



普通高等教育“十二五”规划教材

能源动力类专业英语

车德勇 孙佰仲 魏高升 李少华 编



中国电力出版社
CHINA ELECTRIC POWER PRESS



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内 容 提 要

本书为普通高等教育“十二五”规划教材。全书共8章。前3章为热能与动力工程和建筑环境与设备工程专业的通用内容，分别讲述工程热力学、工程流体力学和传热学这三门基础课的基本概念和理论；第4、5章为热能与动力工程专业课程内容，分别讲述火力发电厂锅炉和汽轮机的基本结构和工作原理；第6、7章为建筑环境与设备工程专业课程内容，讲述空调用制冷技术和空气调节技术原理及应用；第8章介绍核能及新能源（风能、生物质能、太阳能、水能和地热能）的利用及发展情况。

为了便于读者使用，文中的专业词汇均标记成斜体并加粗，每章后均附有词汇表和阅读材料。阅读材料是该章内容的延伸与补充，为该章主题的扩展知识，有助于读者了解和掌握最新的发展动态。

本书可作为普通高等院校热能与动力工程专业、建筑环境与设备工程专业本科专业英语教材，也可供能源动力类工程技术人员参考，还可作为研究生相关专业的英语阅读资料。

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前 言

本书涵盖了热能与动力工程专业、建筑环境与设备工程专业及能源动力类相关专业领域的主要内容,在介绍工程热力学、流体力学、传热学的基本知识的基础上,介绍了锅炉、汽轮机及热力发电厂、制冷、空气调节等相关内容,为拓宽读者视野,本书还介绍了新能源利用的相关知识。每一部分内容均配有专业词汇及生僻词汇的中英文对照,便于读者对相应内容的理解。此外,每一章节还包括与本章内容相关的阅读材料。书中的每一章节内容都有相当的独立性,读者可根据兴趣和专业方向选择阅读。

编者在多年从事高等学校专业英语教学的基础上,参考了大量的国外文献并总结了以往的教学经验,编写了此书。本书内容专业知识系统性强,内容由浅入深,先讲述基础理论后讲实际应用,便于读者更好地掌握专业知识;专业词汇覆盖面宽,为便于读者使用,文中的专业词汇均标记成了斜体并加黑;阅读材料内容丰富,每章后面的阅读材料是该章内容的延伸与补充,以与本章内容相关的综述为主,有助于读者深入了解本章内容。

本书作为高等院校热能与动力工程专业、建筑环境与设备工程专业本科生专业英语教材,也可供相关专业研究生和能源动力类工程技术人员阅读。

本书由东北电力大学车德勇、孙佰仲、李少华及华北电力大学魏高升合编。孙佰仲编写第1、4章,李少华编写第2章,车德勇编写第3、6、7章,魏高升编写第5、8章。李少华对全书进行统稿。

研究生杨文广、何志超、张锐等在本书的内容整理、排版等方面做了大量的工作,在此表示衷心的感谢!本书参考了有关教材和论文集,还参考了一些非正式出版的资料,在此一并向原作者表示真诚的感谢!

编 者

2011年7月

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Chapter 1 Thermodynamics

1.1 Thermodynamics and Energy

Thermodynamics can be defined as the science of **energy**. Although everybody has a feeling of what energy is, it is difficult to give a precise definition for it. Energy can be viewed as the ability to cause changes.

The name **thermodynamics** stems from the Greek words **therme** (*heat*) and **dynamics** (*power*), which is most descriptive of the early efforts to convert heat into power. Today the same name is broadly interpreted to include all aspects of energy and energy transformations, including **power generation**, **refrigeration**, and relationships among the properties of **matter**.

One of the most fundamental laws of nature is the **conservation of energy principle**. It simply states that during an interaction energy can change from one form to another, but the total amount of energy remains constant, that is, energy cannot be created or destroyed. A rock falling off a cliff, for example, picks up speed as a result of its **potential energy** being converted to **kinetic energy**. 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. 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

$$E_{\text{in}} - E_{\text{out}} = \Delta E \quad (1-1)$$

The first law of thermodynamics is simply an expression of the conservation of energy principle, and it asserts that **energy** is a **thermodynamic property**. **The second law of thermodynamics** asserts that energy has **quality** as well as **quantity** and actual processes occur in the direction of decreasing quality of energy. For example, a cup of hot coffee left on a table eventually cools, but a cup of cool coffee in the same room never gets hot by itself. The high-temperature energy of the coffee is degraded (transformed into a less useful form at a lower temperature) once it is transferred to the surrounding air.

