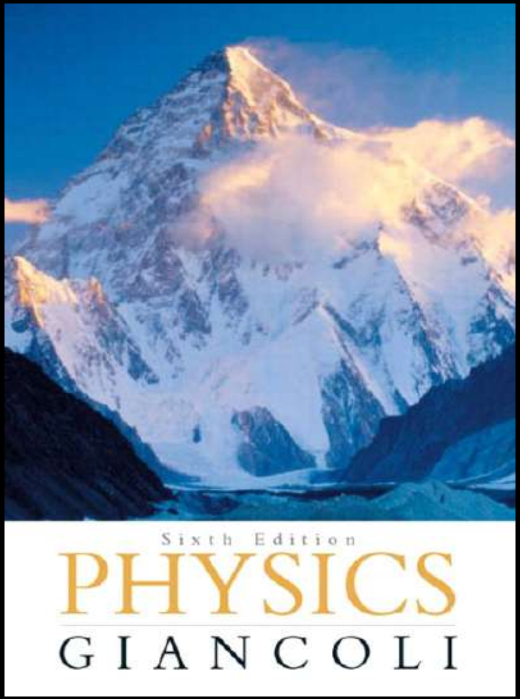


Lecture PowerPoints

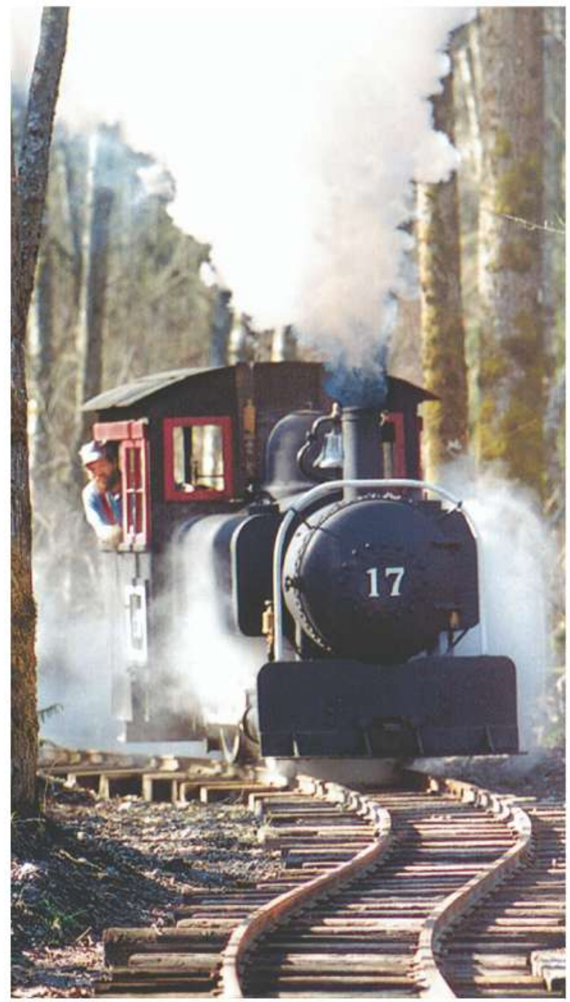
Chapter 15

Physics: Principles with Applications, 6th edition

Giancoli

Chapter 15

The Laws of Thermodynamics



15-1 The First Law of Thermodynamics

The change in internal energy of a closed system will be equal to the heat added to the system minus the work done by the system on its surroundings.

$$\Delta U = Q - W \qquad (15\text{-}1)$$

($\Delta U = Q + W$ *on formula sheet*)

This is the law of conservation of energy, written in a form useful to systems involving heat transfer.

15-1 The First Law of Thermodynamics

- If work is done **on** the system, W is negative and the internal energy increases.
- If Heat leaves the system, Q is negative and the internal energy decreases.
- If the system is isolated, $\Delta U = 0$.

15-1 The First Law of Thermodynamics

An amount of heat equal to 2500 J is added to a system, and 1800 J of work is done on the system. What is the change in internal energy of the system?

$$Q = +2500\ J \qquad W = -1800\ J$$

$$\Delta U = Q - W = +2500 - (-1800) = 4300\ J$$

15-1 The First Law of Thermodynamics

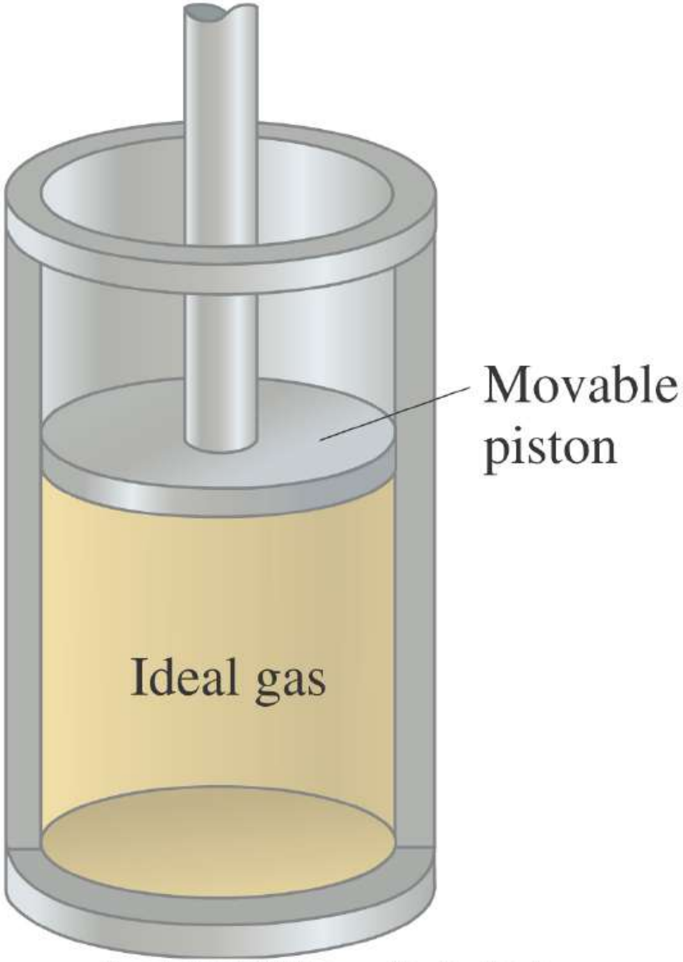
What would be the internal energy change if 2500 J of heat is added to the system and 1800 J of work is done *by* the system (i.e. as output)?

$$Q = +2500\ J \qquad W = +1800\ J$$

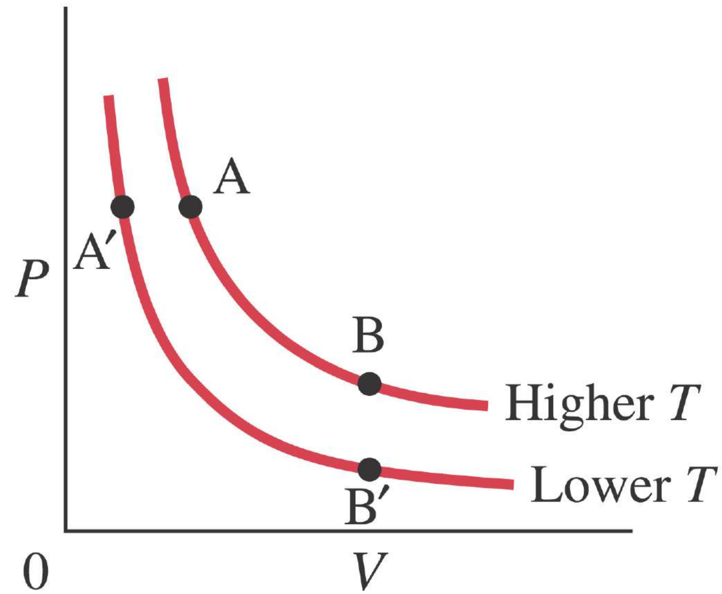
$$\Delta U = Q - W = +2500 - (+1800) = 700\ J$$

A 3.0 g bullet traveling at a speed of 400. m/s enters a tree and exits the other side with a speed of 200. m/s. Where did the bullet's lost KE go, and how much energy was transferred?

15-2 Thermodynamic Processes and the First Law



An **isothermal** process is one where the **temperature** does not change.



