699	4.153	283.3	710	724.04	520.23	2.58810	30.38	67.07
420	421.26	300.69	2.04142	4.522	266.6	720	734.82	528.14	2.60319	32.02	64.53
430	431.43	307.99	2.06533	4.915	251.1	730	745.62	536.07	2.61803	33.72	62.13
440	441.61	315.30	2.08870	5.332	236.8	740	756.44	544.02	2.63280	35.50	59.82

THE LANGUAGE OF THERMODYNAMICS

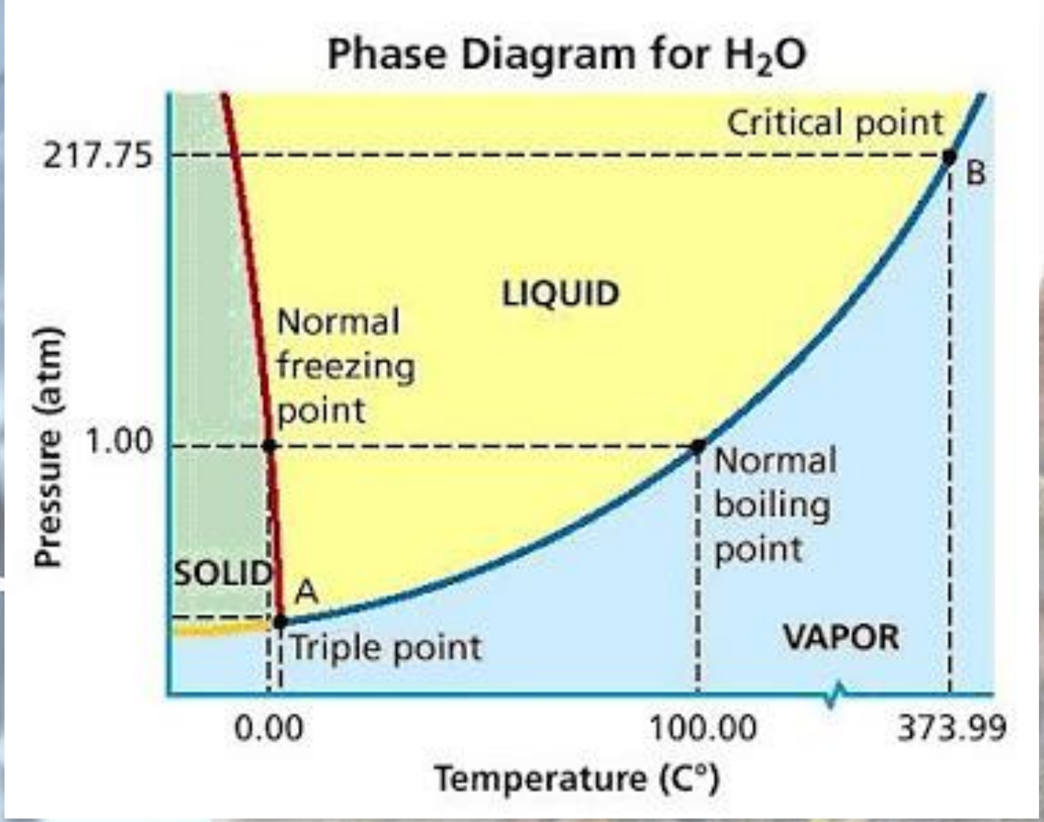
Physical phase

A molecular configuration of matter, categorized as either solid, liquid, or vapor (or gas).

Pure substance: A substance containing a uniform chemical composition in all its physical states

Homogeneous system: A system containing only a single physical phase of a substance

Simple substance A homogeneous pure substance



THE LANGUAGE OF THERMODYNAMICS

Thermodynamic state: The condition of a thermodynamic system as specified by the values of its independent thermodynamic properties.

Thermodynamic property: Any characteristic of a thermodynamic system that depends on the system’s thermodynamic state and is independent of how that state is achieved.

Thermodynamic equation of state: A formula relating the dependent and independent properties of a system

SYSTEMS AND CONTROL VOLUMES

- **Boundary**: The real or imaginary surface that separates the system from its surroundings.
- The boundary of a system can be *fixed* or *movable*.

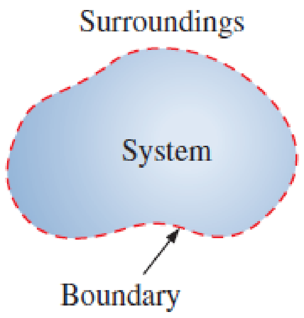


FIGURE 1–18
System, surroundings, and boundary.

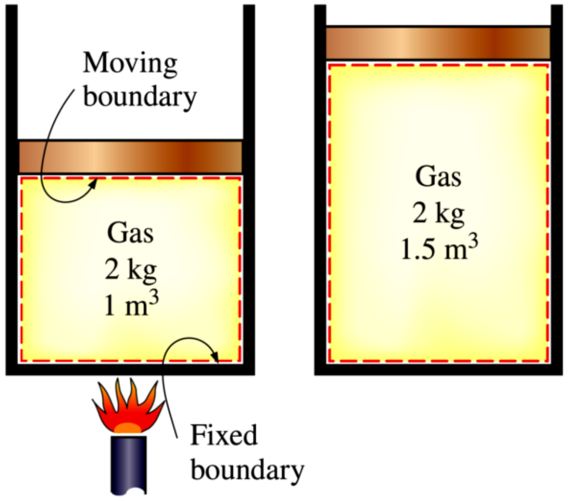
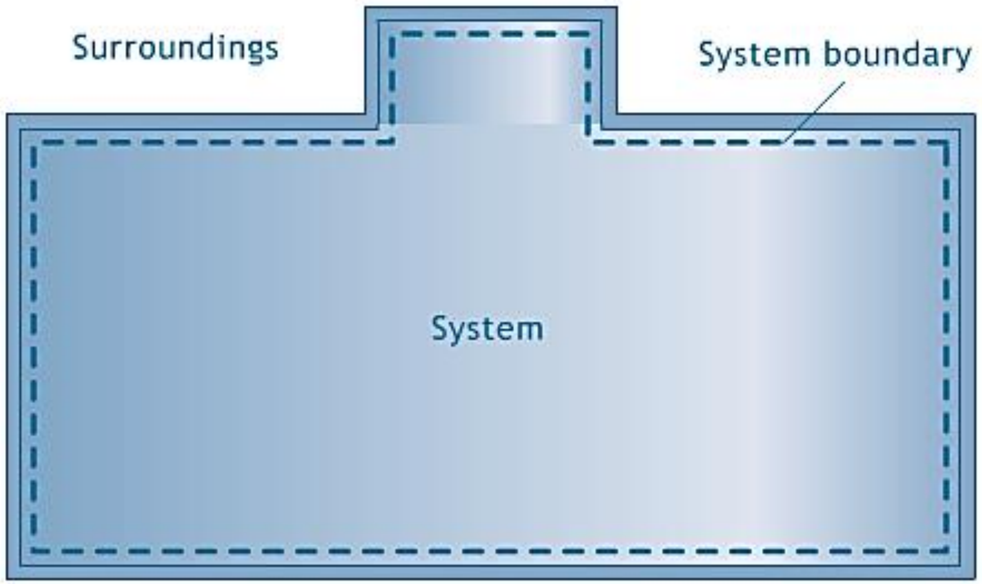


FIGURE 1–20
A closed system with a moving boundary.

a. Definitions | b. Closed System | c. Isolated System | d. Control Volume – Transient Operation | e. Control Volume – Steady-State Operation



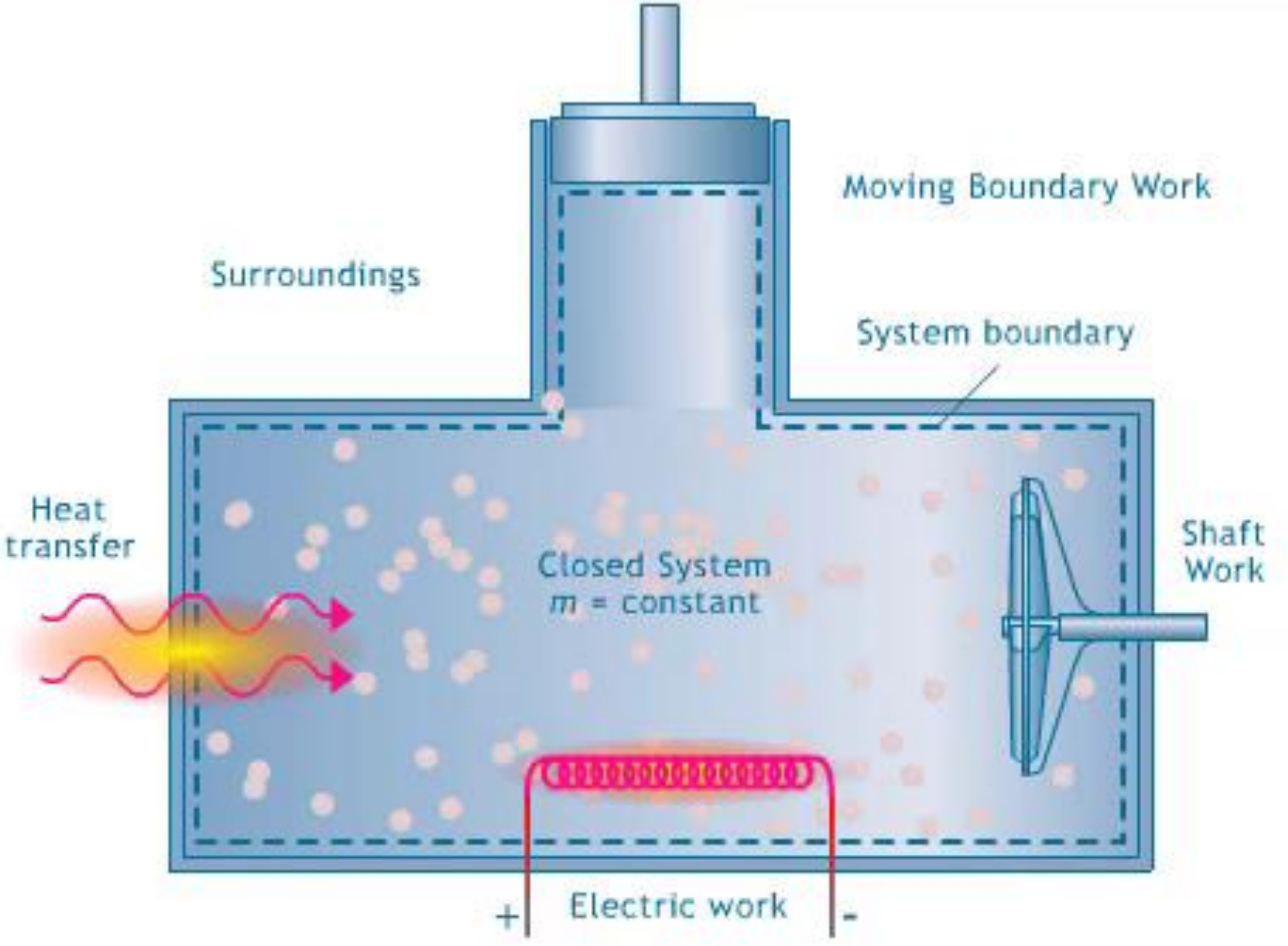
Generic system with system boundary and surroundings

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.

The two basic types of systems are closed systems and control volumes.

a. Definitions | b. Closed System | c. Isolated System | d. Control Volume – Transient Operation | e. Control Volume – Steady-State Operation

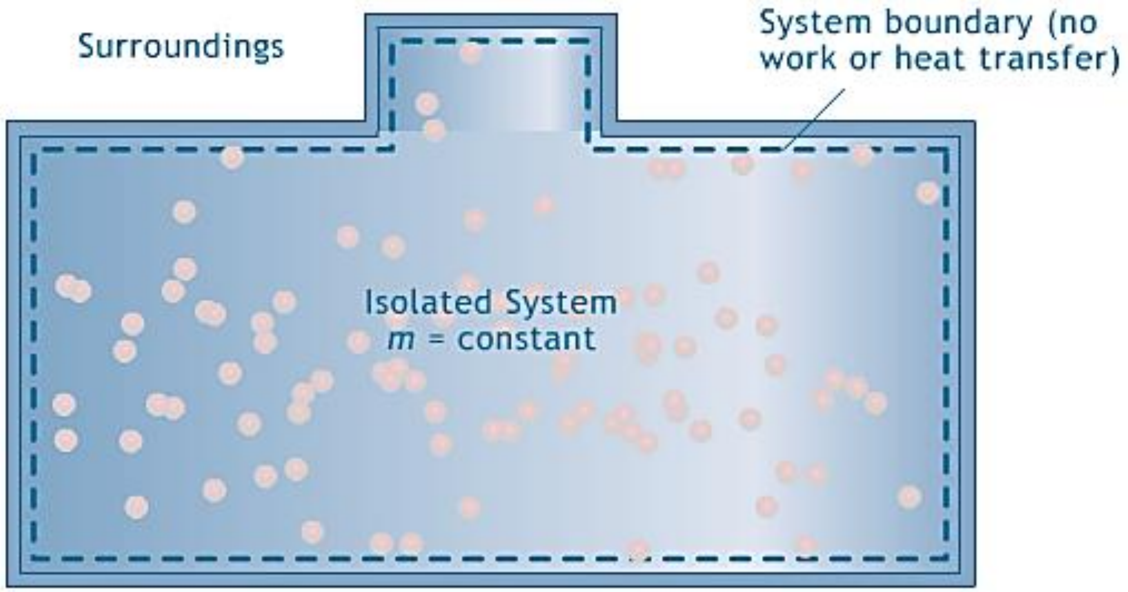


Closed System

A closed system is defined when a particular quantity of matter is under study.