Although the principles of thermodynamics have been in existence since the creation of the universe, thermodynamics did not emerge as a science until the construction of 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 (formerly

William Thomson). The term thermodynamics was first used in a publication by Lord Kelvin in 1849. The first thermodynamics textbook was written in 1859 by William Rankine, a professor at the University of Glasgow.

It is well-known that a substance consists of a large number of particles called *molecules*. The properties of the substance naturally depend on the behavior of these particles. For example, the pressure of a gas in a container is the result of momentum transfer between the molecules and the walls of the container. However, one does not need to know the behavior of the gas particles to determine the pressure in the container. It would be sufficient to attach a pressure gage to the container. This macroscopic approach to the study of thermodynamics that does not require a knowledge of the behavior of individual particles is called *classical thermodynamics*. It provides a direct and easy way to the solution of engineering problems. A more elaborate approach, based on the average behavior of large groups of individual particles, is called *statistical thermodynamics*.

1.2 Application Areas of Thermodynamics

All activities in nature involve some interaction between energy and matter; thus, it is hard to imagine an area that do not relate to thermodynamics in some manner. Therefore, developing a good understanding of basic principles of thermodynamics has long been an essential part of engineering education.

Thermodynamics is commonly encountered in many engineering systems and other aspects of life, and one does not need to go very far to see some application areas of it. In fact, one does not need to go anywhere. The heart is constantly pumping blood to all parts of the human body, various energy conversions occur in trillions of body cells, and the body heat generated is constantly rejected to the environment. The human comfort is closely tied to the rate of this metabolic heat rejection. We try to control this heat transfer rate by adjusting our clothing to the environmental conditions.

Other applications of thermodynamics are right where one lives. An ordinary house is, in some respects, an exhibition hall filled with wonders of thermodynamics. Many ordinary household utensils and appliances are designed, in whole or in part, by using the principles of thermodynamics. Some examples include the electric or gas range, the heating and air-conditioning systems, the refrigerator, the humidifier, the pressure cooker, the water heater, the shower, the iron, and even the computer and the TV. On a larger scale, thermodynamics plays a major part in the design and analysis of automotive engines, rockets, jet engines, and conventional or nuclear power plants, solar collectors and the design of vehicles from ordinary cars to airplanes. The energy-efficient home that you may be living in, for example, is designed on the basis of minimizing heat loss in winter and heat gain in summer. The size, location, and the power input of the fan of your computer are also selected after all analysis that involves thermodynamics.

1.3 Closed and Open System

A **thermodynamic system**, or simply a **system**, is defined as a quantity matter or a region in space chosen for study. These terms are illustrated in Fig.1-1. 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.

Systems may be considered to be closed or open, depending on whether a fixed mass or a fixed volume in space is chosen for study. A **closed system** (also known as a **control mass**) 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. 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**.

Consider the piston-cylinder device shown in Fig. 1-2. Let us say that we would like to find out what happens to the enclosed gas when it is heated. Since we are focusing our attention on the gas, it is our system. The inner surfaces of the piston and the cylinder form the boundary, and since no mass is crossing this boundary, it is a closed system. Notice that energy may cross the boundary, and part of the boundary (the inner surface of the piston, in this case) may move. Everything outside the gas, including the piston and the cylinder, is the **surroundings**.

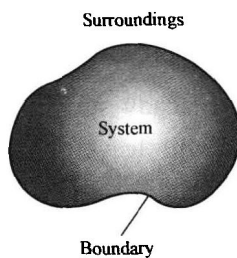


Fig. 1-1 System, surrounding and boundary

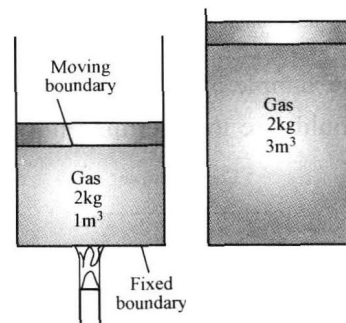


Fig. 1-2 A closed system with a moving boundary

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, a turbine, or a 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.