15-2 Thermodynamic Processes and the First Law

Isothermal process

- *$PV = nRT$, so PV = constant*
- *If T = constant then $\Delta U = 0$*

(since $U = 3/2\ nRT$)

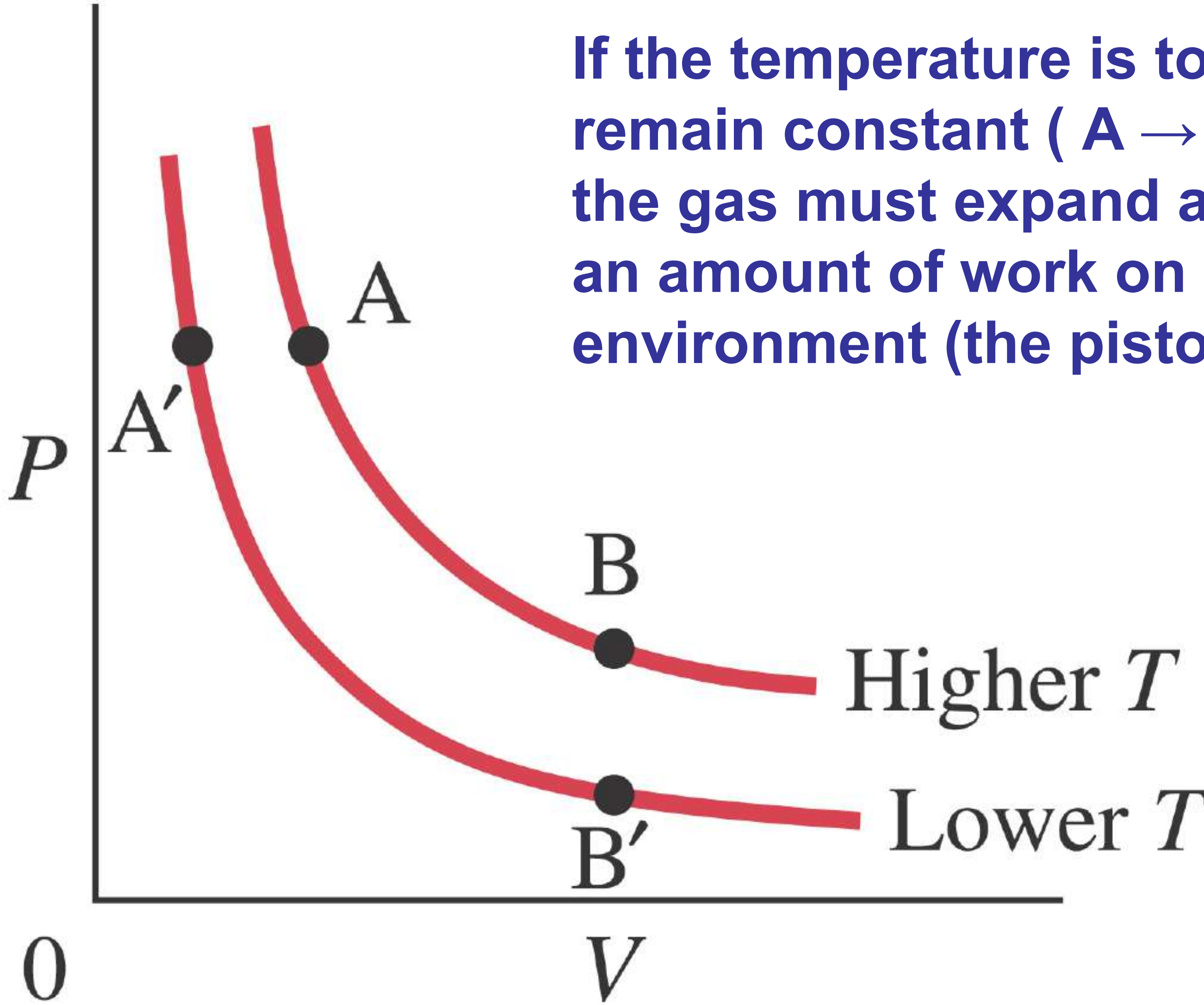
- *$\Delta U = Q - W$ becomes $Q = W$*
- *The heat added to the gas = The work done by the gas.*

15-2 Thermodynamic Processes and the First Law

In order for an isothermal process to take place, we assume the system is in contact with a **heat reservoir** – a body whose mass is so large that its temperature does not change significantly when heat is exchanged with our system.

In general, we assume that the system remains in **equilibrium** throughout all processes.

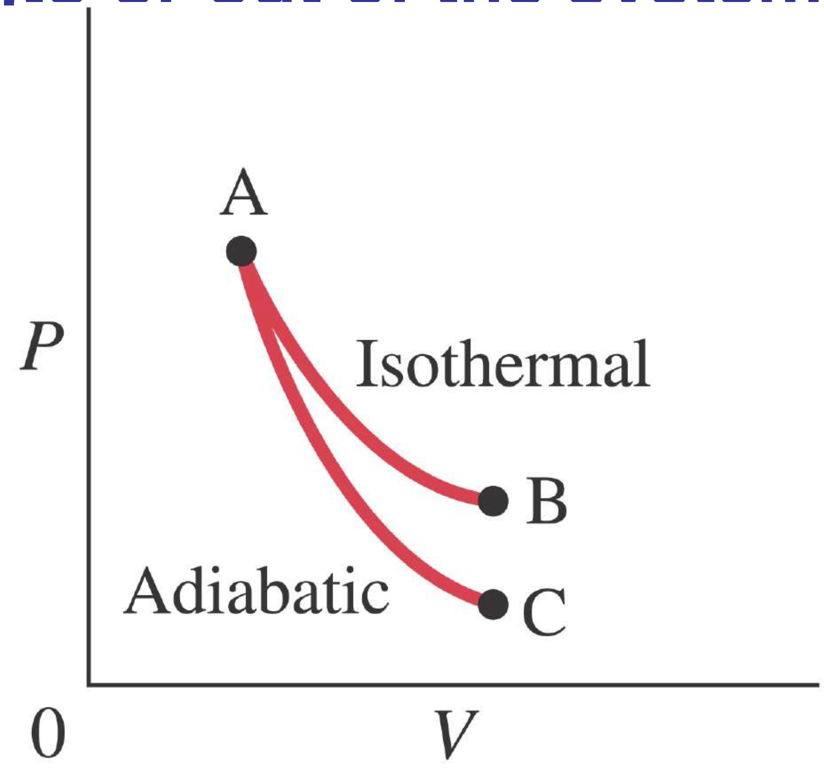
PV diagram for an ideal gas undergoing isothermal processes at two different temperatures.



If the temperature is to remain constant (A → B), the gas must expand and do an amount of work on the environment (the piston).

15-2 Thermodynamic Processes and the First Law

An adiabatic process is one where there is no **heat flow** into or out of the system (A → C).

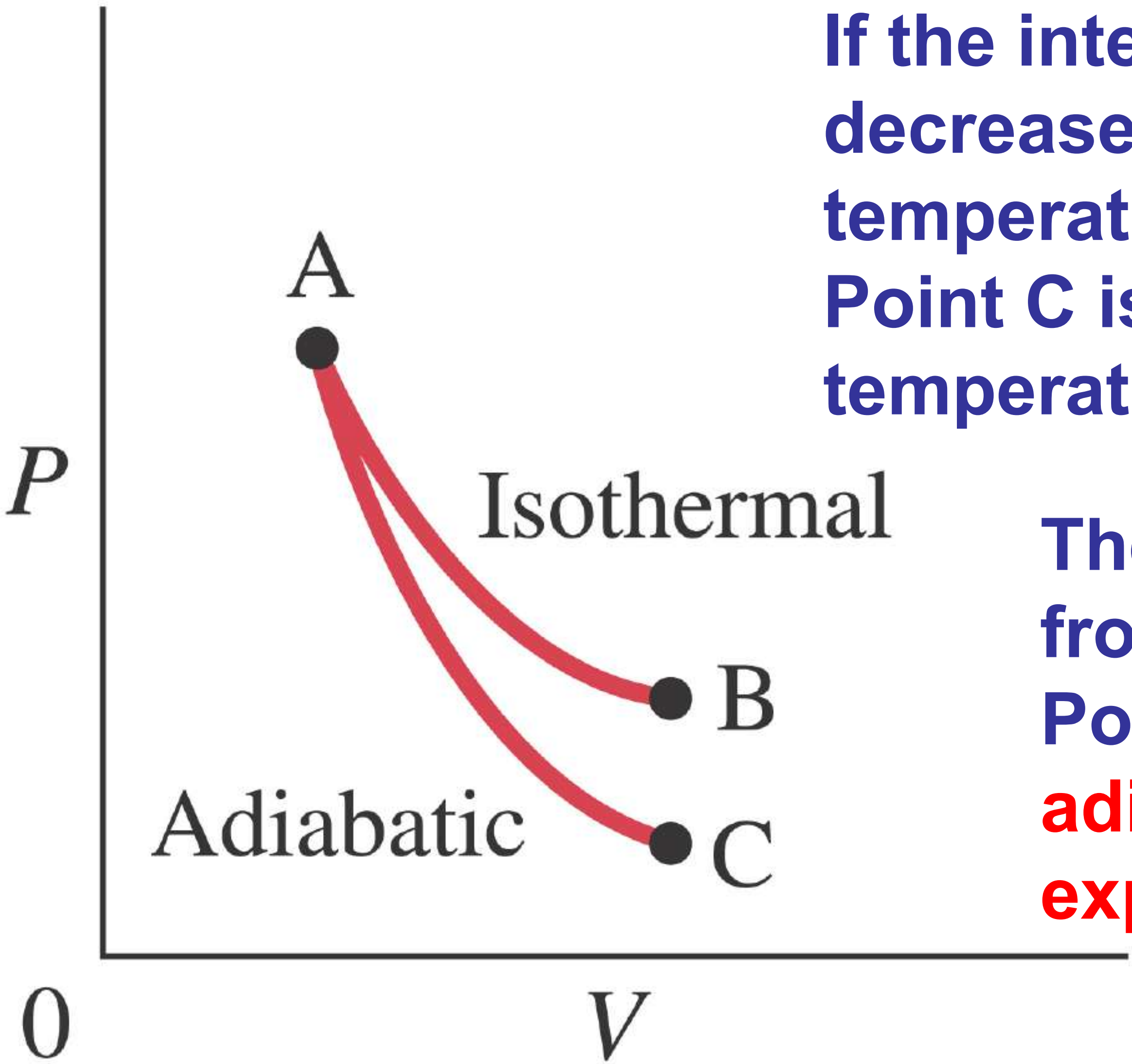


15-2 Thermodynamic Processes and the First Law

Adiabatic process

- *$Q = 0$ so $\Delta U = - W$*
- *The internal energy decreases if system does work, such as when the gas expands the piston in a cylinder.*
- *An adiabatic process can happen if the system is well-insulated or if the process happens very quickly.*