In a closed system, no transfer of mass across the system boundary can occur, but energy transfer across the system boundary may occur by work and heat transfer.

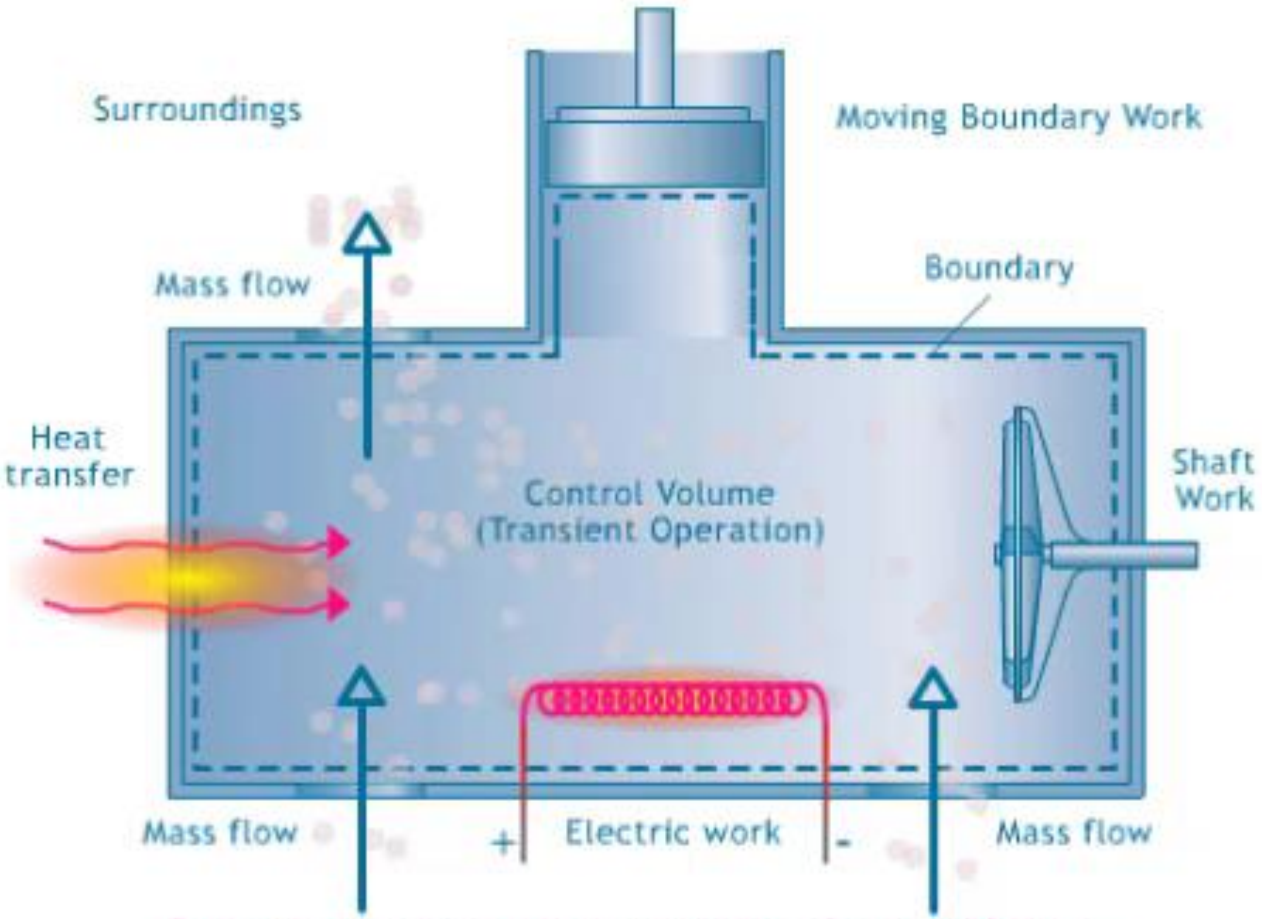
a. Definitions | b. Closed System | c. Isolated System | d. Control Volume – Transient Operation | e. Control Volume – Steady-State Operation



Isolated System

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

a. Definitions | b. Closed System | c. Isolated System | d. Control Volume – Transient Operation | e. Control Volume – Steady-State Operation



During transient operation, properties change with time.

Control Volume - Transient Operation

A control volume is a region within a prescribed boundary through which mass flows.

In a control volume, mass crosses the boundary (control surface). In addition to the energy of the mass crossing the boundary, other energy transfers across the boundary may occur by work and heat transfer.

During transient operation, property values, work and heat transfer rates, and mass flow rates may vary with time.

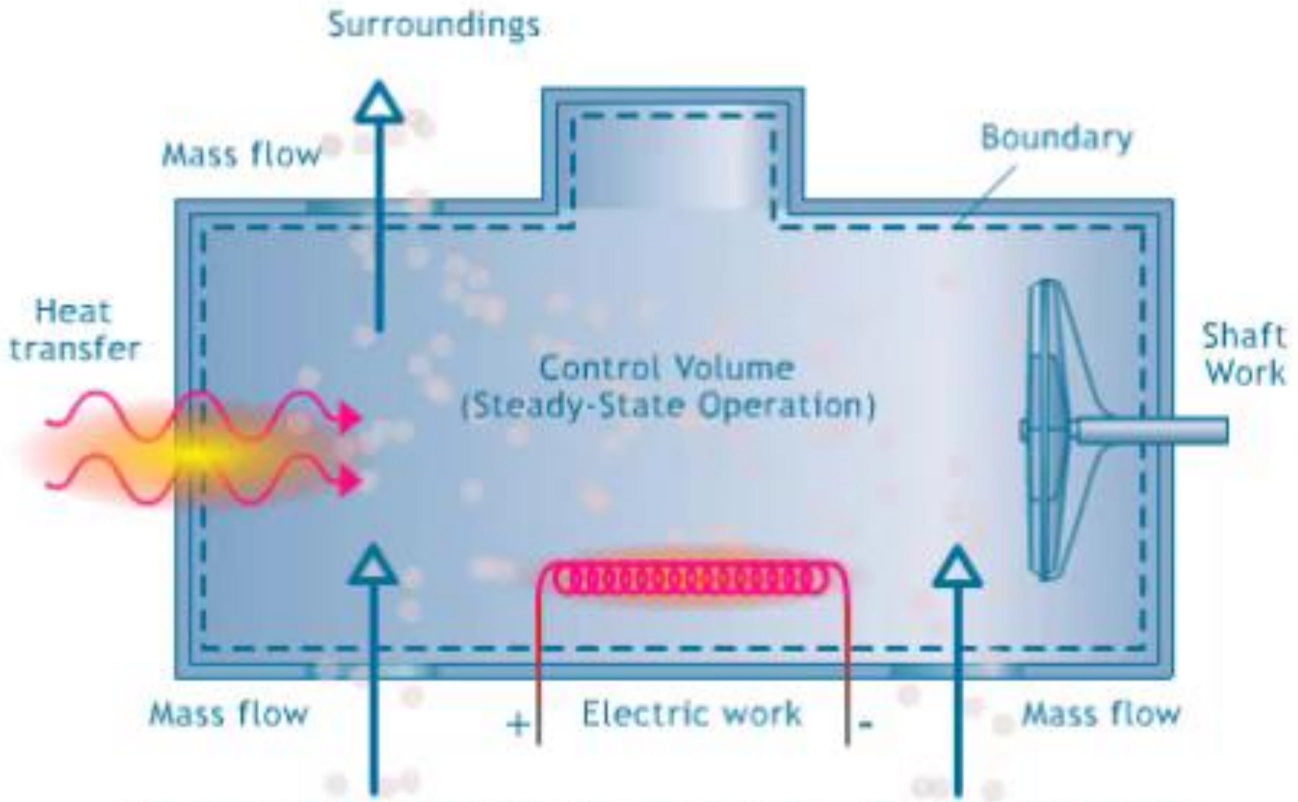
a. Definitions | b. Closed System | c. Isolated System | d. Control Volume – Transient Operation | e. Control Volume – Steady-State Operation

Control Volume - Steady-State Operation

A control volume is a region within a prescribed boundary through which mass flows.

In a control volume, mass crosses the boundary (control surface). In addition to the energy of the mass crossing the boundary, other energy transfers across the boundary may occur by work and heat transfer.

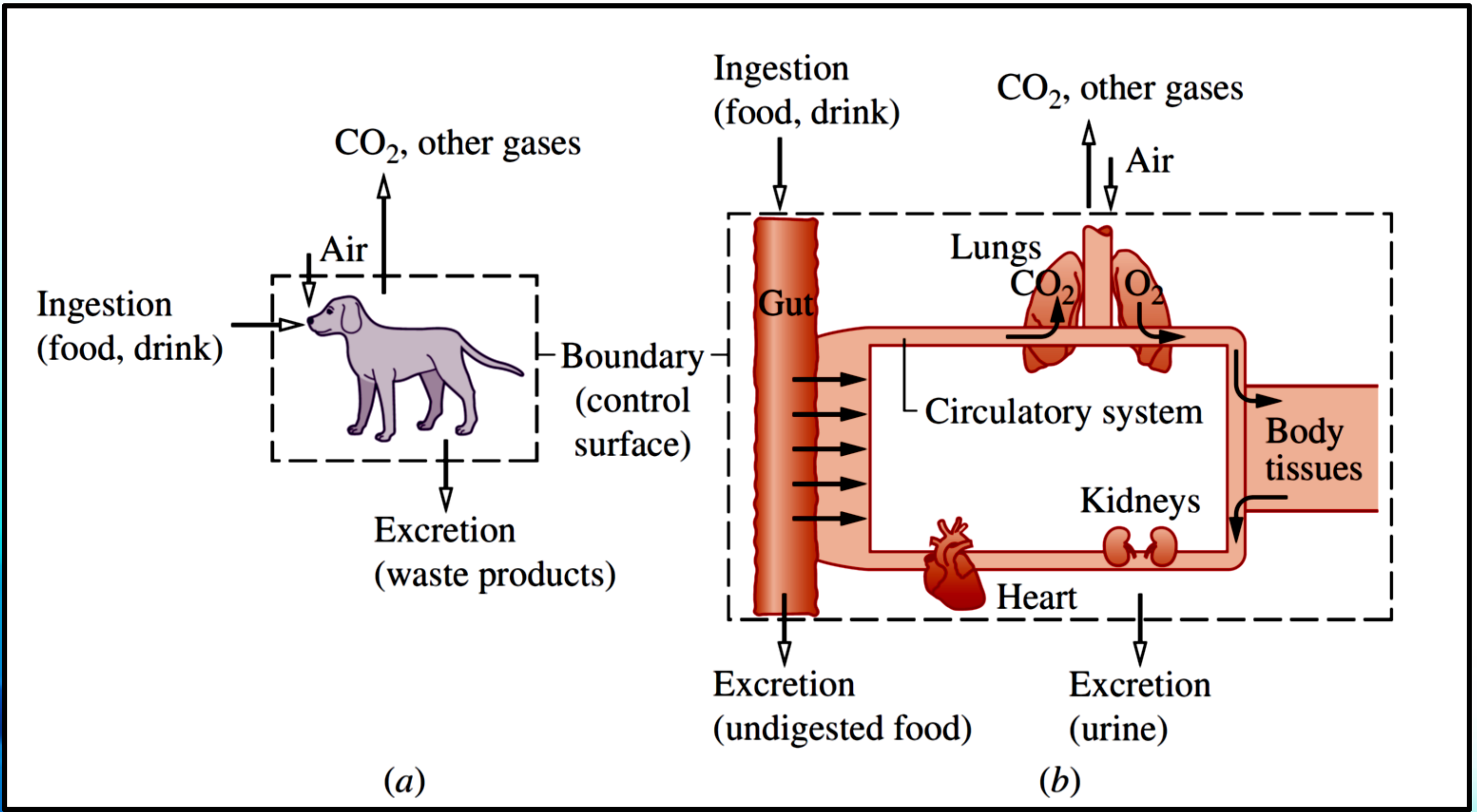
During steady-state operation, no properties change with time.

