Chapter 2

Energy and the
First Law of Thermodynamics
Part 1

Learning Outcomes

- Demonstrate understanding of key concepts related to energy and the first law of thermodynamics. . . including internal, kinetic, and potential energy, work and power, heat transfer and heat transfer modes, heat transfer rate, power cycle, refrigeration cycle, and heat pump cycle.

Learning Outcomes, cont.

- ►Apply closed system energy balances, appropriately modeling the case at hand, and correctly observing sign conventions for work and heat transfer.

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- ►Apply closed system energy balances, appropriately modeling the case at hand, and correctly observing sign conventions for work and heat transfer.
- ►Conduct energy analyses of systems undergoing thermodynamic cycles, evaluating as appropriate thermal efficiencies of power cycles and coefficients of performance of refrigeration and heat pump cycles.

Closed System Energy Balance

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► For closed systems, energy is transferred in and out across the system boundary by two means only: by work and by heat.

► Energy is conserved. This is the first law of thermodynamics.

Closed System Energy Balance

- The closed system energy balance states:

$$\left[\begin{array}{c}\text{The } \textit{change} \text{ in the} \\ \text{amount of energy} \\ \text{contained within} \\ \text{a closed system} \\ \text{during some time} \\ \text{interval}\end{array}\right] = \left[\begin{array}{c}\textit{Net} \text{ amount of energy} \\ \text{transferred in and out} \\ \text{across the system boundary} \\ \text{by heat and work during} \\ \text{the time interval}\end{array}\right]$$

- We now consider several aspects of the energy balance, including what is meant by energy change and energy transfer.

Change in Energy of a System

In engineering thermodynamics the change in energy of a system is composed of three contributions:

- ►Kinetic energy
- ►Gravitational potential energy
- ►Internal energy

Change in Kinetic Energy

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- For a system of mass $\boldsymbol{m}$ the change in kinetic energy from state 1 to state 2 is

$$\Delta KE = KE_2 - KE_1 = \frac{1}{2} m \left(V_2^2 - V_1^2 \right) \qquad \textbf{(Eq. 2.5)}$$

where

- V_1 and V_2 denote the velocities at their respective states.
- The symbol Δ denotes: final value minus initial value.

Change in Gravitational Potential Energy

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- ►The change in gravitational potential energy is associated with the position of the system in the earth's gravitational field.
- ►For a system of mass ***m*** the change in potential energy from state 1 to state 2 is

$$\Delta \mathrm{PE} = \mathrm{PE}_2 - \mathrm{PE}_1 = mg(z_2 - z_1) \qquad \textbf{(Eq. 2.10)}$$

where

►z_1 and z_2 denote the elevations relative to the surface of the earth at states 1 and 2, respectively.

►g is the acceleration of gravity.

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- There is no simple expression comparable to Eqs. 2.5 and 2.10 for evaluating internal energy change for a wide range of applications. In most cases we will evaluate internal energy change using data from tables in appendices of the textbook.
- Like kinetic and gravitational potential energy, internal energy is an extensive property.
  - Internal energy is represented by U.
  - The specific internal energy on a mass basis is u.
  - The specific internal energy on a molar basis is $\bar{u}$.

Change in Energy of a System

►In summary, the change in energy of a system from state 1 to state 2 is

$$E_2 - E_1 = (U_2 - U_1) + (\mathrm{KE}_2 - \mathrm{KE}_1) + (\mathrm{PE}_2 - \mathrm{PE}_1)$$

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$$\Delta E = \Delta U + \Delta \mathrm{KE} + \Delta \mathrm{PE}$$ **(Eq. 2.27b)**

►It is frequently the *changes* in the *energy* of a system between states that have significance.

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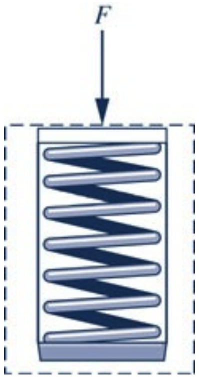
- You have studied work in mechanics and those concepts are retained in the study of thermodynamics.

Illustrations of Work

►When a spring is compressed, energy is transferred to the spring by work.



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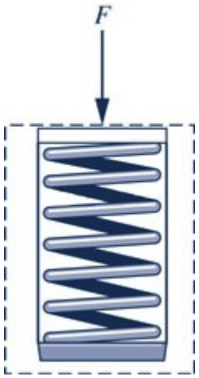
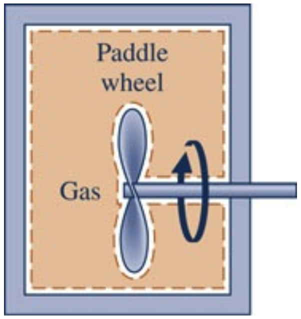


►When a spring is compressed, energy is transferred to the spring by work.

►When a gas in a closed vessel is stirred, energy is transferred to the gas by work.