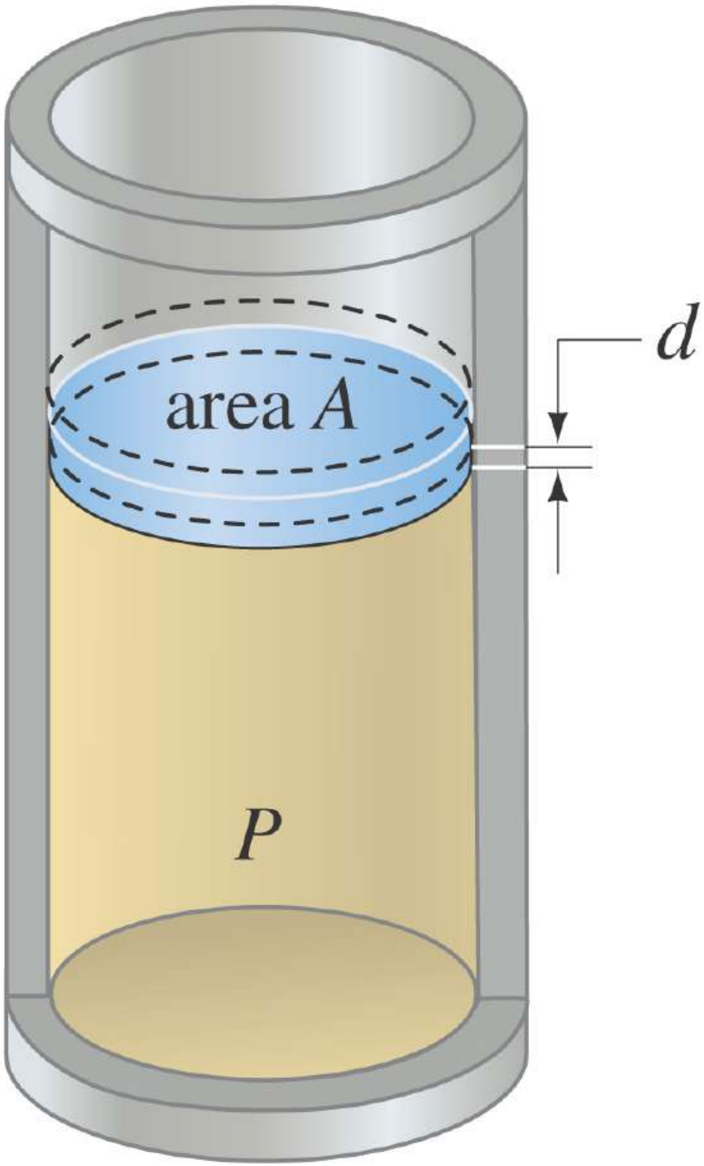
PV diagram for adiabatic (AC) and isothermal (AB) processes on an ideal gas.



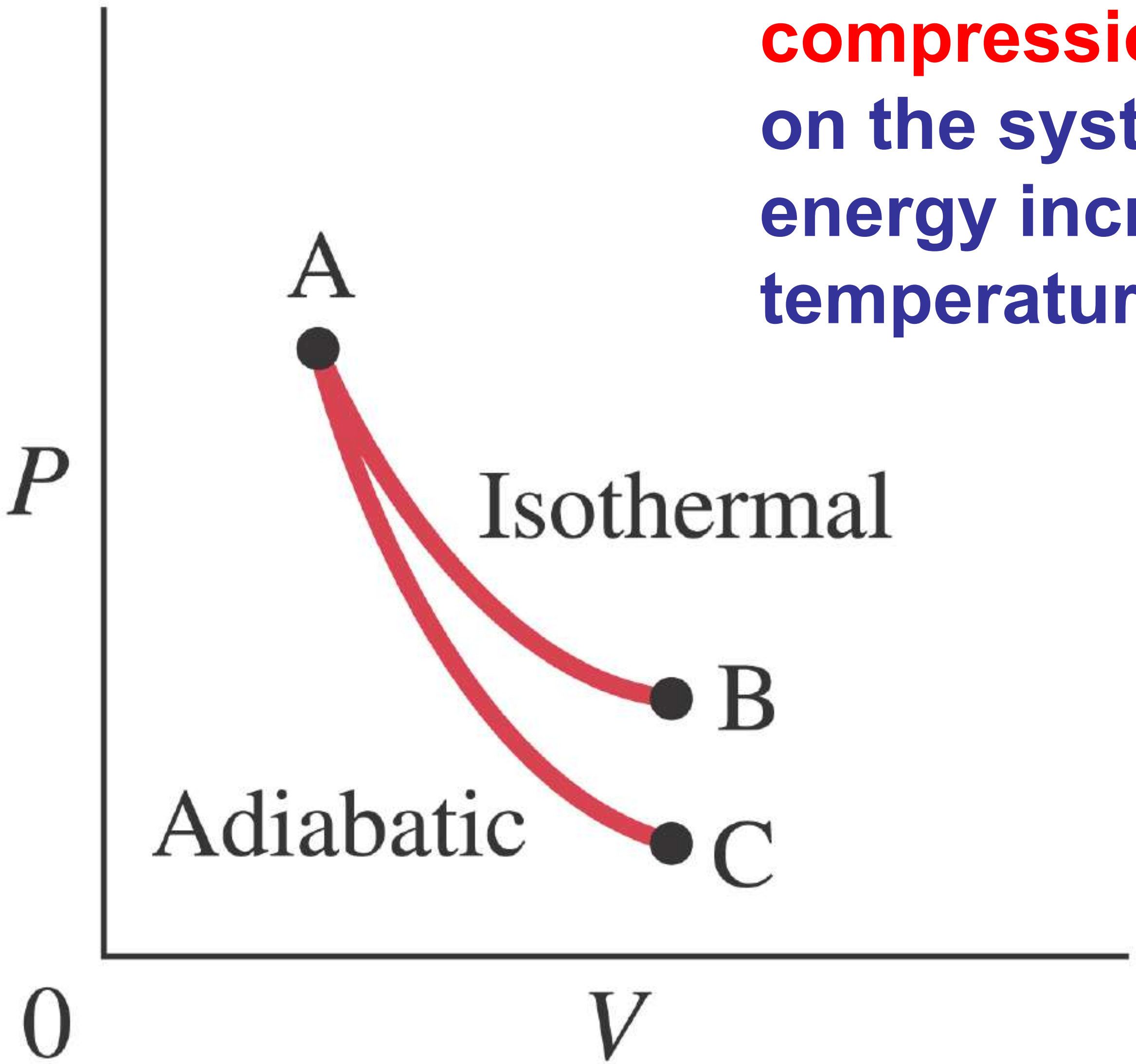
If the internal energy decreases, the temperature decreases. Point C is at a lower temperature than point A.

The process from Point A to Point C is called **adiabatic expansion**.

Work is done on the piston when the gas expands, moving the piston a distance d.

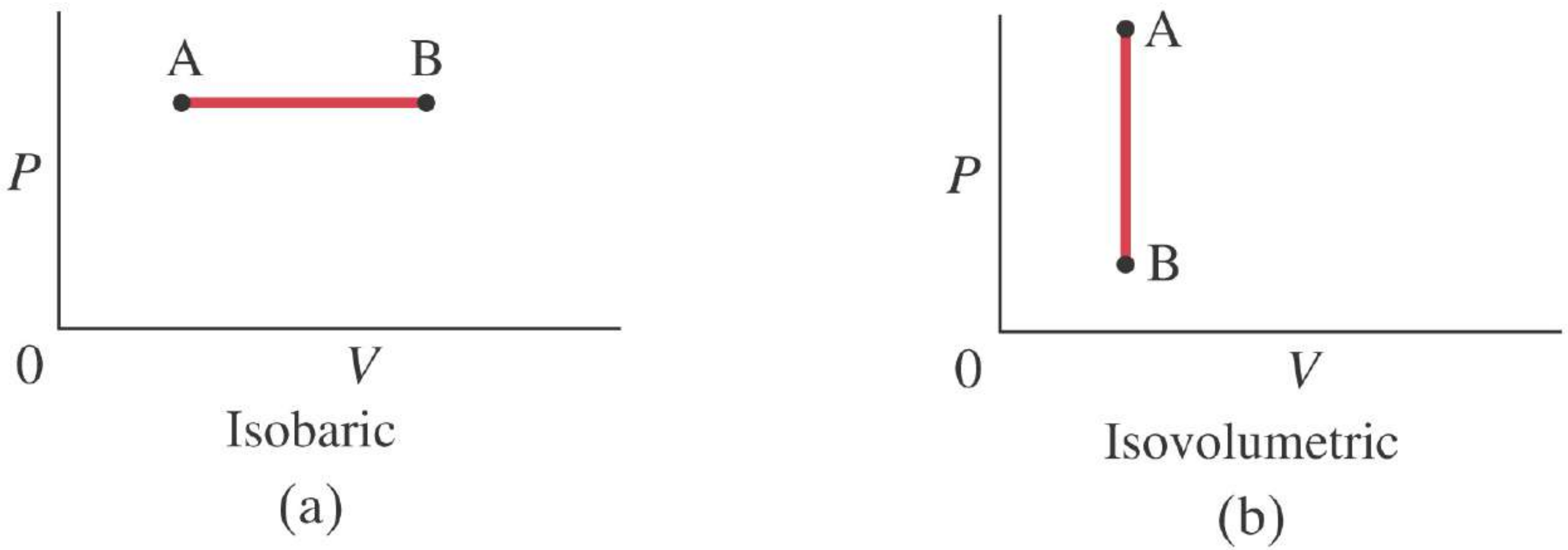


The process from Point C to Point A is called **adiabatic compression**. Work is done on the system, the internal energy increases, and the temperature increases.