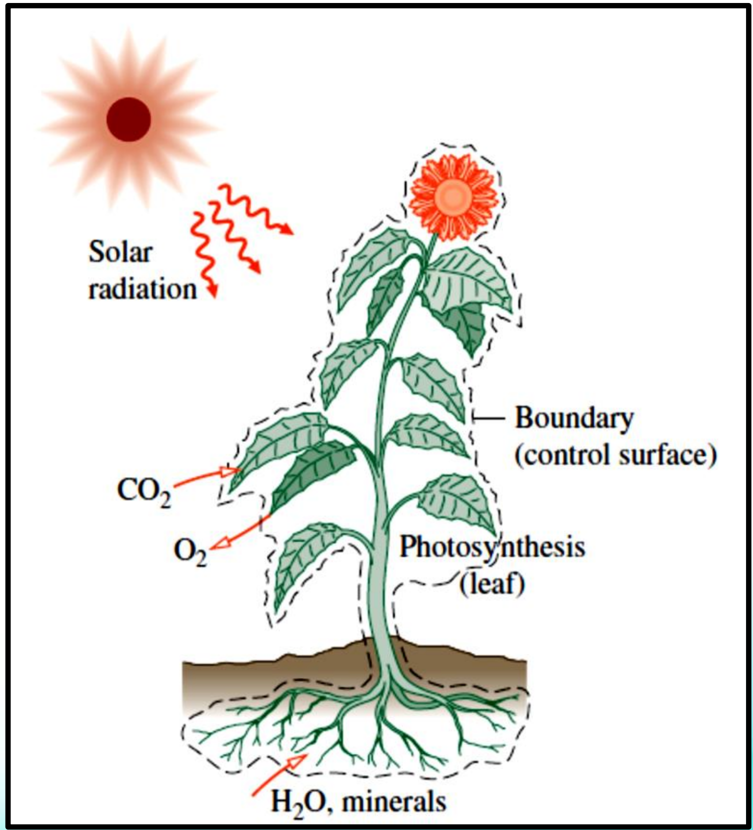


During steady-state operation, no properties change with time.

Selecting the System Boundary

Example of a control volume (open system) in biology.





The choice of system boundary is governed by two considerations:

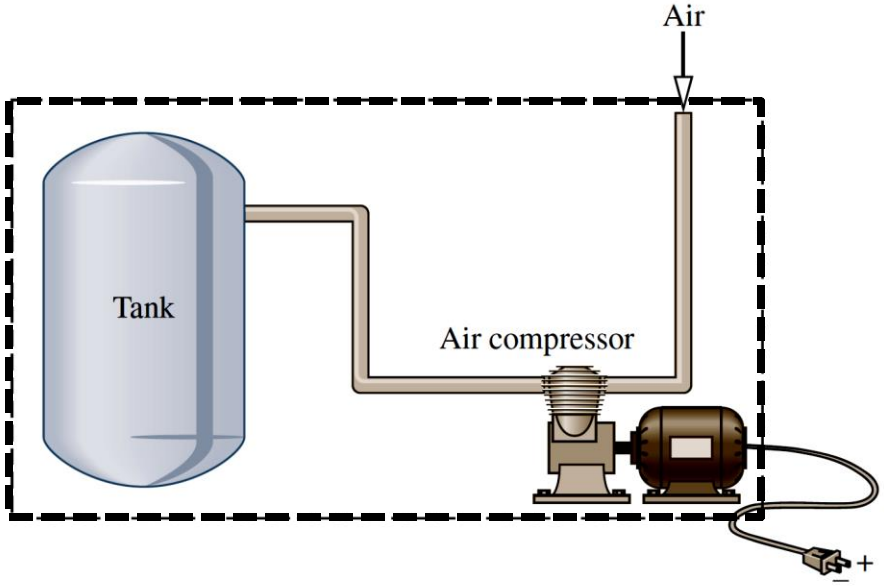
(1) What is known about a possible system, particularly at its boundaries,

(2) the objective of the analysis.

For Example

- The photo and sketch shows an air compressor connected to a storage tank.

- The **system boundary** shown on the figure encloses the compressor, tank, and all of the piping.
- This boundary might be selected if the electrical power input is known, and the **objective** of the analysis *is to determine how long the compressor must operate for the pressure in the tank to rise to a specified value*.
- Since mass crosses the boundary, the system would be a **control volume**.
- A **control volume** enclosing only the compressor might be chosen if the condition of the air entering and exiting the compressor is known, and the objective is to determine the electric power input.

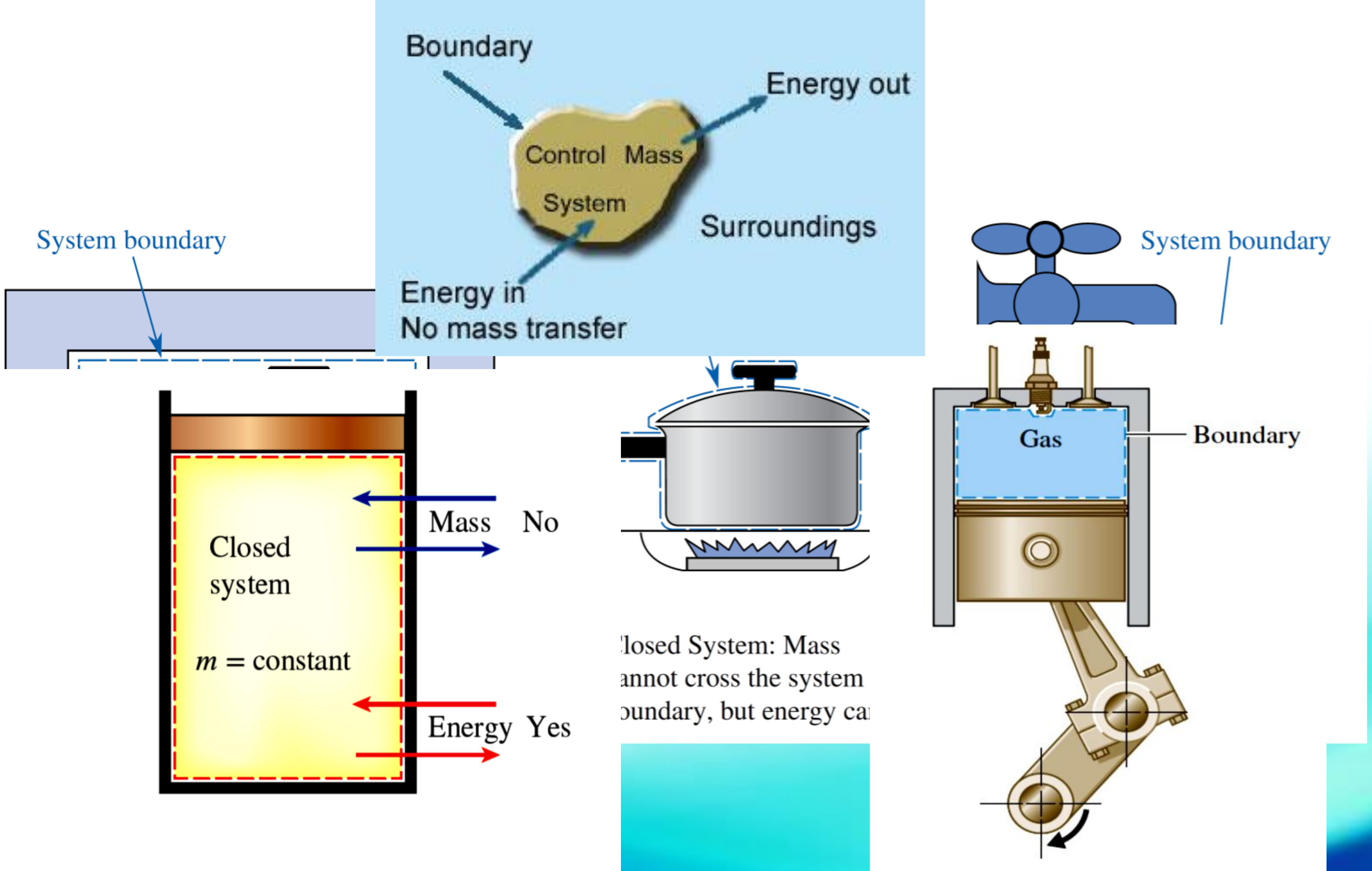


THE LANGUAGE OF THERMODYNAMICS

The three types of thermodynamic systems

- A **closed system** (also known as a **control mass** or just ***system***) consists of a fixed amount of mass, and no mass can cross its boundary.

- That is, no mass can enter or leave a closed system, as shown in.
- But energy, in the form of heat or work, can cross the boundary; and the volume of a closed system does not have to be fixed.
- If, as a special case, even energy is not allowed to cross the boundary, that system is called an **isolated system**.



Mass cannot cross the boundaries of a closed system, but energy can.

Closed system: A gas in a piston–cylinder assembly.

- As an example of an **open system**, consider the water heater shown in Figure.
- Let us say that we would like to determine how much heat we must transfer to the water in the tank in order to supply a steady stream of hot water.
- Since hot water will leave the tank and be replaced by cold water, it is not convenient to choose a fixed mass as our system for the analysis.
- Instead, we can concentrate our attention on the volume formed by the **interior surfaces of the tank** and consider the hot and cold water streams as mass leaving and entering the **control volume.**
- The interior surfaces of the tank form the control surface for this case, and mass is crossing the control surface at two locations.

In an engineering analysis, the system under study ***must be defined carefully.*** In most cases, the system investigated is quite simple and obvious, and defining the system may seem like a tedious and unnecessary task. In other cases, however, the system under study may be rather involved, and a proper choice of the system may greatly simplify the analysis.

FIGURE 1–22
An open system (a control volume) with one inlet and one exit.

PROPERTIES OF A SYSTEM

- **Property:** Any characteristic of a system.
- Some familiar properties are pressure *P*, temperature *T*, volume *V*, and mass *m*.
- Properties are considered to be either *intensive* or *extensive*.
- **Intensive properties:** Those that are independent of the mass of a system, such as temperature, pressure, and density.
- **Extensive properties:** Those whose values depend on the size—or extent—of the system.
- **Specific properties:** Extensive properties per unit mass.