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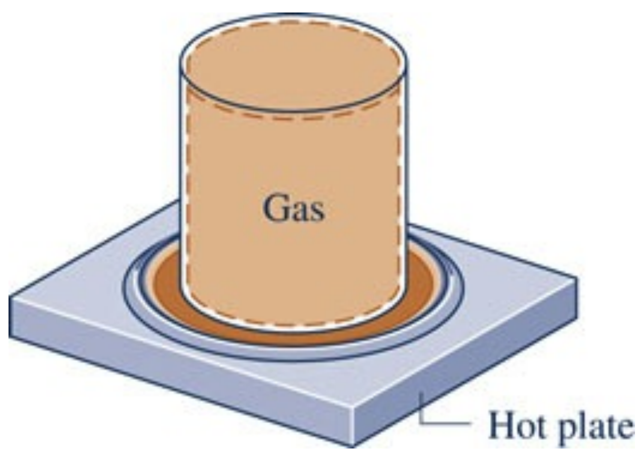
► Since engineering thermodynamics is often concerned with internal combustion engines, turbines, and electric generators whose purpose is to do work, it is convenient to regard the work done by a system as positive.

- ► W **> 0**: work ***done by*** the system
- ► W **< 0**: work ***done on*** the system

The same sign convention is used for the rate of energy transfer by work (power!), denoted by $\dot{W}$.

Energy Transfer by Heat

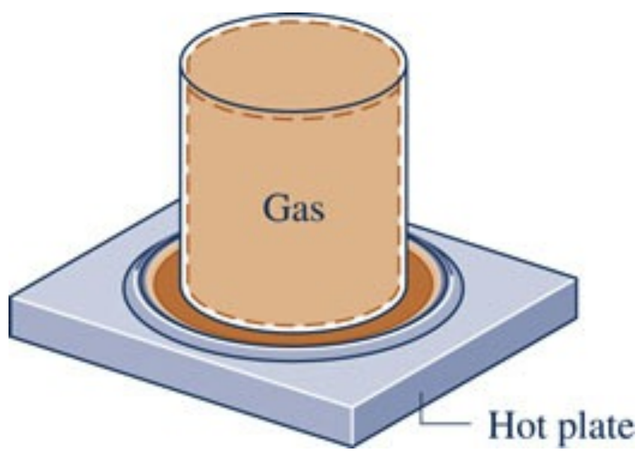
►Energy transfers by heat are induced only as a result of a temperature difference between the system and its surroundings.



Energy Transfer by Heat

► Energy transfers by heat are induced only as a result of a temperature difference between the system and its surroundings.

► Net energy transfer by heat occurs only in the direction of decreasing temperature.



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►If a system undergoes a process involving no heat transfer with its surroundings, that process is called *adiabatic*.

Summary: Closed System Energy Balance

► The energy concepts introduced thus far are summarized in words as follows:

$$\begin{bmatrix} \textit{change} \text{ in the amount} \\ \text{of energy contained} \\ \text{within a system} \\ \text{during some time} \\ \text{interval} \end{bmatrix} = \begin{bmatrix} \textit{net} \text{ amount of energy} \\ \text{transferred } \textit{in} \text{ across} \\ \text{the system boundary by} \\ \textit{heat transfer} \text{ during} \\ \text{the time interval} \end{bmatrix} - \begin{bmatrix} \textit{net} \text{ amount of energy} \\ \text{transferred } \textit{out} \text{ across} \\ \text{the system boundary} \\ \text{by } \textit{work} \text{ during the} \\ \text{time interval} \end{bmatrix}$$

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► Using previously defined symbols, this can be expressed as: $E_2 - E_1 = Q - W$ **(Eq. 2.35a)**

► Alternatively, $\Delta \mathrm{KE} + \Delta \mathrm{PE} + \Delta U = Q - W$ **(Eq. 2.35b)**

In Eqs. 2.35, a **minus sign** appears **before** W because energy transfer by work from the system to the surrounding is taken as positive.

Summary: Closed System Energy Balance

► The time rate form of the closed system energy balance is

$$\frac{dE}{dt} = \dot{Q} - \dot{W}$$

(Eq. 2.37)

► The rate form expressed in words is

$$\left[\begin{array}{c}\text{time } \textit{rate of change} \\ \text{of the energy} \\ \text{contained within} \\ \text{the system } \textit{at} \\ \textit{time } t\end{array}\right] = \left[\begin{array}{c}\text{net } \textit{rate} \text{ at which} \\ \text{energy is being} \\ \text{transferred in} \\ \text{by heat transfer} \\ \textit{at time } t\end{array}\right] - \left[\begin{array}{c}\text{net } \textit{rate} \text{ at which} \\ \text{energy is being} \\ \text{transferred out} \\ \text{by work } \textit{at} \\ \textit{time } t\end{array}\right]$$