15-2 Thermodynamic Processes and the First Law

An **isobaric** process (a) occurs at constant pressure; an **isovolumetric** (or isochoric) one (b) at constant volume.



15-2 Thermodynamic Processes and the First Law

If the **pressure** is constant, $W = Fd$ *and* $F = PA$ so the **work** done is the pressure multiplied by the change in volume ($W = PAd$)

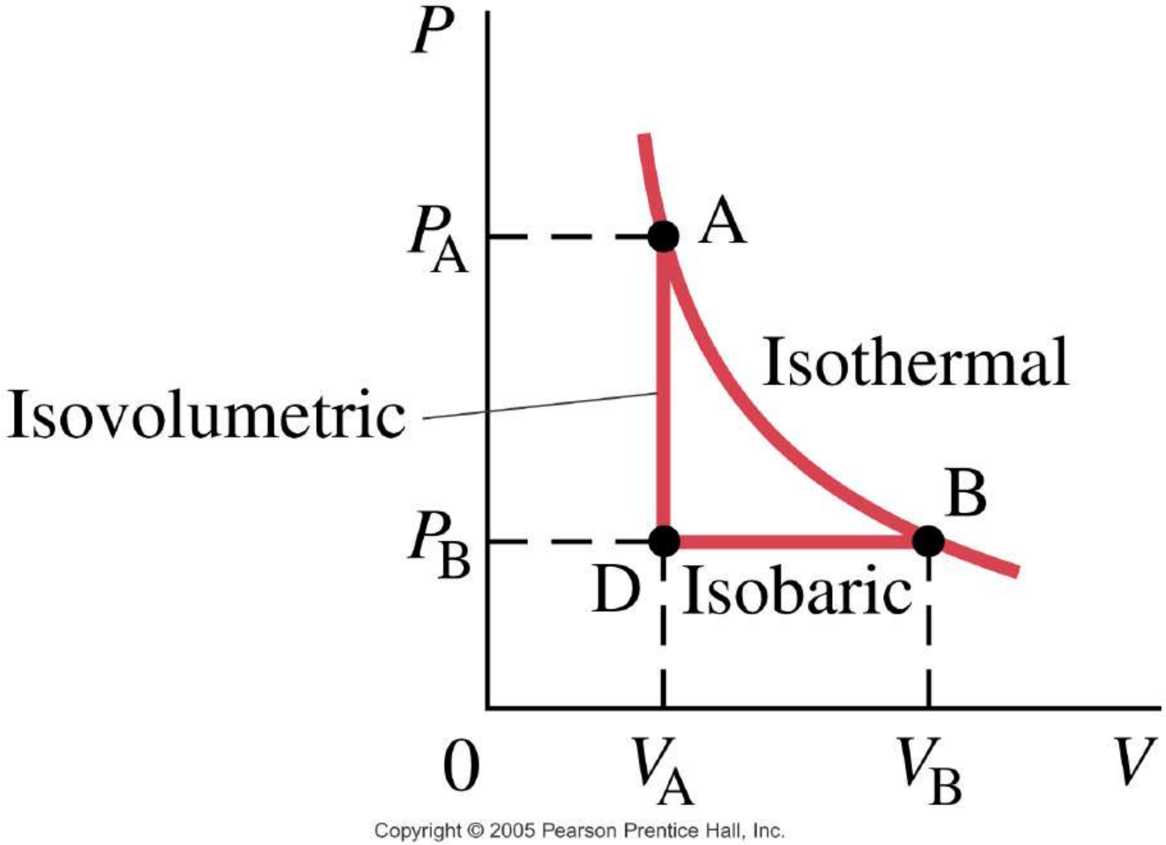
$$W = P\,\Delta V$$

($W = -P\,\Delta V$ on formula sheet)

In an **isovolumetric** process, the volume does not change, so the work done is **zero**.

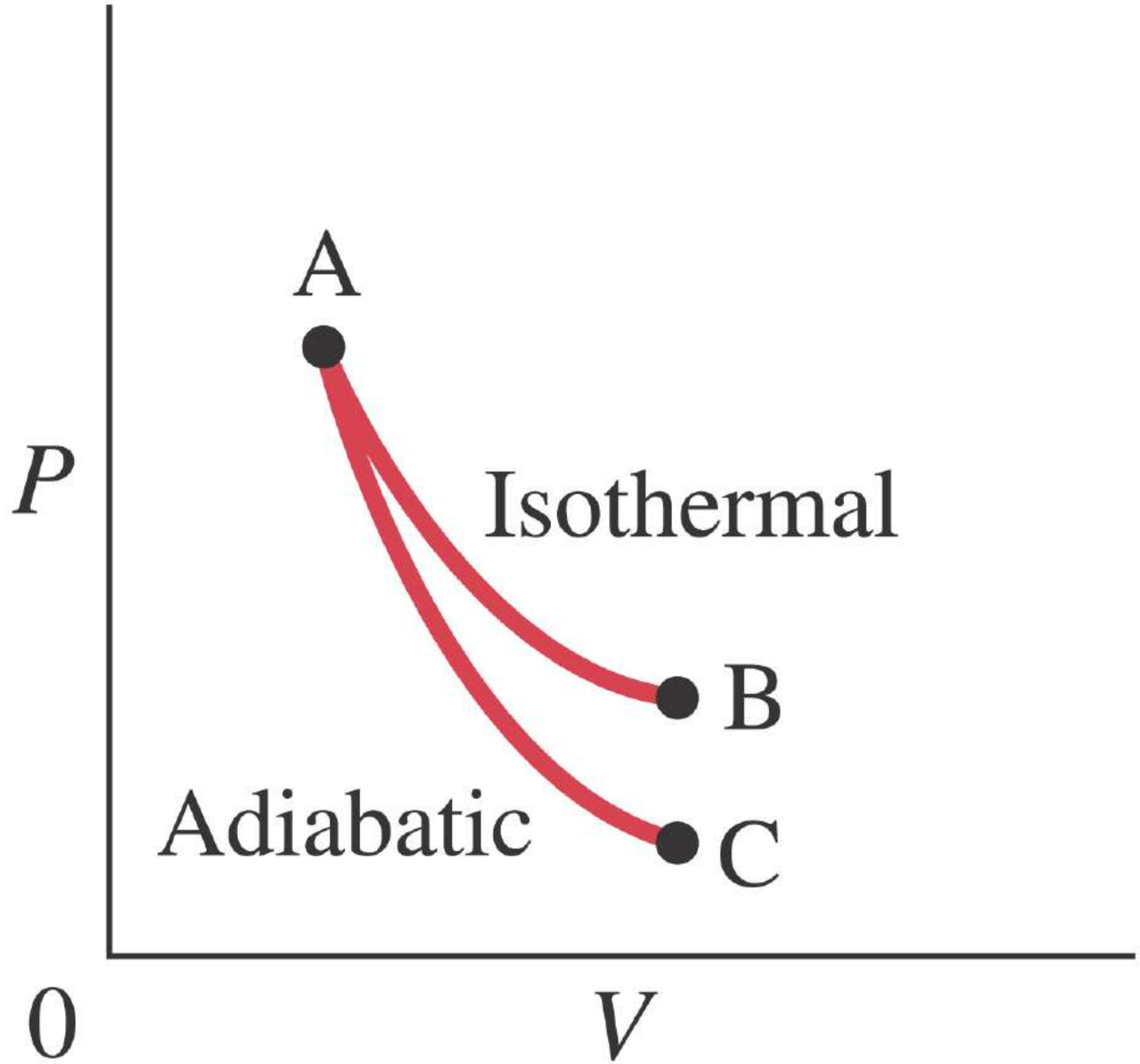
15-2 Thermodynamic Processes and the First Law

For processes where the pressure varies, the work done is the area under the P-V curve.

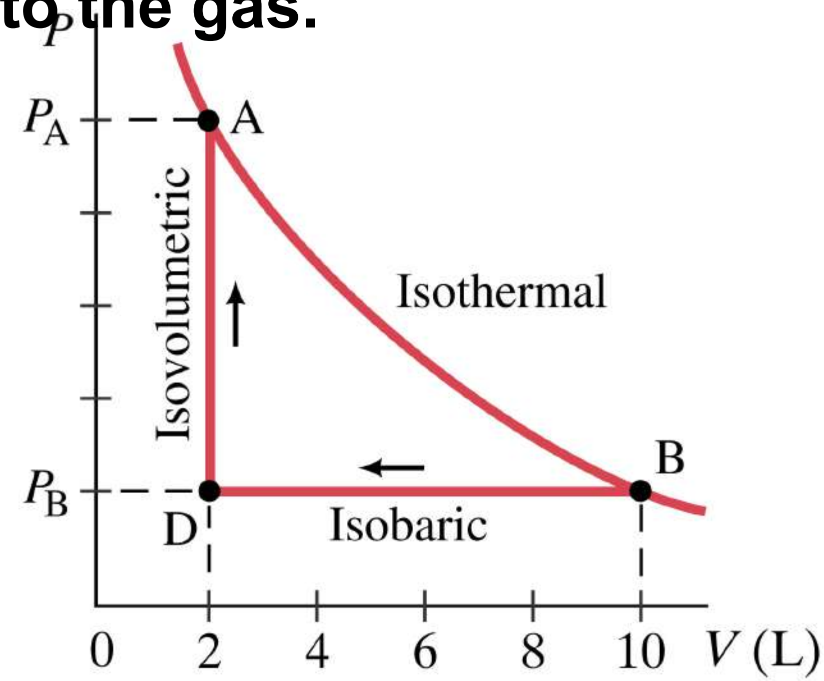


For an isothermal process, estimate the area or use calculus.

In which process was more work done by the gas?