A large number of engineering problems involve mass flow to and out of a system and, therefore, are modeled as control volumes. A water heater, a car radiator, a turbine, and a compressor all involve mass flow and should be analyzed as control volumes (open systems) instead of as control masses (closed systems). In general, any arbitrary region in space can be

selected as a control volume. There are no concrete rules for the selection of control volumes, but the proper choice certainly makes the analysis much easier. If we were to analyze the flow of air through a nozzle, for example, a good choice for the control volume would be the region within the nozzle.

The boundaries of a control volume are called a **control surface**, and they can be real or imaginary. In the case of a nozzle, the inner surface of the nozzle forms the real part of the boundary, and the entrance and exit areas form the imaginary part, since there are no physical surfaces there [Fig. 1-3(a)].

A control volume can be fixed in size and shape, as in the case of a nozzle, or it may involve a moving boundary, as shown in Fig. 1-3(b). Most control volumes, however, have fixed boundaries and thus do not involve any moving boundaries. A control volume may also involve heat and work interactions just as a closed system, in addition to mass interaction.

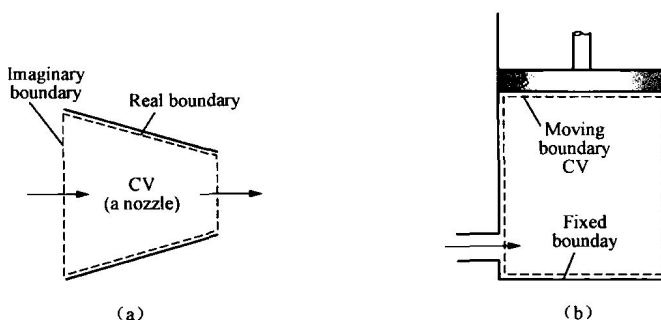


Fig. 1-3 Control volumes involving fixed, moving, real, or imaginary boundaries

(a) A control volume with real and imaginary boundaries; (b) A control volume with fixed and moving boundaries

As an example of all open system, consider the water heater shown in Fig. 1-4. Let us say that we would like to determine how much heat we must transfer to the water in the tank in

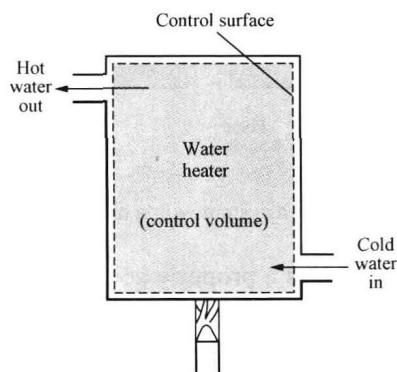


Fig. 1-4 An open system (a control volume) with one inlet and one exit

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 surfaces for this case, and mass is crossing the control surface at two locations.

In all thermodynamic analyses, 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.

1.4 Properties of a System

Any characteristic of a system is called a **property**. Some familiar properties are **pressure** p , **temperature** T , **volume** V , and **mass** m . The list can be extended to include less familiar ones such as **viscosity**, **thermal conductivity**, **modulus of elasticity**, **thermal expansion coefficient**, **electric resistivity**, and even **velocity** and **elevation**.

Not all properties are independent. However, some are defined in terms of other ones. For example, **density** is defined as mass per unit volume.

The density of a substance, in general, depends on temperature and pressure. The density of most gases is proportional to pressure, and inversely proportional to temperature. Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible. At 20°C, for example, the density of water changes from 998 kg/m³ at 1atm to 1003 kg/m³ at 100atm, a change of just 0.5 percent. The density of liquids and solids depends more strongly on temperature than they do on pressure. At 1atm, for example, the density of water changes from 998 kg/m³ at 20°C to 975 kg/m³ at 75°C, a change of 2.3 percent, which can still be neglected in most cases.

Sometimes the density of a substance is given relative to the density of a well-known substance. Then it is called **specific gravity**, or **relative density**, and is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C, for which $\rho_{\text{H}_2\text{O}}=1000\text{kg/m}^3$).

A more frequently used property in thermodynamics is the **specific volume**. It is the reciprocal of density and is defined as the volume per unit mass.

