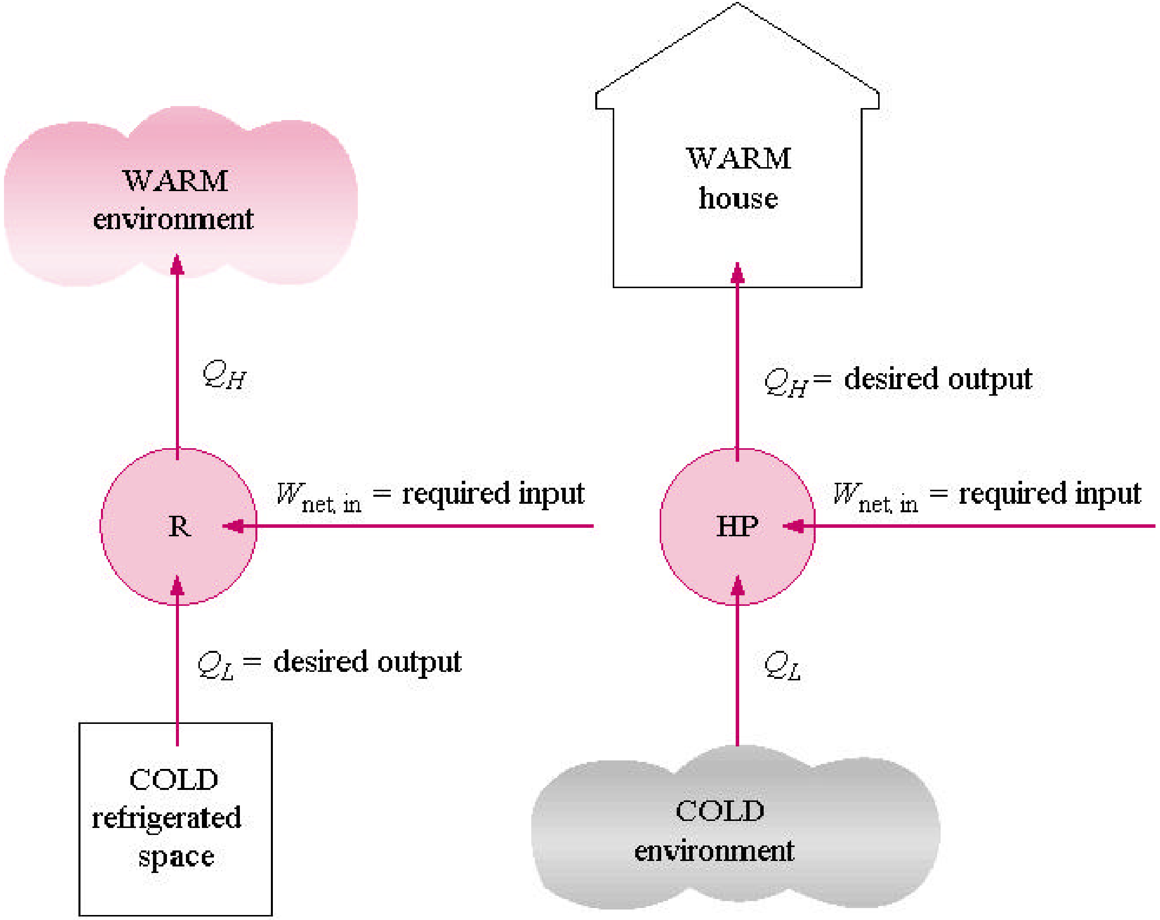
CHAPTER 10

Refrigeration Cycles

Refrigerator and Heat Pump Objectives

The objective of a refrigerator is to remove heat (Q_L) from the cold medium; the objective of a heat pump is to supply heat (Q_H) to a warm medium



(*a*) Refrigerator

(*b*) Heat pump

Some Basic Definitions

- The transfer of heat from lower temperature regions to higher temperature ones is called *refrigeration*.
- Devices that produce refrigeration are called *refrigerators*, and the cycles on which they operate are called *refrigeration cycles*.
- The working fluids used in refrigerators are called *refrigerants*.
- Refrigerators used for the purpose of heating a space by transferring heat from a cooler medium are called *heat pumps*.