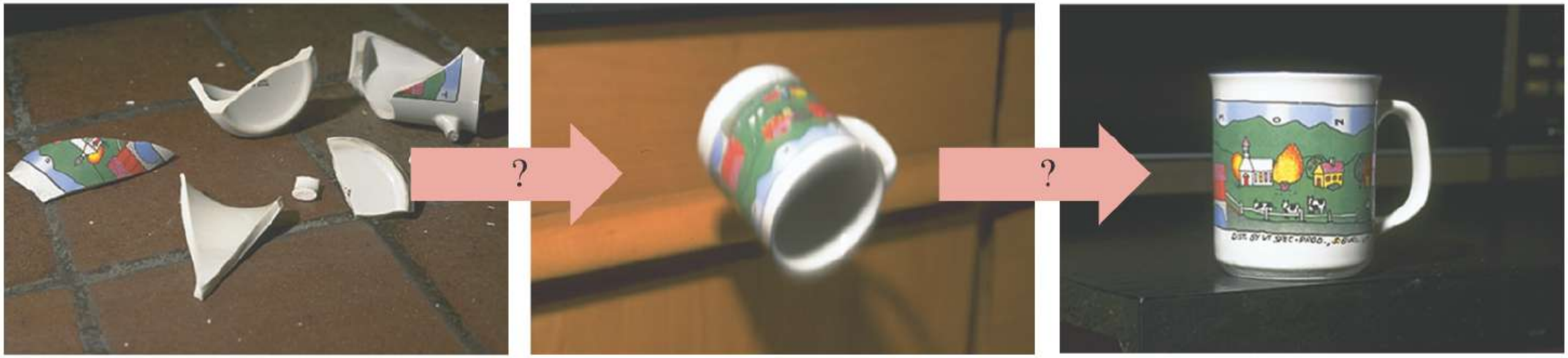
An ideal gas is slowly compressed at a constant pressure of 2.0 atm from 10.0 L to 2.0 L as shown below from B to D. In this process, some heat flows out of the gas and the temperature goes __________.
Heat is then added to the gas, holding the volume constant, and the pressure and temperature are allowed to rise (line DA) until the temperature reaches its initial value. Calculate the total work done by the gas in the process BDA and the total heat flow into the gas.



In an engine, 0.25 moles of an ideal monatomic gas in the cylinder expands rapidly and adiabatically against the piston. In the process, the temperature of the gas drops from 1150 K to 400 K. How much work does the gas do?

Determine the change in internal energy of 1.00 L of water at 100.°C when it is fully boiled from liquid to gas, which results in 1671 L of steam at 100.°C. (Assume atmospheric pressure)

15-4 The Second Law of Thermodynamics – Introduction



(a) Initial state.

(b) Later: cup reassembles and rises up.

(c) Later still: cup lands on table.

The process above does not violate the first law of thermodynamics and the law of conservation of energy. Since this process does not occur in nature, the second law of thermodynamics was formulated.

15-4 The Second Law of Thermodynamics – Introduction

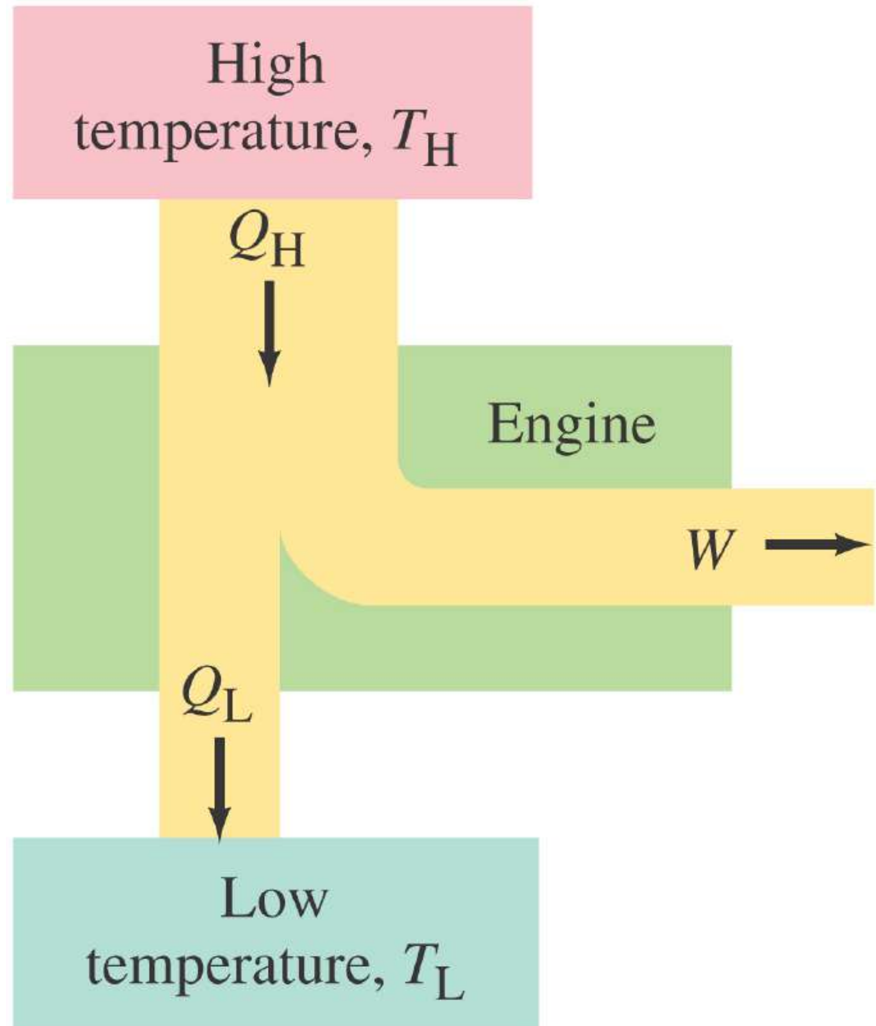
The **second law of thermodynamics** is a statement about which processes occur and which do not. There are many ways to state the second law; here is one:

Heat can flow spontaneously from a hot object to a cold object; it will not flow spontaneously from a cold object to a hot object.

15-5 Heat Engines

It is easy to produce **thermal energy** using work, but how does one produce **work** using thermal energy?

This is a **heat engine**; mechanical energy can be obtained from thermal energy only when heat can **flow** from a **higher** temperature to a **lower** temperature.



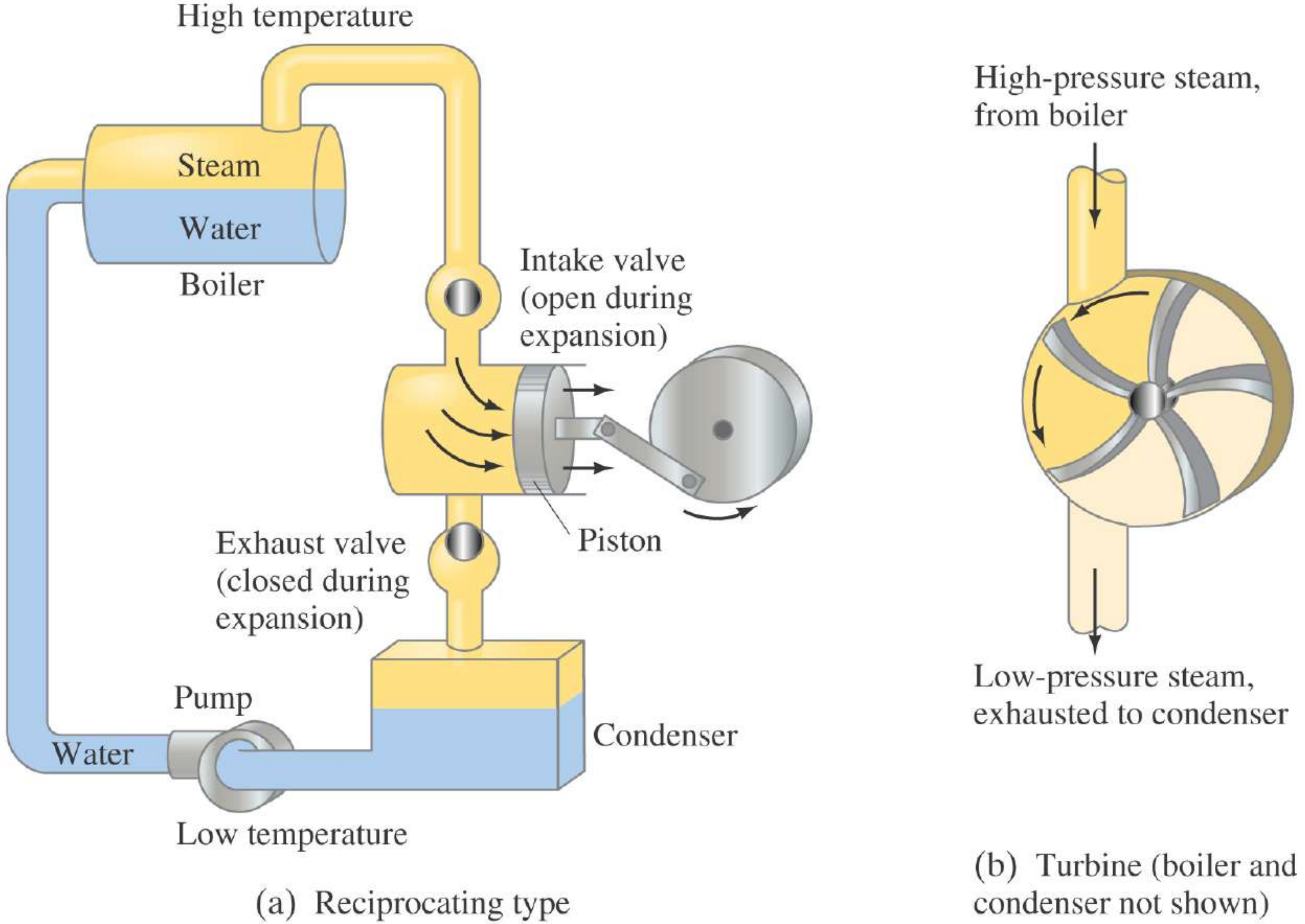
15-5 Heat Engines

We will discuss only engines that run in a **repeating** cycle; the change in internal energy over a cycle is **zero**, as the system returns to its initial state.