$(v = V/m)$ $(e = E/m)$

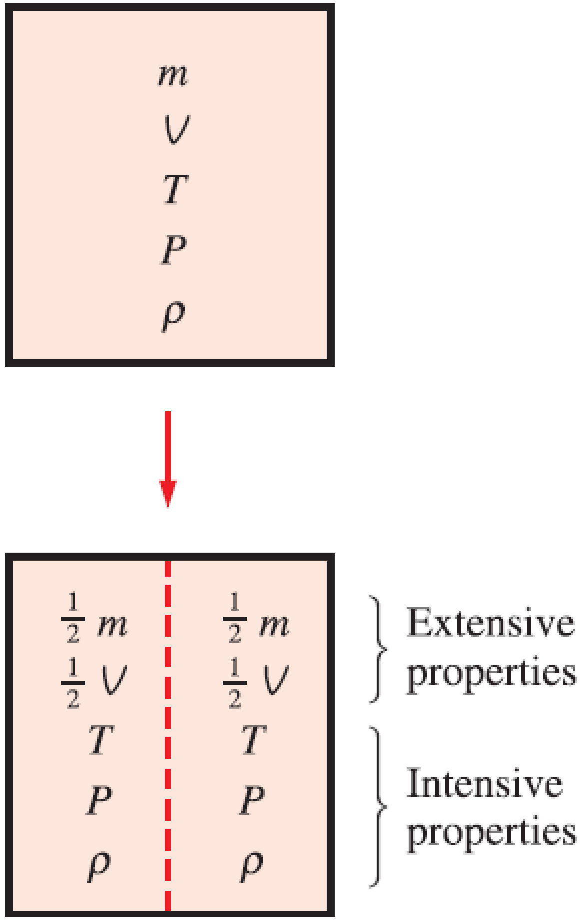
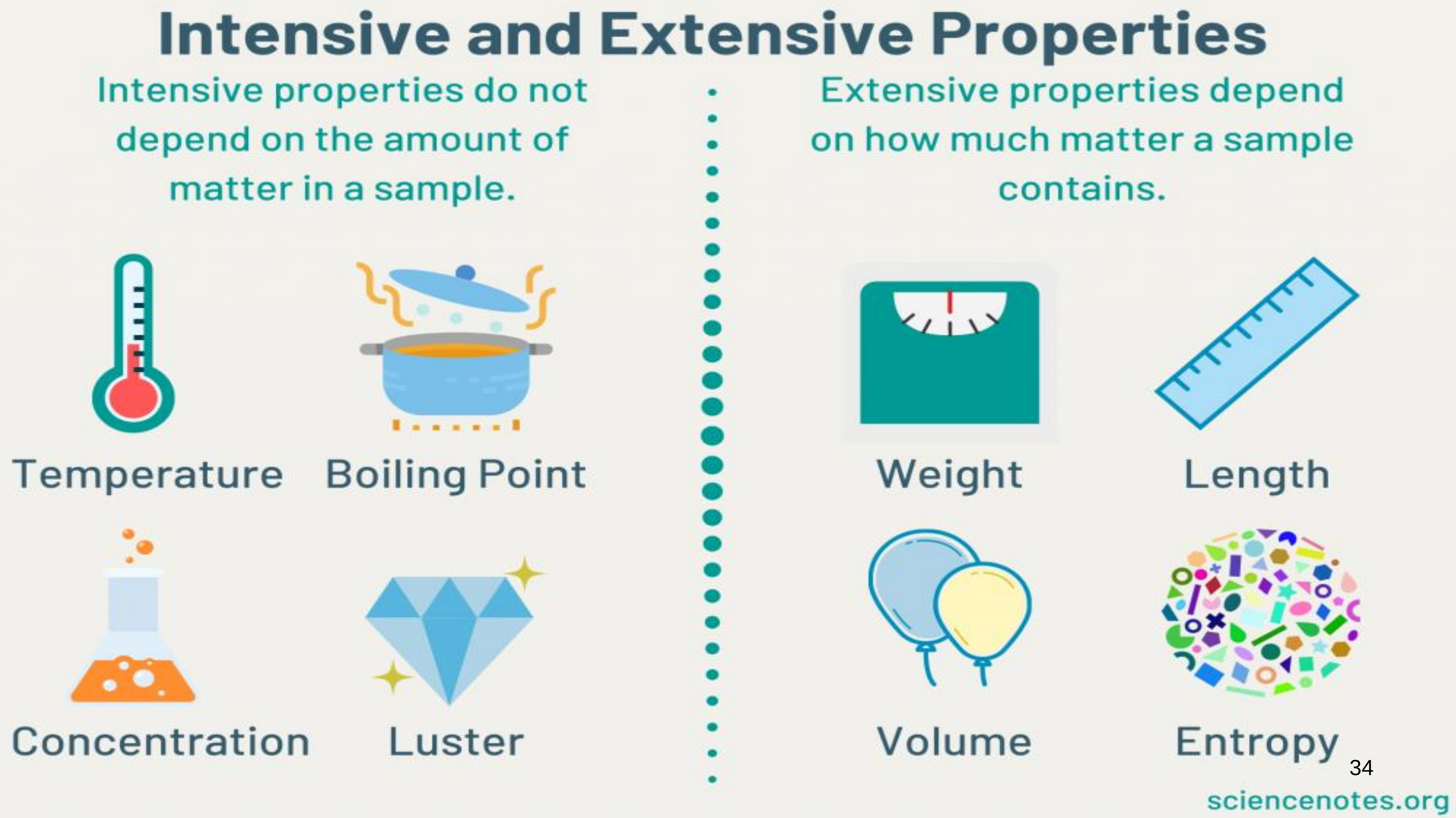
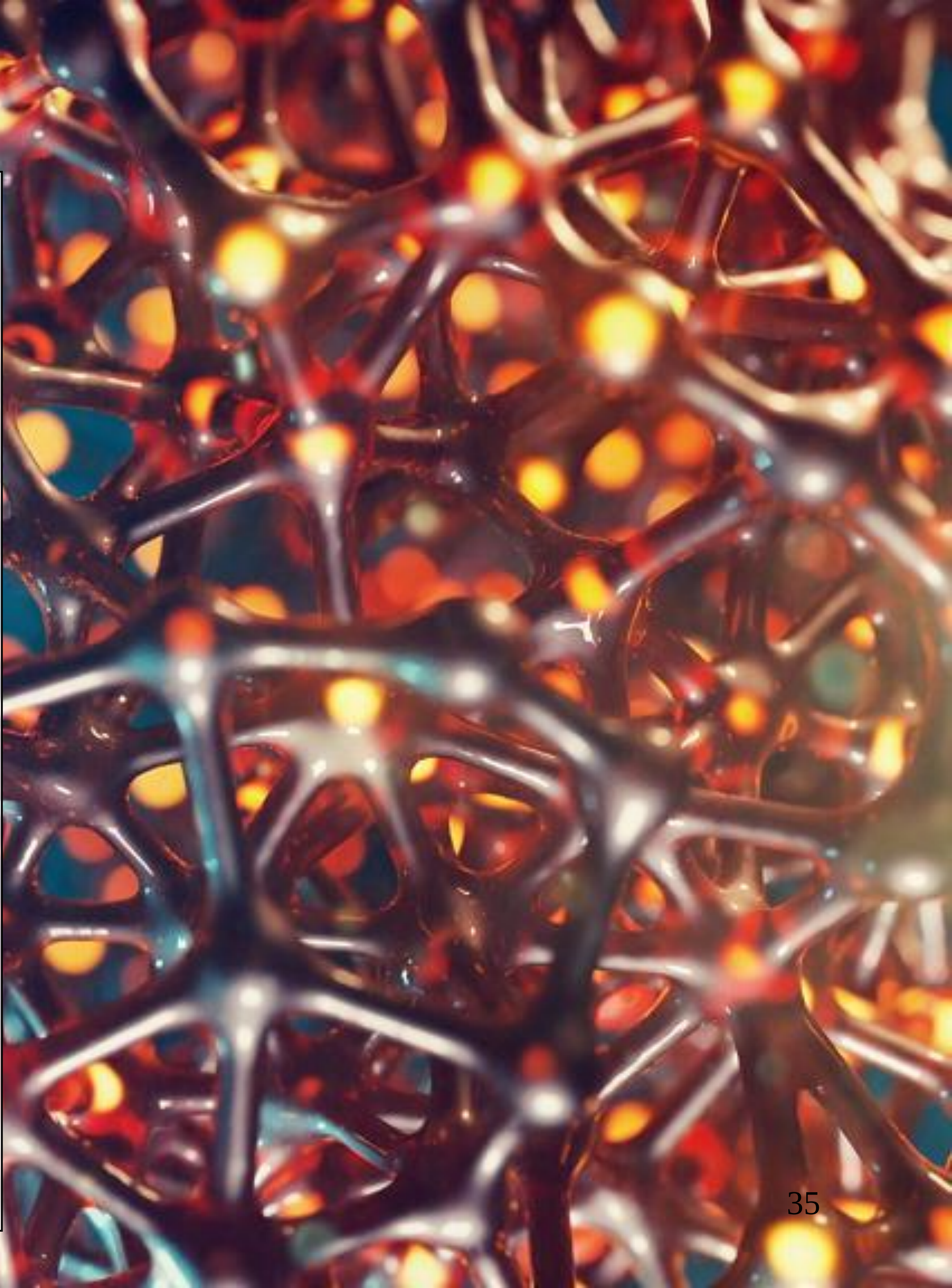


FIGURE 1–23
Criterion to differentiate intensive and extensive properties.


Intensive and Extensive Properties
Intensive properties do not depend on the amount of matter in a sample.
Temperature
Boiling Point
Concentration
Luster
Extensive properties depend on how much matter a sample contains.
Weight
Length
Volume
Entropy
sciencenotes.org

Continuum

- **Matter** is made up of atoms that are widely spaced in the gas phase.
- Yet it is very ***convenient to disregard the atomic nature*** of a substance and view it as a **continuous**, **homogeneous matter** with **no holes**, that is, a **continuum**.
- The **continuum idealization** allows us to ***treat properties as point functions and to assume the properties vary continually in space with no jump discontinuities***.
- This idealization is valid ***as long as the size of the system we deal with is large relative to the space between the molecules***.
- This is the case in practically all problems.
- In this text we will limit our consideration to substances that can be modeled as a continuum.



STATE AND EQUILIBRIUM

- Thermodynamics deals with *equilibrium* states.
- **Equilibrium:** A state of balance.
- In an equilibrium state there are no unbalanced potentials (or driving forces) within the system.
- **Thermal equilibrium:** If the temperature is the same throughout the entire system.
- **Mechanical equilibrium:** If there is no change in pressure at any point of the system with time.
- **Phase equilibrium:** If a system involves two phases and when the mass of each phase reaches an equilibrium level and stays there.
- **Chemical equilibrium:** If the chemical composition of a system does not change with time, that is, no chemical reactions occur.

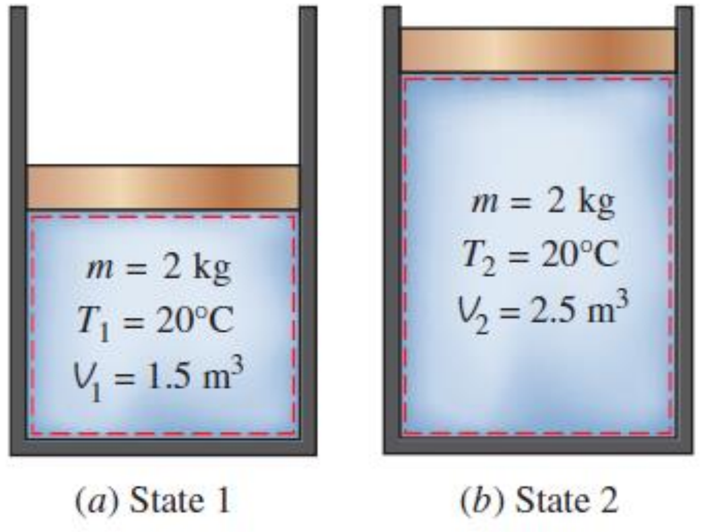


FIGURE 1–26
A system at two different states.

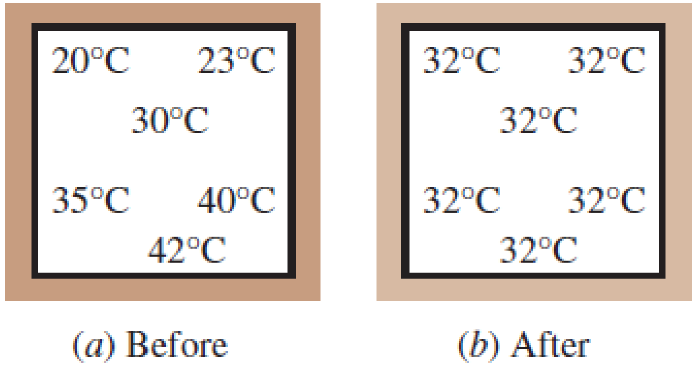


FIGURE 1–27
A closed system reaching thermal equilibrium.

The State Postulate

- The number of properties required to fix the state of a system is given by the **state postulate**:
  - ✓ *The state of a simple compressible system is completely specified by two independent, intensive properties.*
- **Simple compressible system:** If a system involves no electrical, magnetic, gravitational, motion, and surface tension effects.

FIGURE 1–28
The state of nitrogen is fixed by two independent, intensive properties.

PROCESSES AND CYCLES

- **Process:** Any change that a system undergoes from one equilibrium state to another.
- **Path:** The series of states through which a system passes during a process.
- To describe a process completely, one should specify the initial and final states, as well as the path it follows, and the interactions with the surroundings.
- **Quasistatic or quasi-equilibrium process:** When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times.

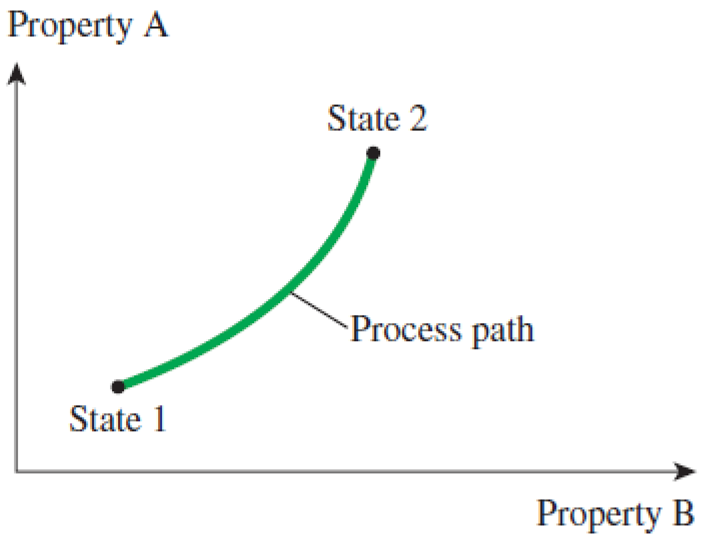


FIGURE 1–29
A process between states 1 and 2 and the process path.