Properties are considered to be either intensive or extensive. **Intensive properties** are those that are independent of the size of a system, such as temperature, pressure, and density. **Extensive properties** are those whose values depend on the size -or extent- of the system. Mass m , volume V and total energy E are some examples of extensive properties. An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with a partition. Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties.

Extensive properties per unit mass are called **specific properties**. Some examples of specific properties are specific volume ($v=V/m$) and specific total energy ($e=E/m$).

1.5 State and Equilibrium

Consider a system not undergoing any change. At this point, all the properties can be measured or calculated throughout the entire system, which gives us a set of properties that

completely describes the condition or the **state** of the system. At a given state, all the properties of a system have fixed values. If the value of even one property changes, the state will change to a different one. In Fig. 1-5 a system is shown at two different states.

Thermodynamics deals with **equilibrium states**. The word **equilibrium** implies a state of balance. In an equilibrium state there are no unbalanced potentials (or driving forces) within the system. A system in equilibrium experiences no changes when it is isolated from its surroundings.

There are many types of equilibrium, and a system is not in thermodynamic equilibrium unless the conditions of all the relevant types of equilibrium are satisfied. For example, a system is in **thermal equilibrium** if the temperature is the same throughout the entire system, as shown in Fig. 1-6. That is, the system involves no temperature differential which is the driving force for heat flow. **Mechanical equilibrium** is related to pressure, and a system is in mechanical equilibrium if there is no change in pressure at any point of the system with time. However, the pressure may vary within the system with elevation as a result of gravitational effects. The higher pressure at a bottom layer is balanced by the extra weight it must carry, and, therefore, there is no imbalance of forces. The variation of pressure as a result of gravity in most thermodynamic systems is relatively small and usually disregarded. If a system involves two phases, it is in **phase equilibrium** when the mass of each phase reaches an equilibrium level and stays there. Finally, a system is in **chemical equilibrium** if its chemical composition does not change with time, that is, no chemical reactions occur. A system will not be in equilibrium unless all the relevant equilibrium criteria are satisfied.

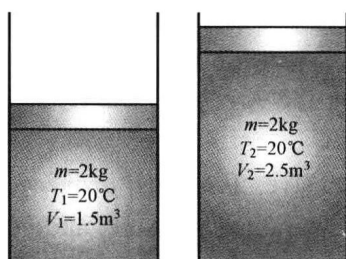


Fig. 1-5 A system at two different states

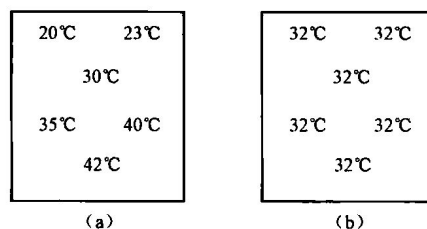


Fig. 1-6 A closed system reaching thermal equilibrium

(a) Before; (b) After

1.6 The State Postulate

As noted earlier, the state of a system is described by its properties. But we know from experience that we do not need to specify all the properties in order to fix a state. Once a sufficient number of properties are specified, the rest of the properties assume certain values automatically. That is, specifying a certain number of properties is sufficient to fix a state. 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.

A system is called a **simple compressible system** in the absence of electrical, magnetic, gravitational, motion, and surface tension effects. These effects are due to external force fields and are negligible for most engineering problems. Otherwise, an additional property needs to be specified for each effect that is significant. If the gravitational effects are to be considered, for example, the elevation z needs to be specified in addition to the two properties necessary to fix the state.

The state postulate requires that the two properties specified be independent to fix the state. Two properties are independent if one property can be varied while the other one is held constant. Temperature and specific volume, for example, are always independent properties, and together they can fix the state of a simple compressible system (shown in Fig. 1-7). Temperature and pressure, however, are independent properties for single-phase systems, but are dependent properties for multiphase systems. At sea level ($p = 1 \text{ atm}$), water boils at 100°C , but on a mountaintop where the pressure is lower, water boils at a lower temperature. That is, $T = f(p)$ during a phase-change process; thus, temperature and pressure are not sufficient to fix the state of a two-phase system.