The **high** temperature reservoir transfers an amount of heat Q_H to the engine, where part of it is transformed into work W and the rest, Q_L, is exhausted to the **lower** temperature reservoir. Note that all three of these quantities are positive.

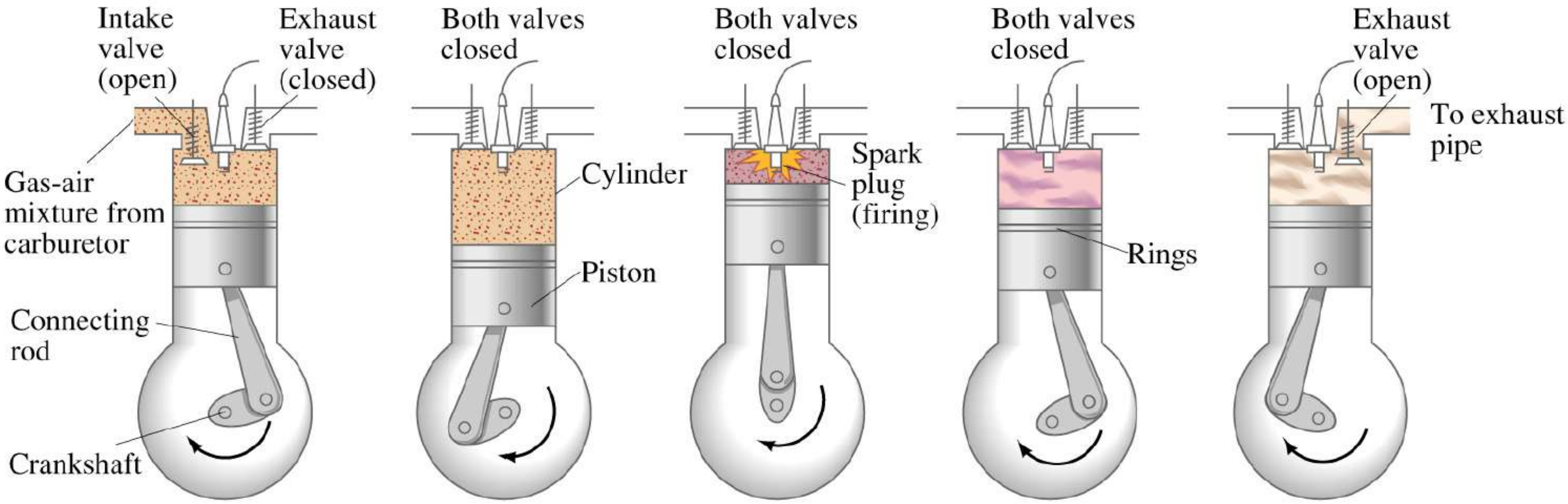
15-5 Heat Engines

A **steam** engine is one type of heat engine.



15-5 Heat Engines

The **internal combustion** engine is a type of heat engine as well.



(a) Intake (b) Compression (c) Ignition (d) Expansion (power stroke) (e) Exhaust

15-5 Heat Engines

Why does a heat engine need a temperature difference?

Otherwise the work done on the system in one part of the cycle will be equal to the work done by the system in another part, and the net work will be zero.

15-5 Heat Engines

The **efficiency** of the heat engine is the ratio of the **work done** to the **heat input (or Q_H)**:

$$e = \frac{W}{Q_{\mathrm{H}}}$$

(on formula sheet)

Using conservation of energy to eliminate W, we find:

$$e = \frac{W}{Q_{\mathrm{H}}} \qquad \text{(15-4a)}$$

$$= \frac{Q_{\mathrm{H}} - Q_{\mathrm{L}}}{Q_{\mathrm{H}}} = 1 - \frac{Q_{\mathrm{L}}}{Q_{\mathrm{H}}} \qquad \text{(15-4b)}$$

15-5 Heat Engines

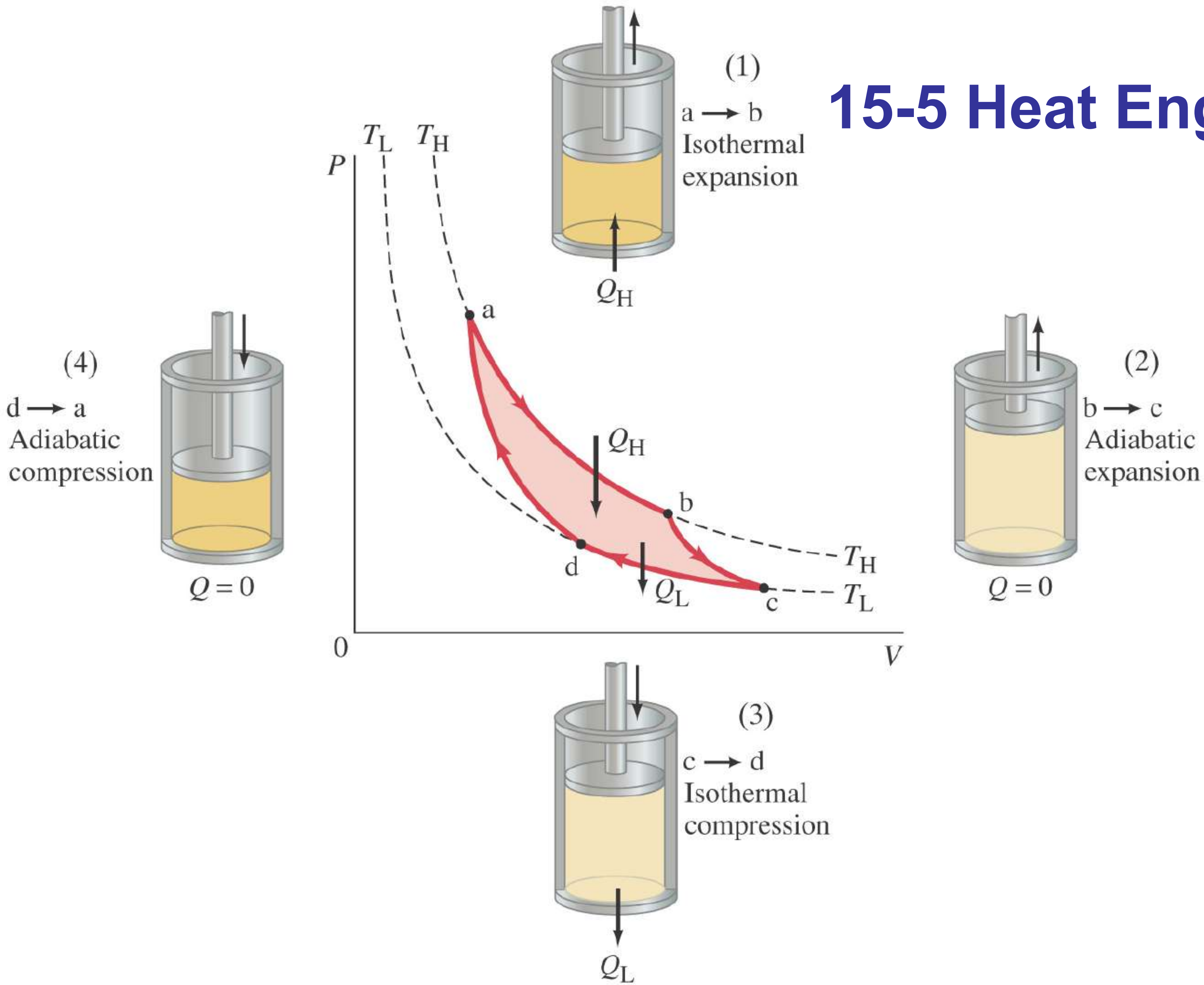
The **Carnot (ideal)** engine was created to examine the efficiency of a heat engine. It is idealized, as it has no friction. Each leg of its cycle is **reversible**.

The Carnot cycle consists of:

- Isothermal expansion
- Adiabatic expansion
- Isothermal compression
- Adiabatic compression

An example is on the next slide.