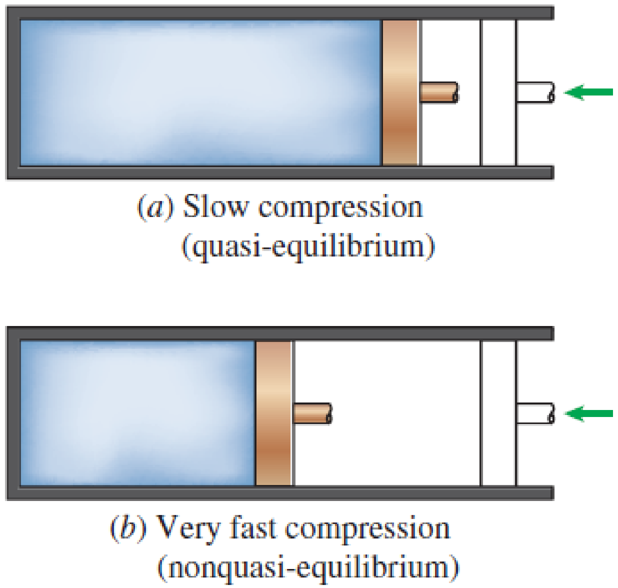


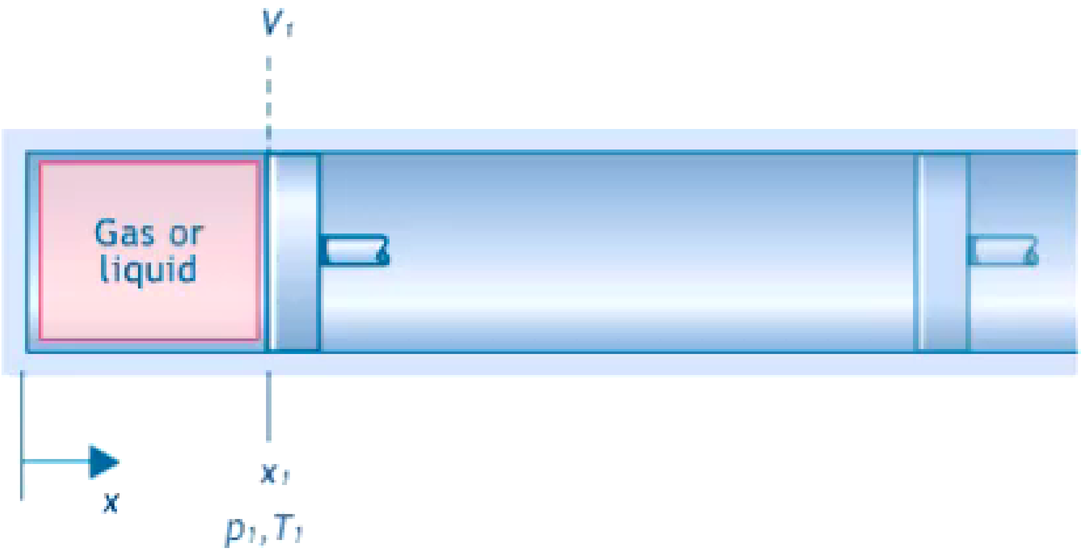
FIGURE 1–30
Quasi-equilibrium and nonquasi-equilibrium compression processes.

a. Property, State, and Process

Property, State, and Process

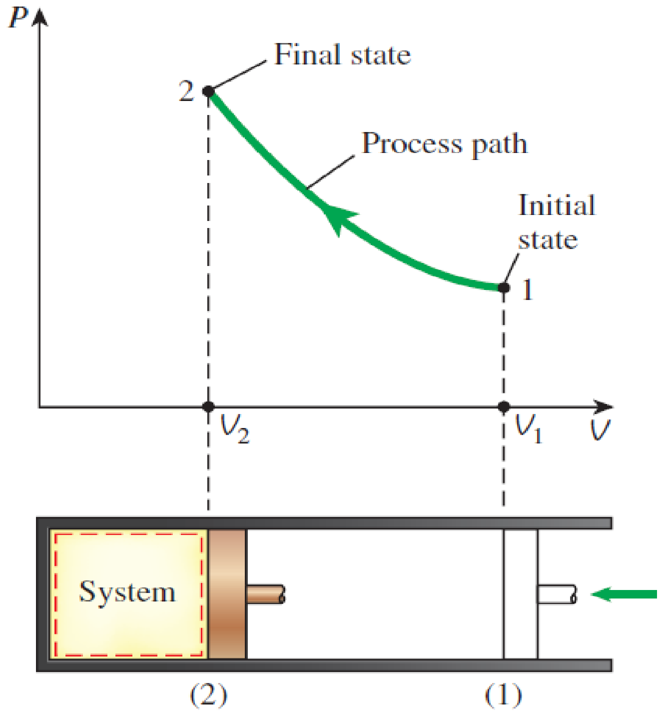
Since system properties have changed, the system is now at a different state than initially. A process is a transformation from one state to another.

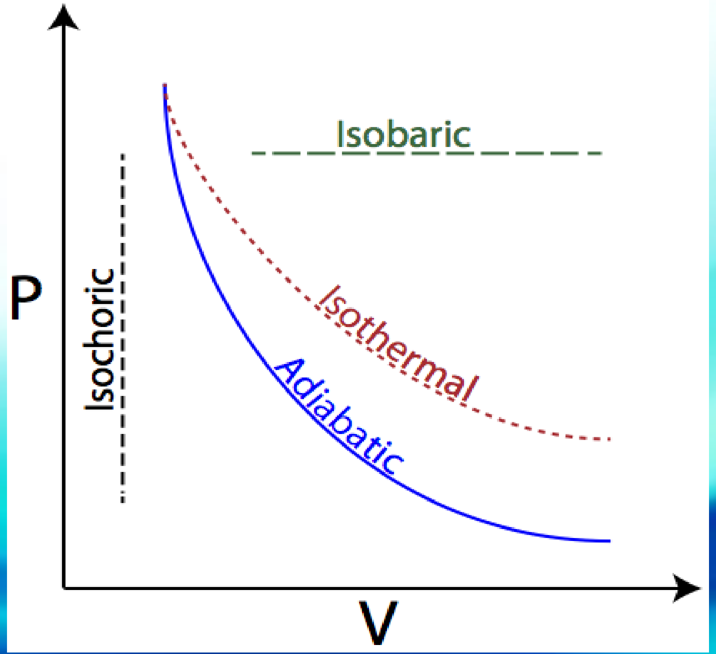
The gas or liquid in the piston-cylinder assembly is undergoing two separate processes: Process 1-2 and Process 2-1.



P- v Diagram

- Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes.
- Some common properties that are used as coordinates are temperature *T*, pressure *P*, and volume *V* (or specific volume *v*).
- The prefix *iso-* is often used to designate a process for which a particularproperty remains constant.
- **Isothermal process**: A process during which the temperature *T* remains constant.
- **Isobaric process**: A process during which the pressure *P* remains constant.
- **Isochoric (or isometric) process**: A process during which the specific volume *v* remains constant.
- **Cycle**: A process during which the initial and final states are identical.





The Steady-Flow Process

- The term *steady* implies *no change with time*. The opposite of steady is *unsteady*, or *transient*.
- A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as *steady-flow devices*.
- **Steady-flow process**: A process during which a fluid flows through a control volume steadily.
- Steady-flow conditions can be closely approximated by devices that are intended for continuous operation such as turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems.

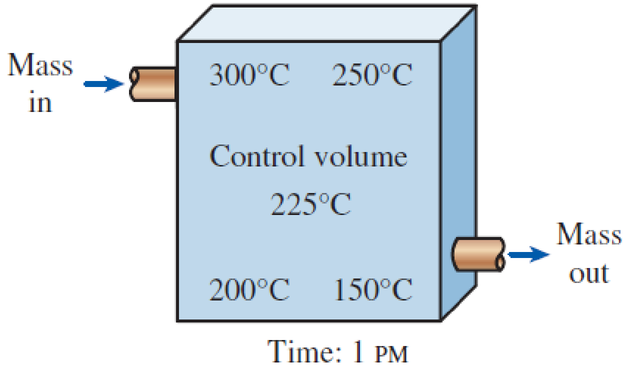


FIGURE 1–32
During a steady-flow process, fluid properties within the control volume may change with position but not with time.

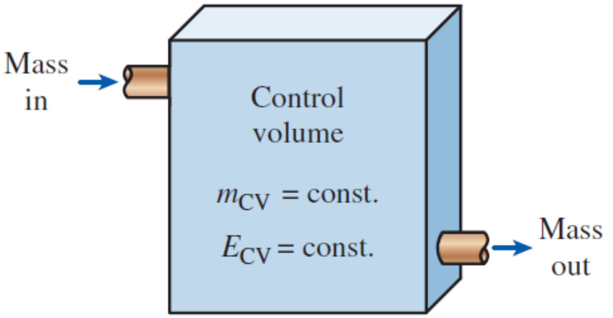


FIGURE 1–33
Under steady-flow conditions, the mass and energy contents of a control volume remain constant.

THE ZEROTH LAW OF THERMODYNAMICS

- The zeroth law was one of the last thermodynamic laws to be developed. It was introduced by R. H. Fowler and E. A. Guggenheim in 1939.

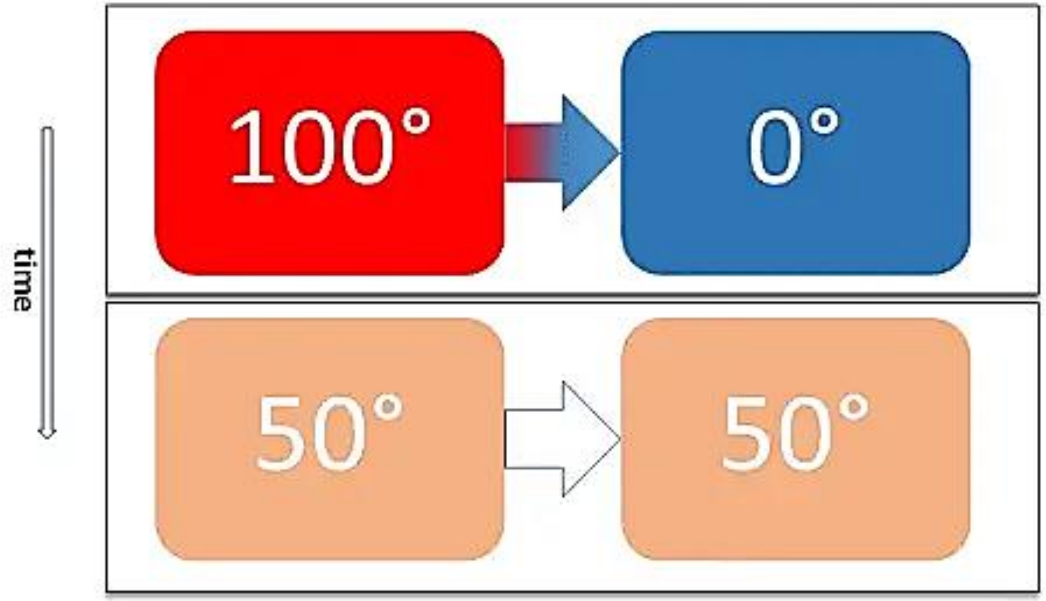
- The **Zeroth law** of thermodynamics states that :
- *if two thermodynamic systems are in thermal equilibrium with the third thermodynamic system, then **they all are in thermal equilibrium with each other.***

- Why is it called the ***zeroth law of thermodynamics***?

- There were three law of thermodynamics originally established and named.
- **Then, the scientists realized that one more law is required to complete the set.**
- However, the ***zeroth law*** is the formal definition of ***temperature*** and it is considered as a more fundamental law when compared to the other three laws.
- The three laws were already well known by their corresponding numbers.
- Renumbering the name would create confusion.
- Calling this as the fourth law and putting it in the last of the list was also being confusing because it is the most fundamental law.
- Since the **law** is the **fundamental** one, the scientist Raplh H Fowler came with an alternative and numbered the **new law as a lower number zero** and the law is called the "***Zeroth law***."

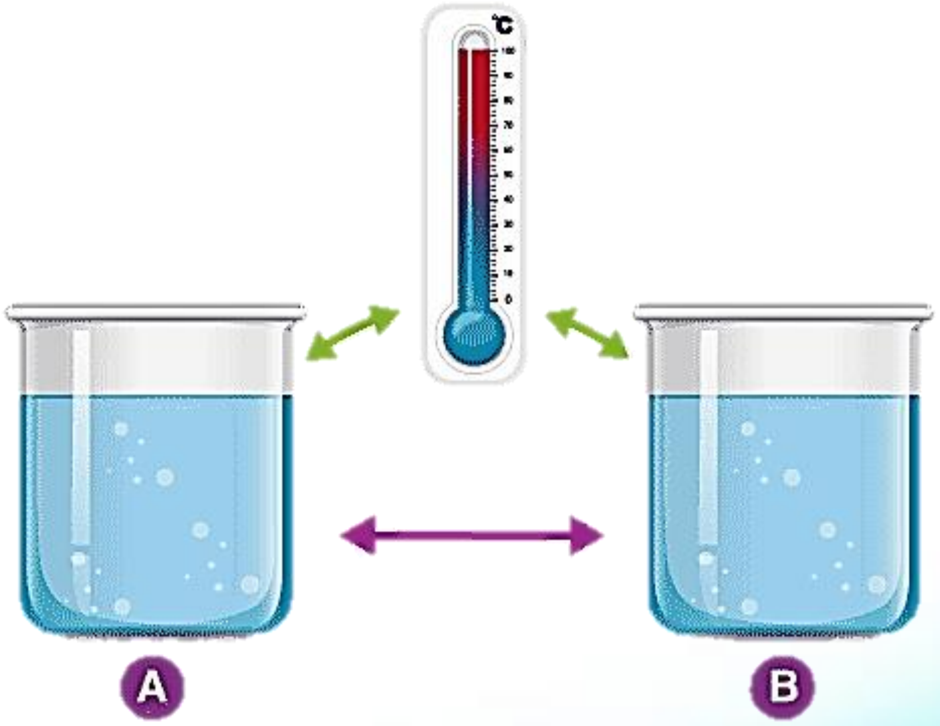
What Is Thermal Equilibrium?

- According to the **thermal equilibrium** definition, when two thermodynamic systems or simply speaking two thermal bodies are in thermal contact with one another, separated by a barrier (permeable only to heat).
- Then, there will be no transfer of heat ***energy*** between two physical systems.