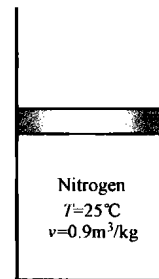


Fig. 1-7 The state of nitrogen fixed by two independent, intensive properties

1.7 Process and Cycle

Any change that a system undergoes from one equilibrium state to another is called a

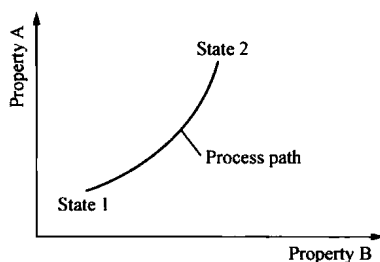


Fig. 1-8 Process path between states 1 and 2

process, and the series of states through which a system passes during a process is called the **path** of the process (shown in Fig. 1-8). To describe a process completely, one should specify the initial and final states of the process, as well as the path it follows, and the interactions with the surroundings.

When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times, it is called a **quasi-static**, or **quasi-equilibrium process**. A quasi-equilibrium process can be viewed as a sufficiently slow process that allows the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts.

When a gas in a piston-cylinder device is compressed suddenly, the molecules near the face of the piston will not have enough time to escape and they will have to pile up in a small region in front of the piston, thus creating a high-pressure region there. Because of this

pressure difference, the system can no longer be said to be in equilibrium, and this makes the entire process non-quasi-equilibrium. However, if the piston is moved slowly, the molecules will have sufficient time to redistribute and there will not be a molecule pileup in front of the piston. As a result, the pressure inside the cylinder will always be uniform and will rise at the same rate at all locations. Since equilibrium is maintained at all times, this is a quasi-equilibrium process.

It should be pointed out that a quasi-equilibrium process is an idealized process and is not a true representation of an actual process. But many actual processes closely approximate it, and they can be modeled as quasi-equilibrium with negligible error. Engineers are interested in quasi-equilibrium processes for two reasons. First, they are easy to analyze; second, work-producing devices deliver the most work when they operate on quasi-equilibrium processes.

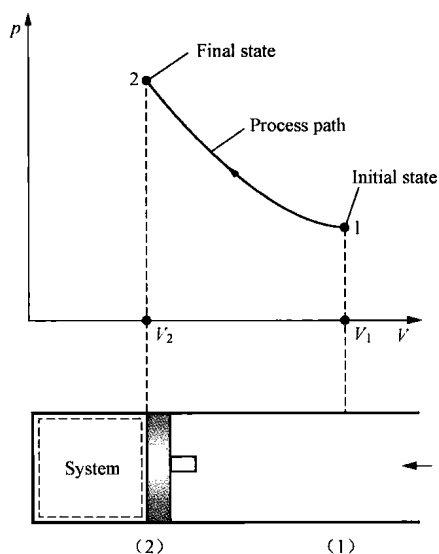


Fig. 1-9 The p - V diagram of a compression process of a gas

Therefore, quasi-equilibrium processes serve as standards to which actual processes can be compared.

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). Fig. 1-9 shows the p - V diagram of a compression process of a gas.

The prefix *iso-* is often used to designate a process for which a particular property remains constant. An **isothermal process**, for example, is a process during which the temperature T remains constant; an **isobaric process** is a process during which the pressure p remains constant; and an **isochoric** (or **isometric**) process is a process during which the specific volume v remains constant.

A system is said to have undergone a cycle if it returns to its initial state at the end of the process. That is, for a cycle the initial and final states are identical.

1.8 The Steady-flow Process

The terms **steady** and **uniform** are used frequently in engineering, and thus it is important to have a clear understanding of their meanings. The term steady implies no change with time. The opposite of steady is **unsteady**, or **transient**. The term uniform, however, implies no change with location over a specified region. These meanings are consistent with their everyday use (steady girl-friend, uniform properties, etc.).

A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as **steady-flow devices**. Processes involving such devices

can be represented reasonably well by a somewhat idealized process, called the **steady-flow process**, which can be defined as a process during which a fluid flows through a control volume steadily. That is, the fluid properties can change from point to point within the control volume, but at any fixed point they remain the same during the entire process. Therefore the volume V , the mass m , and the total energy content E of the control volume remain constant during a steady-flow process (Fig. 1-10).