15-5 Heat Engines



15-5 Heat Engines

For an **ideal** reversible engine, the Carnot (ideal) **efficiency** can be written in terms of the **temperatures:**

$$e_{\text{ideal}} = \frac{T_{\text{H}} - T_{\text{L}}}{T_{\text{H}}} = 1 - \frac{T_{\text{L}}}{T_{\text{H}}}$$

(first part on formula sheet)

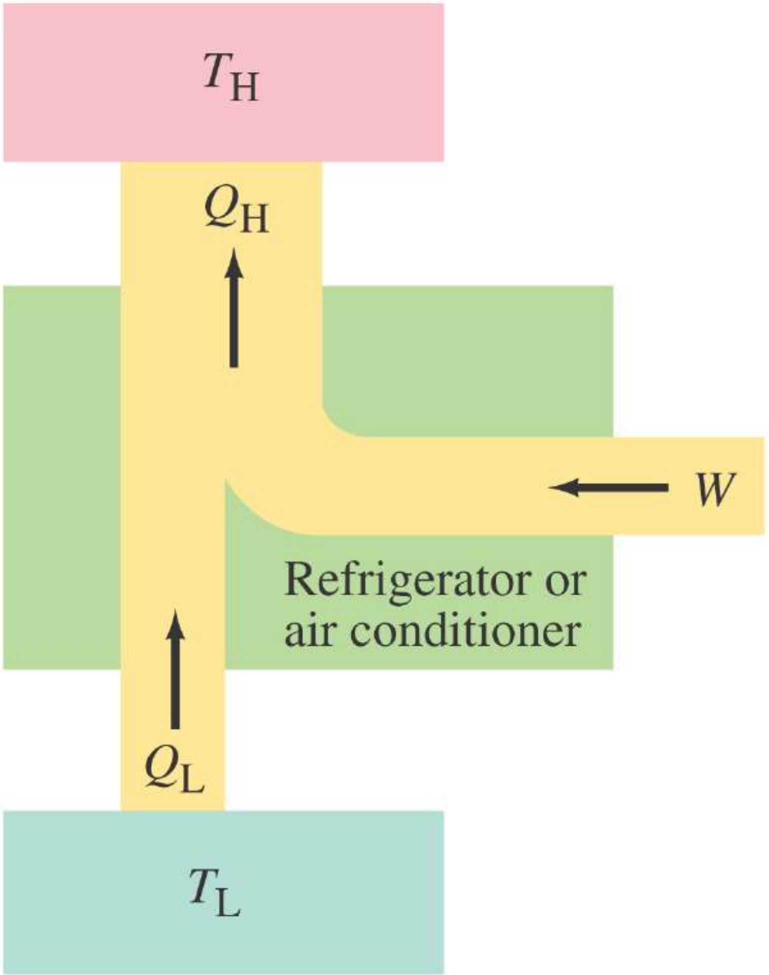
From this we see that **100%** efficiency can be achieved only if the cold reservoir is at **absolute zero**, which is **impossible**.

Real engines have some frictional **losses**; the best achieve **60-80%** of the **Carnot** value of efficiency.

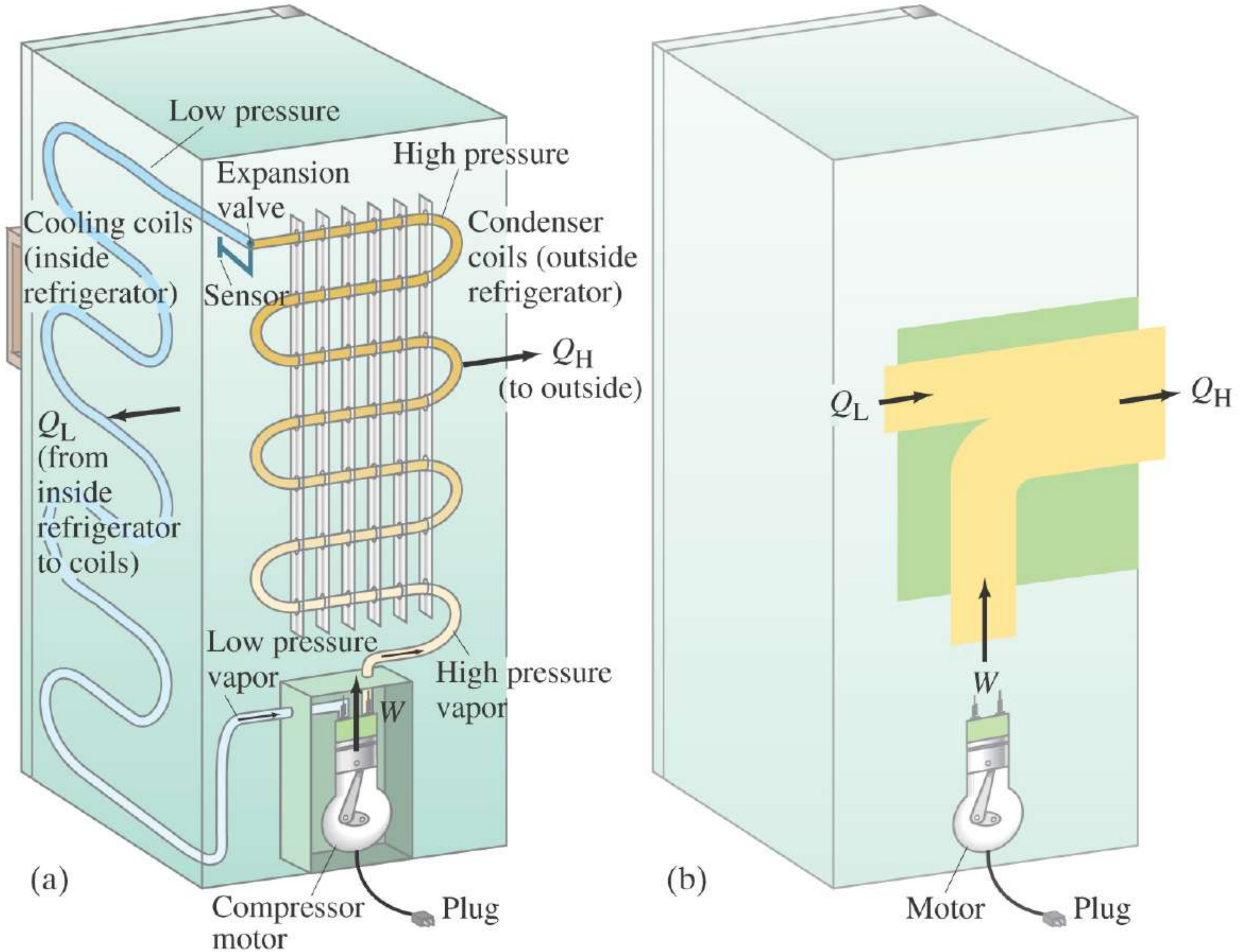
15-6 Refrigerators, Air Conditioners, and Heat Pumps

These appliances can be thought of as heat engines operating in **reverse**.

By doing **work**, heat is **extracted** from the cold reservoir and **exhausted** to the hot reservoir.



15-6 Refrigerators, Air Conditioners, and Heat Pumps



15-6 Refrigerators, Air Conditioners, and Heat Pumps

Refrigerator **performance** is measured by the coefficient of performance (**COP**):

$$\mathrm{COP} = \frac{Q_L}{W} \qquad \textbf{(15-6a)}$$

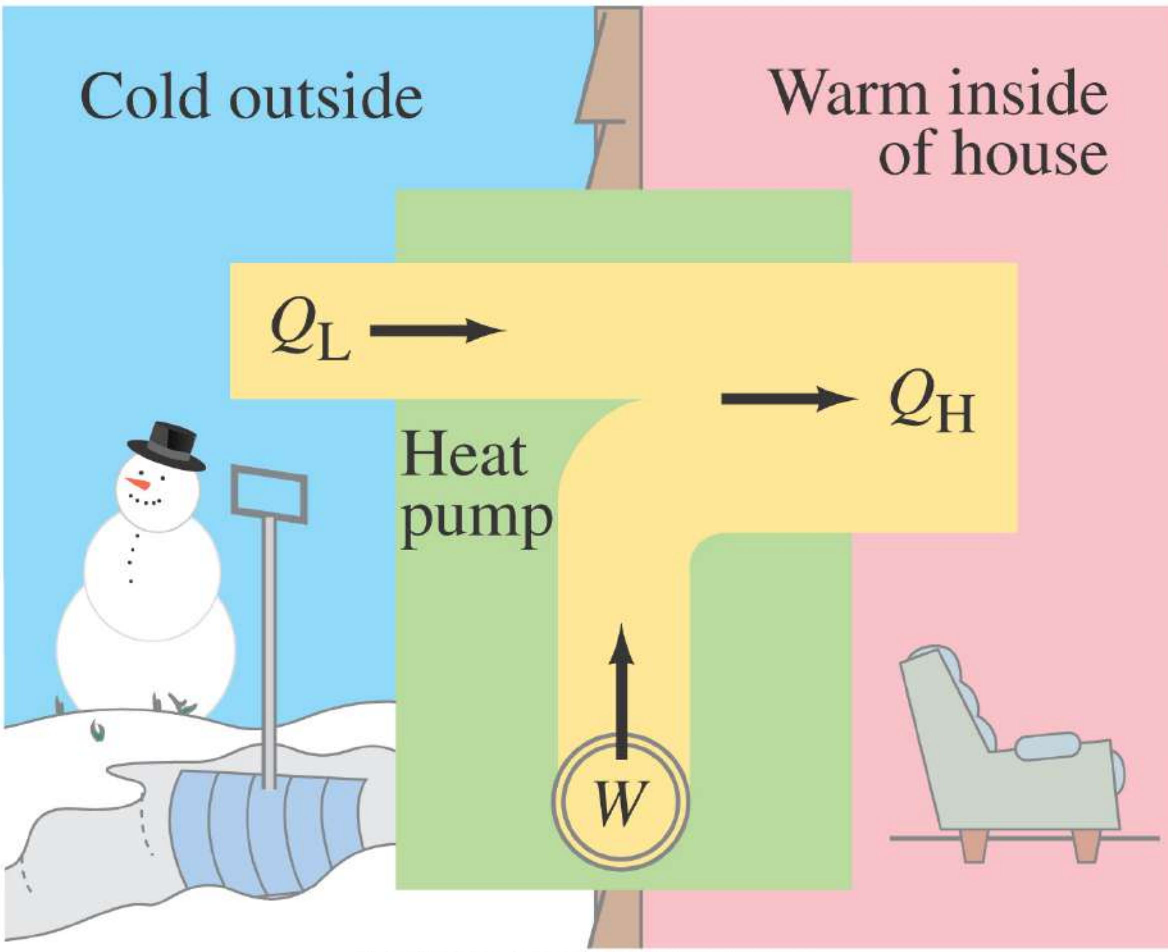
Substituting:

$$\mathrm{COP} = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} \qquad \textbf{(15-6b)}$$

$$\mathrm{COP}_{\mathrm{ideal}} = \frac{T_L}{T_H - T_L} \qquad \textbf{(15-6c)}$$

15-6 Refrigerators, Air Conditioners, and Heat Pumps

A **heat pump** can heat a house in the winter:



$$\text{COP} = \frac{Q_H}{W} \quad (15\text{-}7)$$

15-7 Entropy and the Second Law of Thermodynamics

Definition of the change in entropy S when an amount of heat Q is added:

$$\Delta S = \frac{Q}{T} \tag{15-8}$$

Another statement of the second law of thermodynamics:

The total entropy of an isolated system never decreases.