Examples of The Zero Law of Thermodynamics

- Consider two cups A and B with boiling water.
- When a thermometer is placed in cup A, it gets warmed up by the water until it reads 100 °C.
- When it read 100 °C, we say that the thermometer is in equilibrium with cup A.
- Now when we move the thermometer to cup B to read the temperature, it continues to read 100 °C.
- The thermometer is also in equilibrium with cup B.
- From keeping in mind the zeroth law of thermodynamics, we can conclude that cup A and cup B are in equilibrium with each other.
- The zeroth law of thermodynamics enables us to use thermometers to compare the temperature of any two objects that we like.

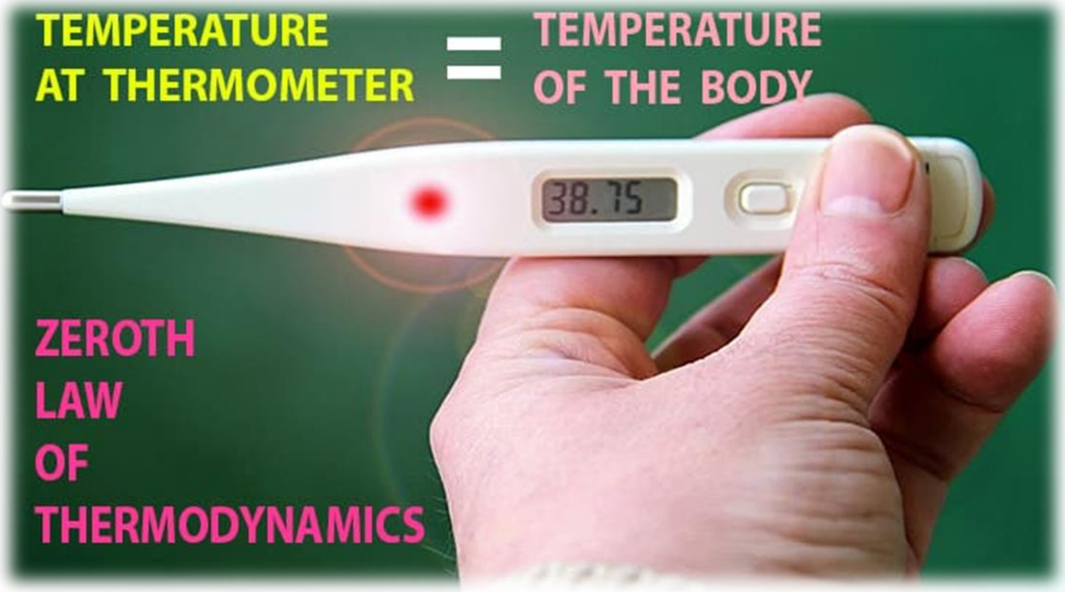


What are the applications of the zeroth law of thermodynamics?

- The **thermometer** may be the most well-known example of the zeroth law in action.

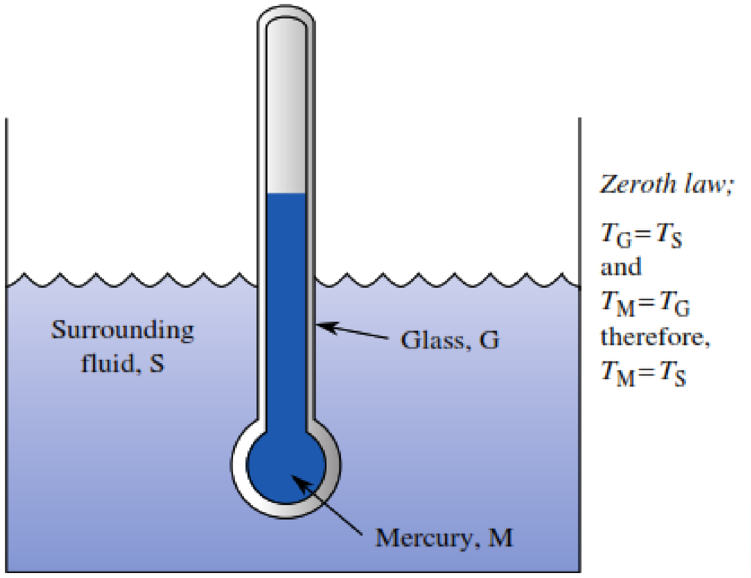
- The **thermometer** is a device that helps to measure the temperature of the body by using a mercury column.

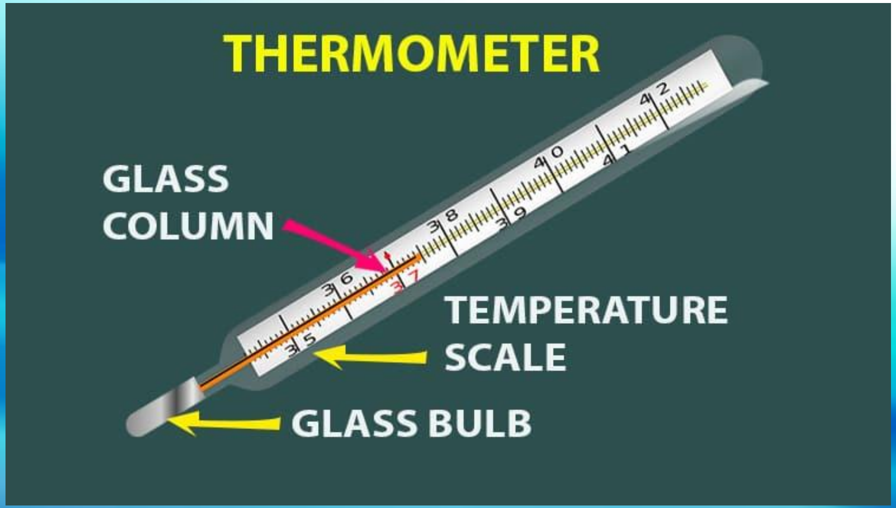
- When the **thermometer** comes in contact with the body, it takes to **heat** and makes an *equilibrium with body temperature*. Due to this *equilibrium* in temperature, doctors are able to measure the temperature of our body.



The zeroth law of thermodynamics applied to a mercury in a glass thermometer

- Consider the mercury in glass thermometer shown in Figure.
- The zeroth law tells us that: if the glass is at the **same temperature** as (i.e., is in thermal equilibrium with) the surrounding **fluid**,
- and if the **mercury** is at the same temperature as the glass, then the **mercury** is at the same temperature as the surrounding fluid.
- Thus, the thermometer can be graduated to show the mercury temperature, and this temperature is automatically (via the zeroth law) equal to the temperature of its surroundings.

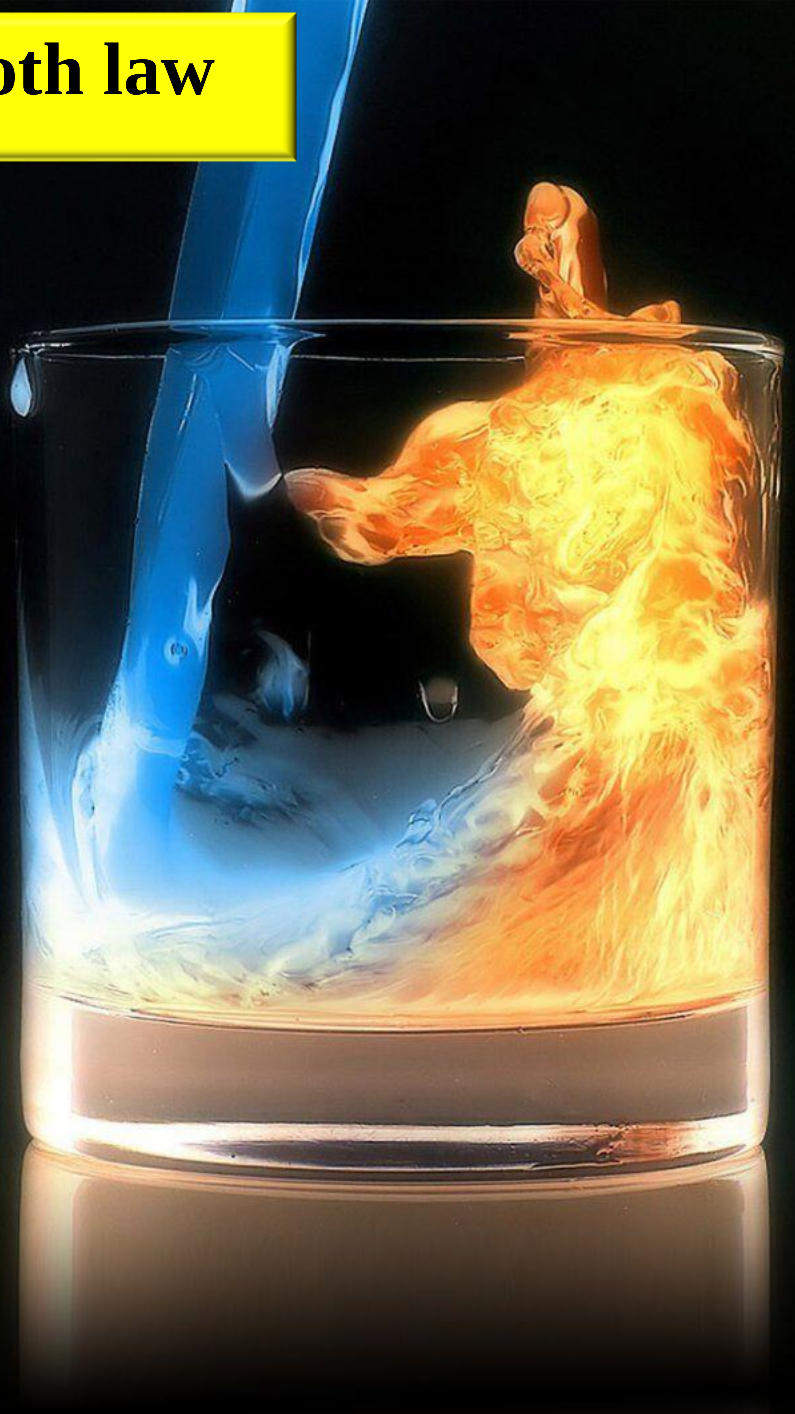




Limitation of the Zeroth law

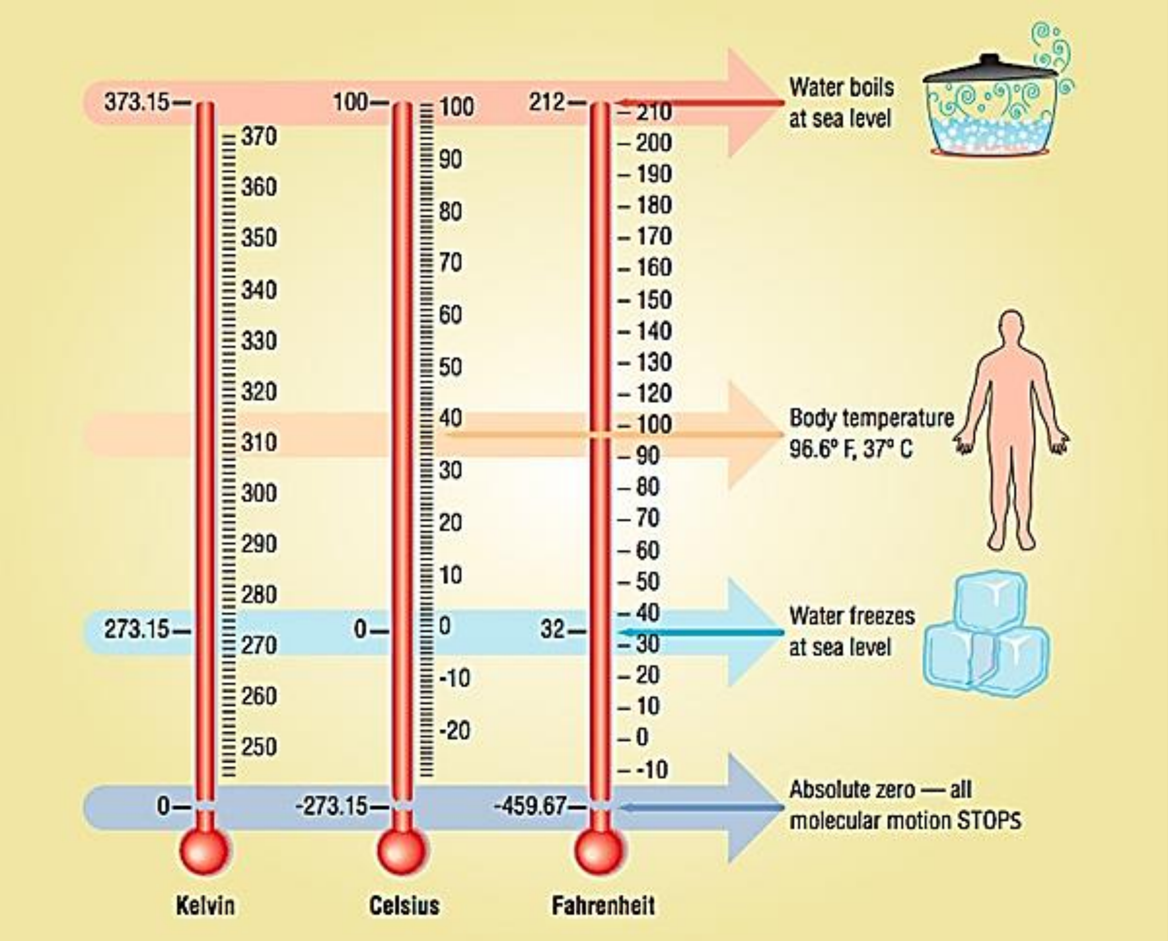
There is a certain limitation of the Zeroth law,

- It does not tell us about the direction in which heat flows when they are in contact.
- When two bodies come in equilibrium conditions, this law is unable to tell about the final temperature or the temperature of the equilibrium conditions.
- It does not tell about energy conservation.
- Zeroth law predicts whether there will be heat transfer between objects or not.
- If two objects are not in physical contact, there may also be a heat transfer. For example, if two objects with different temperatures placed little distance, there may be a heat transfer by radiation.