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. Some cyclic devices, such as reciprocating engines or compressors, do not satisfy any of the conditions stated above since the flow at the inlets and the exits will be pulsating and not steady. However, the fluid properties vary with time in a periodic manner, and the flow through these devices can still be analyzed as a steady-flow process by using time-averaged values for the properties.

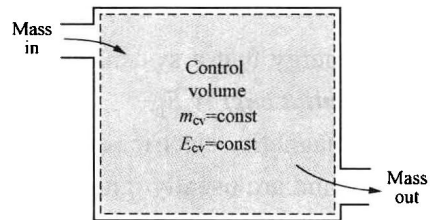


Fig. 1-10 The mass and energy contents of a control volume under steady-flow conditions

1.9 Forms of Energy

Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear, and their sum constitutes the **total energy** E of a system.

Thermodynamics provides no information about the absolute value of the total energy. It only deals with the change of the total energy, which is what matters in engineering problems. Thus the total energy of a system can be assigned a value of zero ($E=0$) at some convenient reference point. The change in total energy of a system is independent of the reference point selected. The decrease in the potential energy of a falling rock, for example, depends on only the elevation difference and not the reference level selected.

In thermodynamic analysis, it is often helpful to consider the various forms of energy that make up the total energy of a system in two groups: **macroscopic** and **microscopic**. The macroscopic forms of energy are those a system possesses as a whole with respect to some outside reference frame, such as **kinetic** and **potential** energies. The microscopic forms of energy are those related to the molecular structure of a system and the degree of the molecular activity, and they are independent of outside reference frames. The sum of all the microscopic forms of energy is called the **internal energy** of a system and is denoted by U .

The term energy was coined in 1807 by Thomas Young, and its use in thermodynamics was proposed in 1852 by Lord Kelvin. The term internal energy and its symbol U first appeared in the works of Rudolph Clausius and William Rankine in the second half of the

nineteenth century, and it eventually replaced the alternative terms inner work, internal work, and intrinsic energy commonly used at the time.

The macroscopic energy of a system is related to motion and the influence of some external effects such as gravity, magnetism, electricity, and surface tension. The energy that a system possesses as a result of its motion relative to some reference frame is called **kinetic energy** E_k .

The energy that a system possesses as a result of its elevation in a gravitational field is called **potential energy** E_p .

The magnetic, electric, and surface tension effects are significant in some specialized cases only and are usually ignored. In the absence of such effects, the total energy of a system consists of the kinetic, potential, and internal energies and is expressed as

$$E = U + E_k + E_p = U + \frac{mv^2}{2} + mgz \quad \text{kJ} \quad (1-2)$$

Most closed systems remain stationary during a process and thus experience no change in their kinetic and potential energies. Closed systems whose velocity and elevation of the center of gravity remain constant during a process are frequently referred to as **stationary systems**. The change in the total energy ΔE of a stationary system is identical to the change in its internal energy ΔU .

1.10 The First Law of Thermodynamics

So far, we have considered various forms of energy such as heat Q , work W and total energy E individually, and no attempt has been made to relate them to each other during a process. The first law of thermodynamics, also known as the conservation of energy principle, provides a sound basis for studying the relationships among the various forms of energy and energy interactions. Based on experimental observations, the first law of thermodynamics

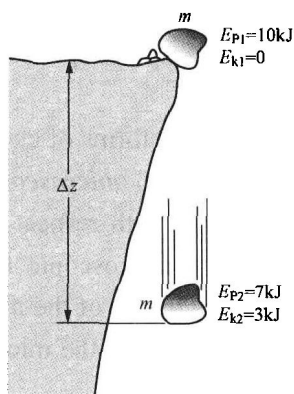


Fig. 1-11 Energy cannot be created or destroyed, it can only change forms

states that energy can be neither created nor destroyed; it can only change forms. Therefore, every bit of energy should be accounted for during a process.

We all know that a rock at some elevation possesses some potential energy and part of this potential energy is converted to kinetic energy as the rock falls (shown in Fig. 1-11). Experimental data show that the decrease in potential energy ($mg\Delta z$) exactly equals the increase in kinetic energy $[m(v_2^2 - v_1^2)/2]$ when the air resistance is negligible, thus confirming the conservation of energy principle.

Consider a system undergoing a series of **adiabatic** processes from a specified state 1 to