15-8 Order to Disorder

Entropy is a measure of the **disorder** of a system. This gives us yet another statement of the **second** law:

Natural processes tend to move toward a state of greater disorder.

Example: If you put milk and sugar in your coffee and stir it, you wind up with coffee that is uniformly milky and sweet. No amount of stirring will get the milk and sugar to come back out of solution.

15-8 Order to Disorder

Another example: when a tornado hits a building, there is major damage. You never see a tornado approach a pile of rubble and leave a building behind when it passes.

Thermal equilibrium is a similar process – the uniform final state has more disorder than the separate temperatures in the initial state.

15-9 Unavailability of Energy; Heat Death

Another **consequence** of the second law:

In any natural process, some energy becomes **unavailable** to do useful work.

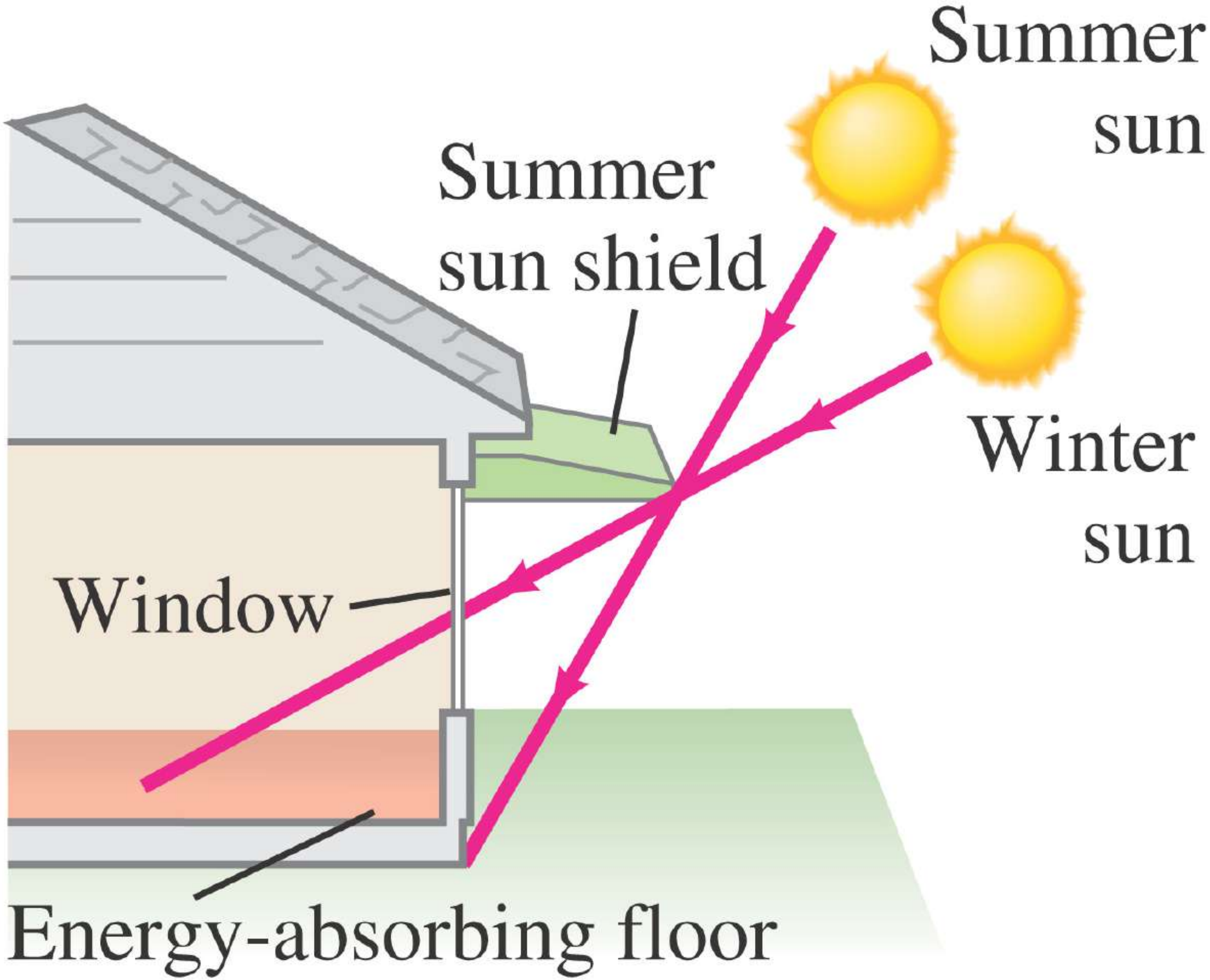
If we look at the universe as a whole, it seems inevitable that, as more and more energy is converted to unavailable forms, the ability to do work anywhere will gradually vanish. This is called the **heat death** of the universe.

15-12 Thermal Pollution and Global Warming

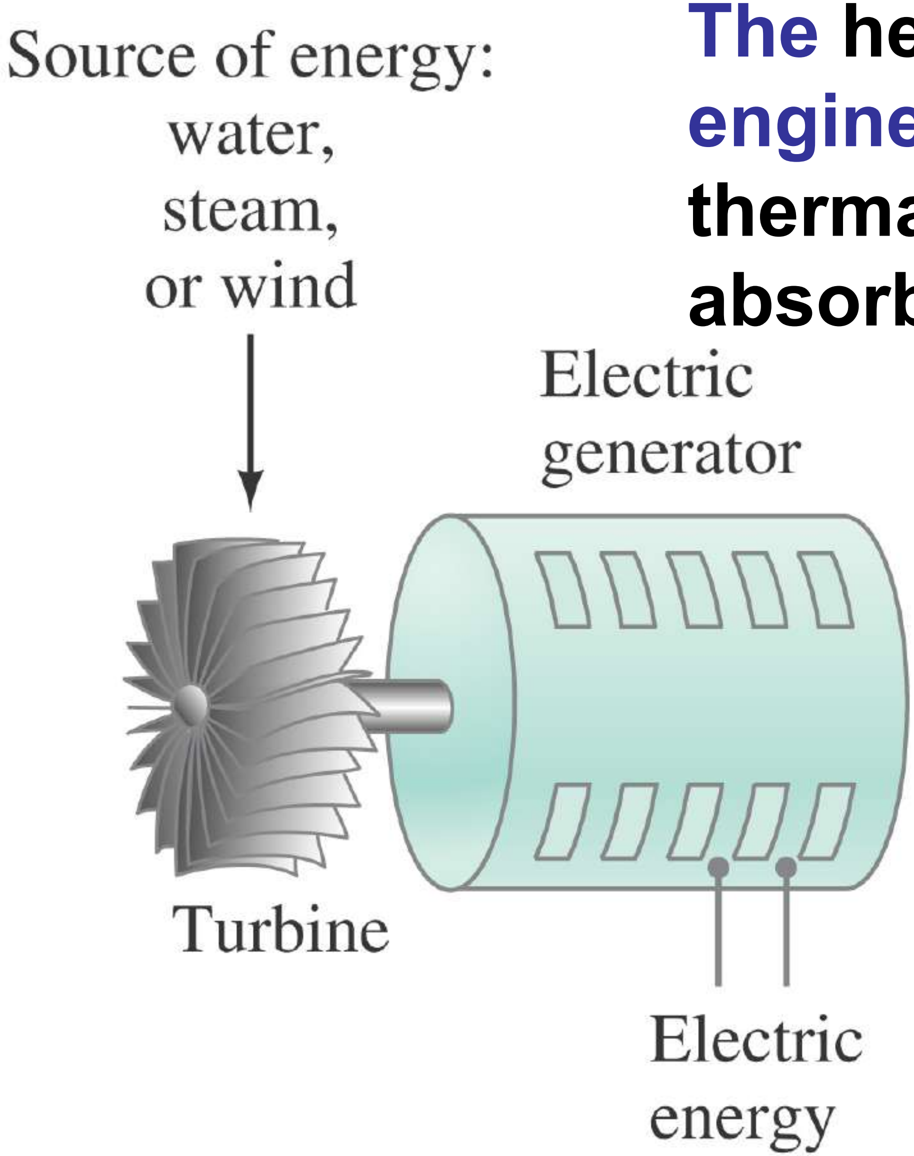
The **generation** of electricity using **solar** energy (a) does not involve a **heat** engine, but **fossil-fuel** plants (b) and **nuclear** plants (c) do.

(a) (b) (c)

Passive solar energy system



15-12 Thermal Pollution and Global Warming



The **heat output** of any heat engine, Q_L, is referred to as **thermal pollution**, as it must be **absorbed** by the environment.

15-12 Thermal Pollution and Global Warming

Air pollution is also emitted by power plants, industries, and consumers. Some of this pollution results in a buildup of CO_2 in the atmosphere, contributing to **global warming**. This can be **minimized** through careful choices of fuels and processes.

The **thermal pollution**, however, is a consequence of the **second law**, and is **unavoidable**; it can be reduced only by **reducing** the amount of energy we use.