Temperature Scales

- All temperature scales are based on some easily reproducible states such as the freezing and boiling points of water: the *ice point* and the *steam point.*
- **Ice point**: A mixture of ice and water that is in equilibrium with air saturated with vapor at 1 atm pressure (0°C or 32°F).
- **Steam point**: A mixture of liquid water and water vapor (with no air) in equilibrium at 1 atm pressure (100°C or 212°F).
- **Celsius scale:** in SI unit system
- **Fahrenheit scale:** in English unit system
- **Thermodynamic temperature scale**: A temperature scale that is independent of the properties of any substance.
- **Kelvin scale** (SI) **Rankine scale** (E)
- A temperature scale nearly identical to the Kelvin scale is the **ideal-gas temperature scale**. The temperatures on this scale are measured using a constant-volume gas thermometer.



Comparison of temperature scales.

$$T(\text{K}) = T(°\text{C}) + 273.15$$

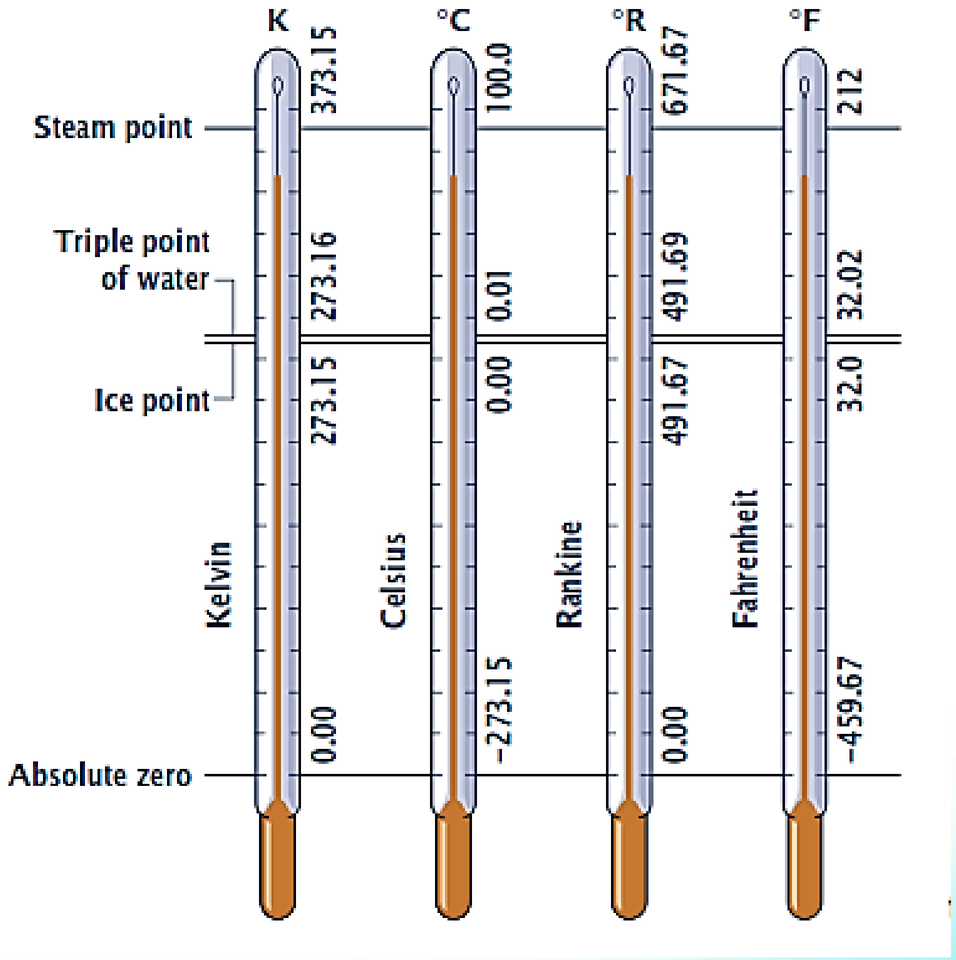
$$T(\text{R}) = T(°\text{F}) + 459.67$$

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

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

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

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



- The reference temperature in the original Kelvin scale was the ***ice point*****,** 273.15 K, which is the temperature at which water freezes (or ice melts).
- The reference point was changed to a much more precisely reproducible point, the ***triple point*** of water (the state at which all three phases of water coexist in equilibrium), which is assigned the value 273.16 K.

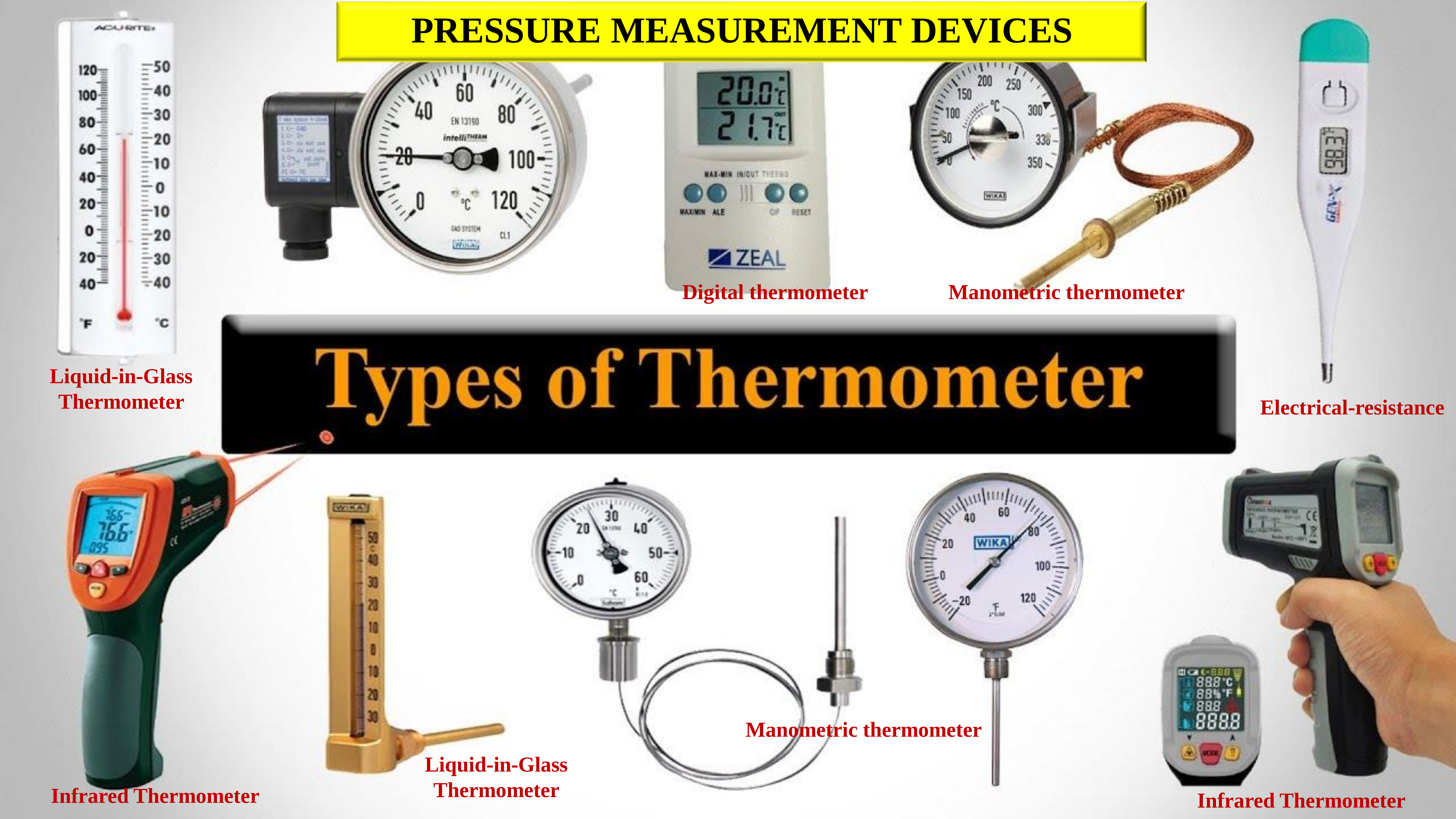
There are so many ways, the zeroth law is applied, these are, as follows

- When we get very hot food, we wait to make it normal. In this case, hot food exchanges heat with surrounding and bring equilibrium.

- We keep things in the fridge, and the things come equilibrium with fridge temperature.

- Temperature measurement with a thermometer or another device.

- In the HVAC system, sensors or thermostats are used to indicate the temperature.
- It always comes in thermal equilibrium with room temperature.


PRESSURE MEASUREMENT DEVICES
Types of Thermometer
Liquid-in-Glass Thermometer
Digital thermometer
Manometric thermometer
Electrical-resistance
Infrared Thermometer
Liquid-in-Glass Thermometer
Manometric thermometer
Infrared Thermometer

PRESSURE

Pressure: A normal force exerted by a fluid per unit area

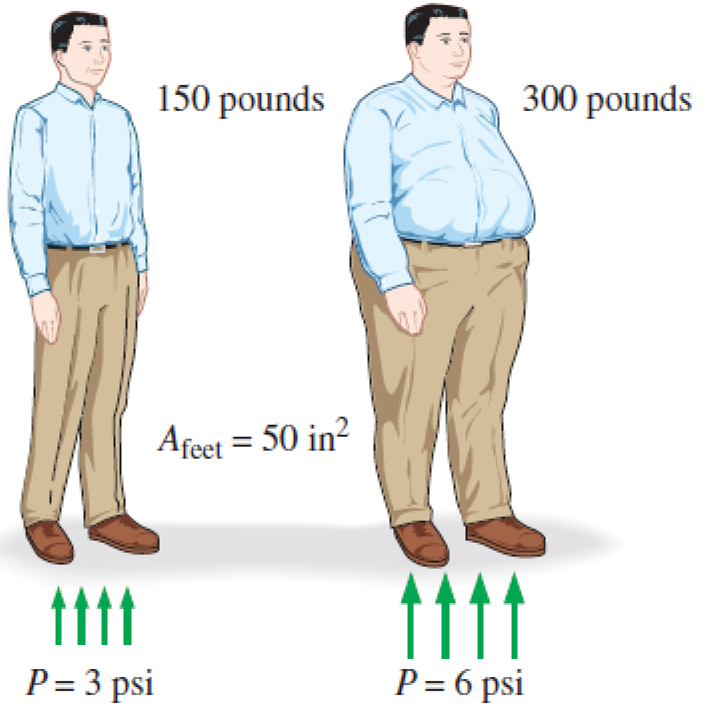
$$1 \text{ Pa} = 1 \text{ N/m}^2$$

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

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

$$1 \text{ kgf/cm}^2 = 9.807 \text{ N/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2 = 9.807 \times 10^4 \text{ Pa}$$
$$= 0.9807 \text{ bar}$$
$$= 0.9679 \text{ atm}$$

Some basic pressure gages.



$$P = \sigma_n = \frac{W}{A_{feet}} = \frac{150 \text{ lbf}}{50 \text{ in}^2} = 3 \text{ psi}$$

FIGURE 1–39
The normal stress (or “pressure”) on the feet of a chubby person is much greater than on the feet of a slim person.

Density (ρ) and Specific Volume (v) (2 of 2)

► **Specific volume** is the reciprocal of density: $v = 1/\rho$.

► **Specific volume** is volume per unit mass.

► **Specific volume** is defined as the number of cubic meters occupied by one kilogram of **matter**.

► **Specific volume** is an intensive property that may vary from point to point.

► SI units are (m^3/kg).

- **Specific volume** is usually preferred for thermodynamic analysis when working with gases that typically have small density values.

Note: ***Specific Volume***

The specific volume of a substance is the ratio of the substance's volume to its mass. It is the reciprocal of density and is an intrinsic property of matter.

v – *Specific Volume* m^3/Kg

$$v = \frac{V}{m} = \rho^{-1}$$

Substance Name	Density	Specific Volume
	Kg/m³	m³/Kg
Air	1.2	0.83
Ice	916.7	0.00109
Water (liquid)	1000	0.00100
Salt Water	1030	0.00097
Mercury	13546	0.00007

- **Properties describe phase of substance**
- **Phase is related to energy content**
- **Phase change is related to energy transfer**
- **Thermodynamics is all about energy transfer and energy transformation**

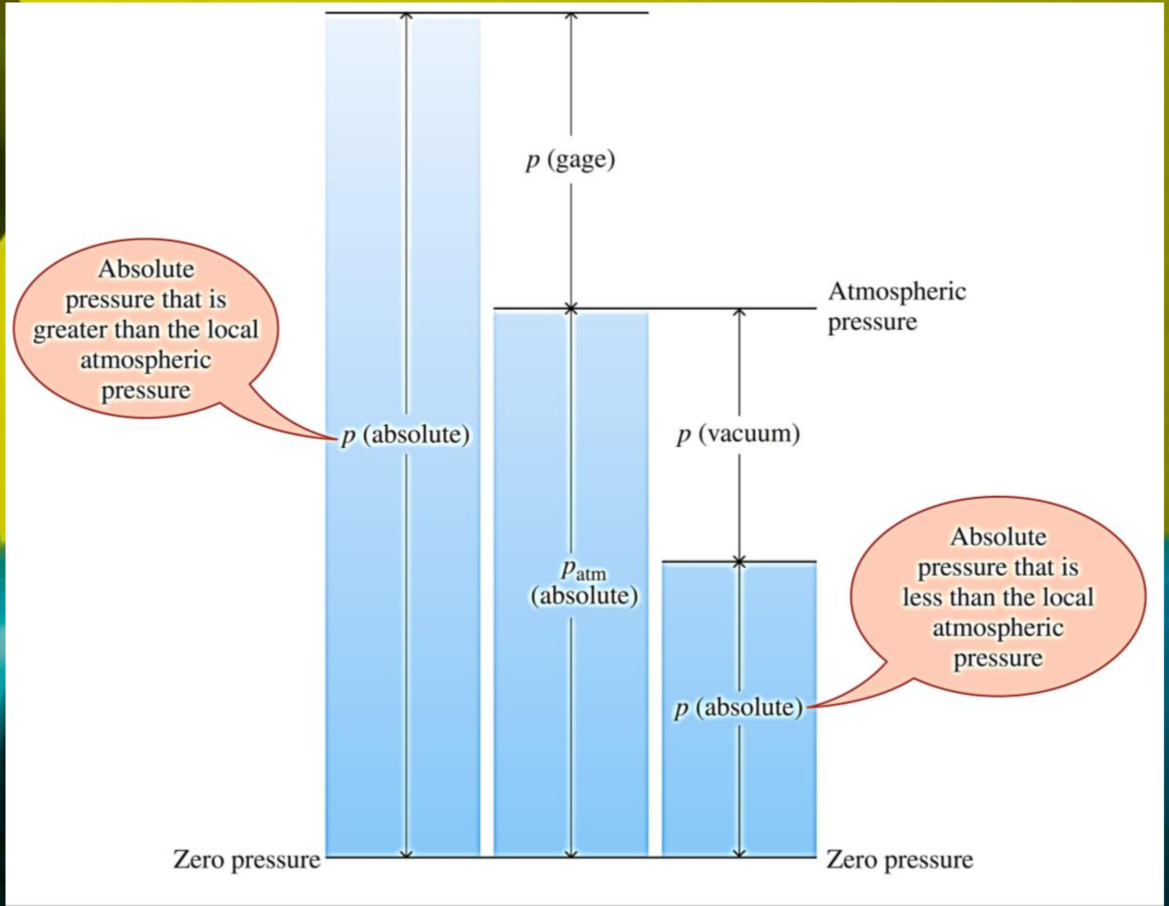
Pressure

- **Absolute pressure**: The actual pressure at a given position. It is measured relative to absolute vacuum (i.e., absolute zero pressure).
- **Gage pressure**: The difference between the absolute pressure and the local atmospheric pressure. Most pressure-measuring devices are calibrated to read zero in the atmosphere, and so they indicate gage pressure.
- **Vacuum pressures**: Pressures below atmospheric pressure.

Throughout this text, the pressure ***P*** will denote ***absolute pressure*** unless specified otherwise.

$$p(\text{gage}) = p(\text{absolute}) - p_{\text{atm}}(\text{absolute})$$

$$p(\text{vacuum}) = p_{\text{atm}}(\text{absolute}) - p(\text{absolute})$$



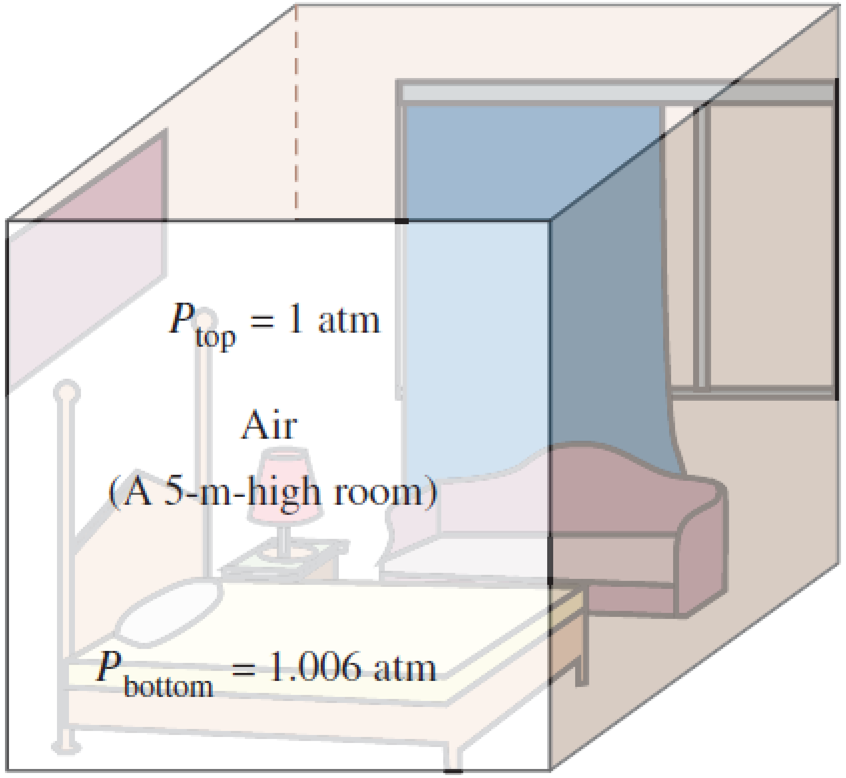


FIGURE 1–44
In a room filled with a gas, the variation of pressure with height is negligible.

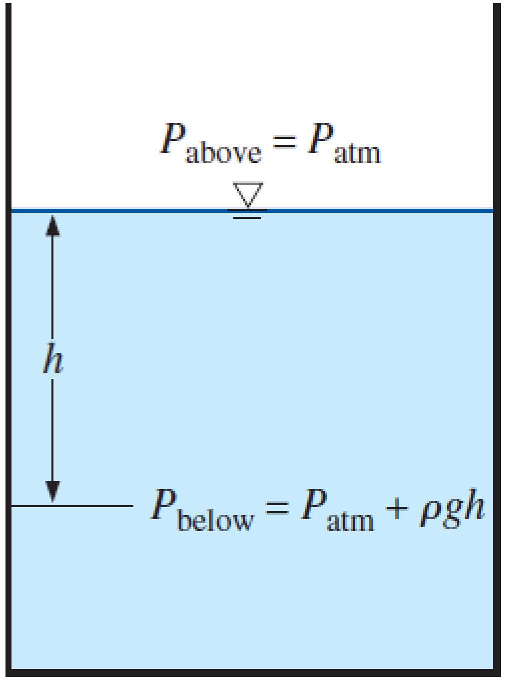


FIGURE 1–45
Pressure in a liquid at rest increases linearly with distance from the free surface.

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, and Discussion

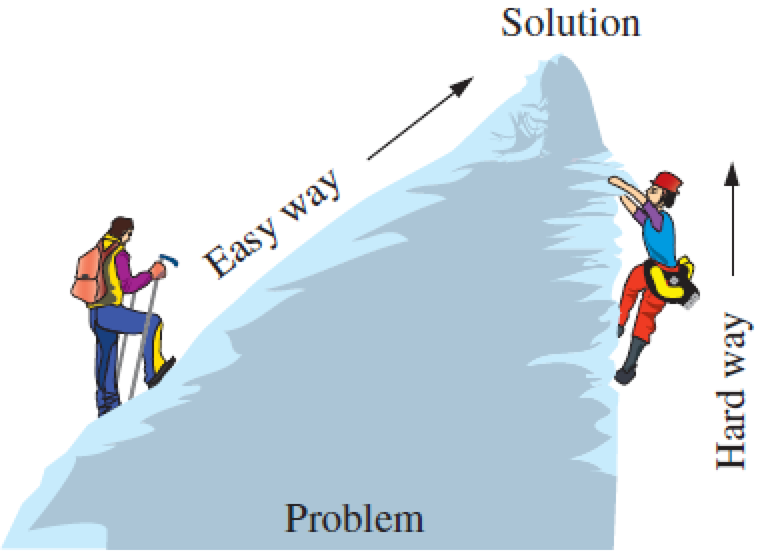


FIGURE 1–62
A step-by-step approach can greatly simplify problem solving.

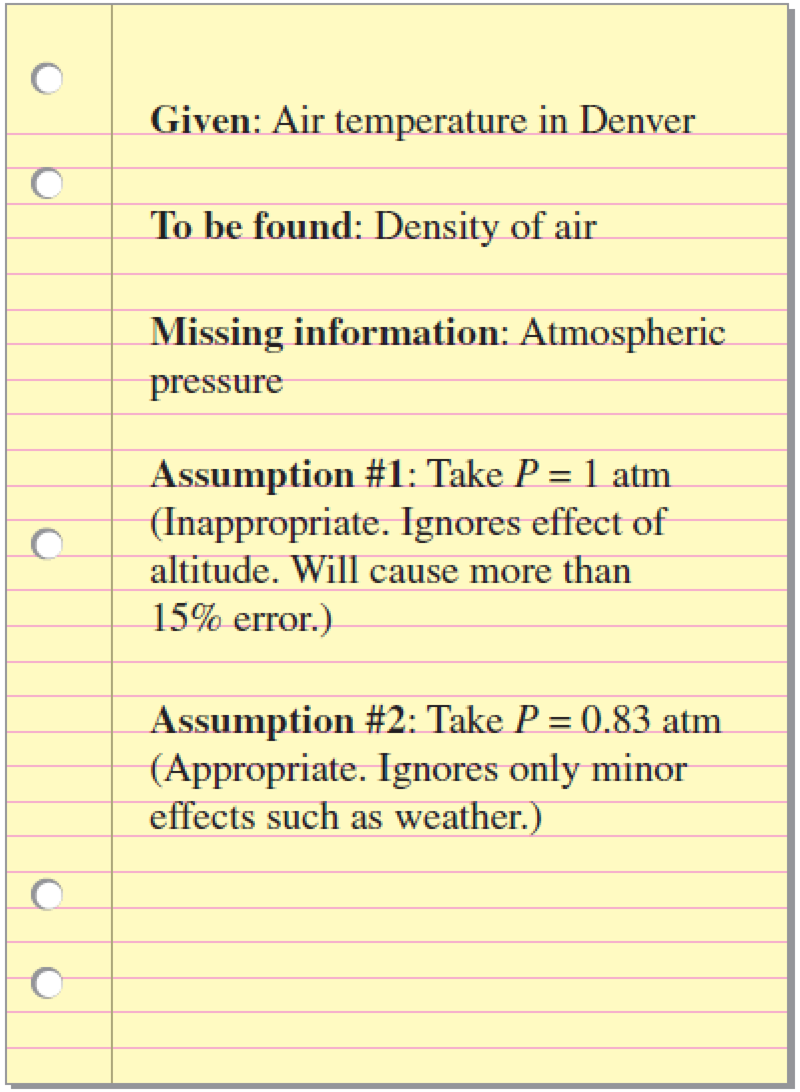


FIGURE 1–63
The assumptions made while solving an engineering problem must be reasonable and justifiable.

A Remark on Significant Digits

In engineering calculations, the information given is not known to more than a certain number of significant digits, usually three digits.

Consequently, the results obtained cannot possibly be accurate to more significant digits.

Reporting results in more significant digits implies greater accuracy than exists, and it should be avoided.

Given: Volume: $V = 3.75$ L

Density: $\rho = 0.845$ kg/L

(3 significant digits)

Also, $3.75 \times 0.845 = 3.16875$

Find: Mass: $m = \rho V = 3.16875$ kg

Rounding to 3 significant digits:

$m = 3.17$ kg

FIGURE 1–69

A result with more significant digits than that of given data falsely implies more precision.

Summary

- Thermodynamics and energy
  - ✓ Application areas of thermodynamics
- Importance of dimensions and units
  - ✓ Some SI and English units, Dimensional homogeneity, Unity conversion ratios
- Systems and control volumes
- Properties of a system
  - ✓ Continuum
- Density and specific gravity
- State and equilibrium
  - ✓ The state postulate
- Processes and cycles
  - ✓ The steady-flow process
- Temperature and the zeroth law of thermodynamics
  - ✓ Temperature scales
  - ✓ ITS-90
- Pressure
  - ✓ Variation of pressure with depth
- The manometer
  - ✓ Other pressure measurement devices
- The barometer and atmospheric pressure
- Problem solving technique