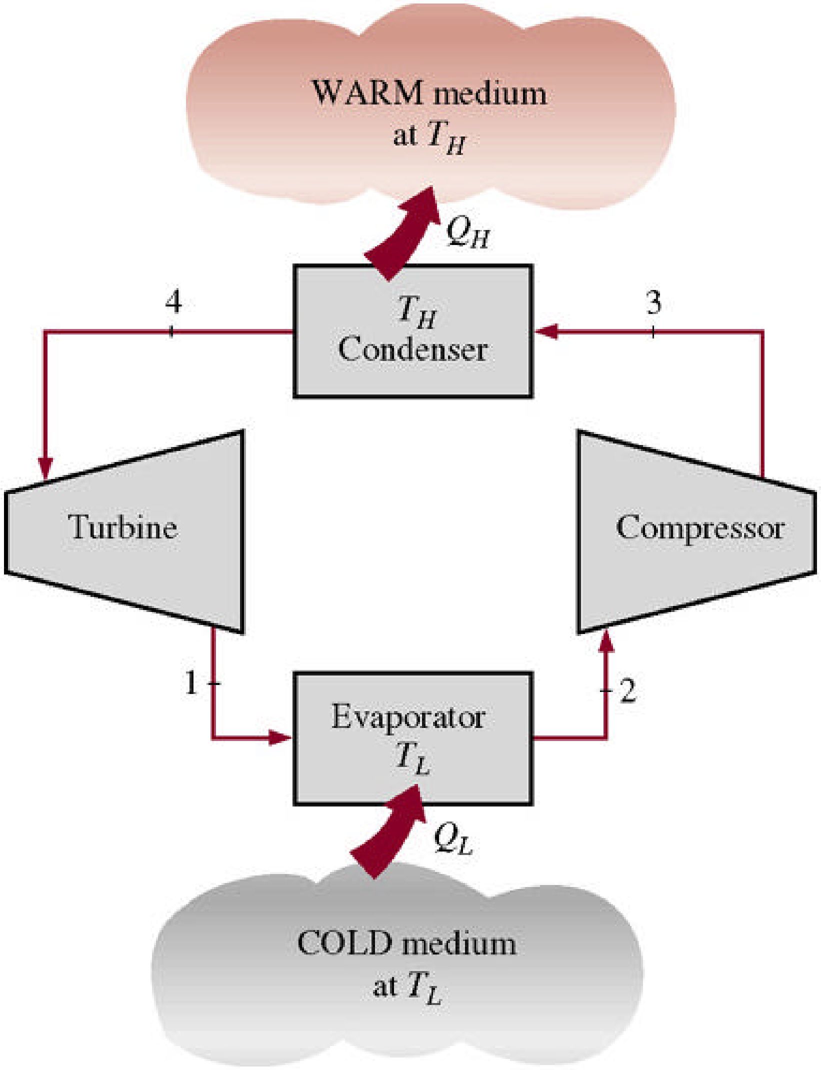
Coefficient of Performance

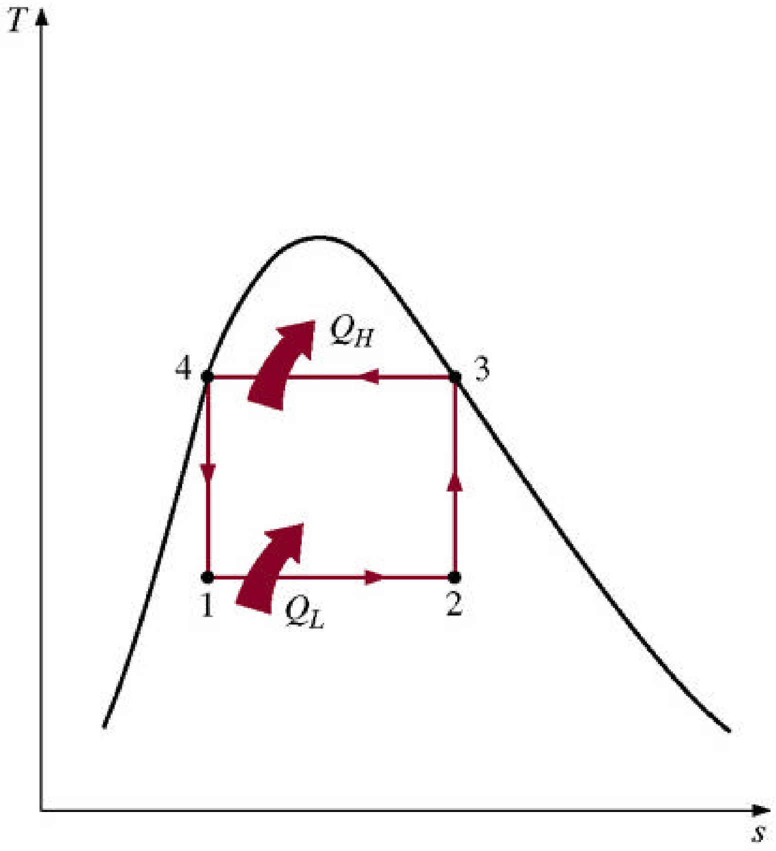
- The performance of refrigerators and heat pumps is expressed in terms of *coefficient of performance* (COP), defined as

$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{net,in}}$$

$$COP_{HP} = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Heating effect}}{\text{Work input}} = \frac{Q_H}{W_{net,in}}$$

The Reversed Carnot Cycle





Carnot Refrigerator and Heat Pump

- **A refrigerator or heat pump that operates on the reversed Carnot cycle is called a *Carnot refrigerator* or a *Carnot heat pump*, and their COPs are**

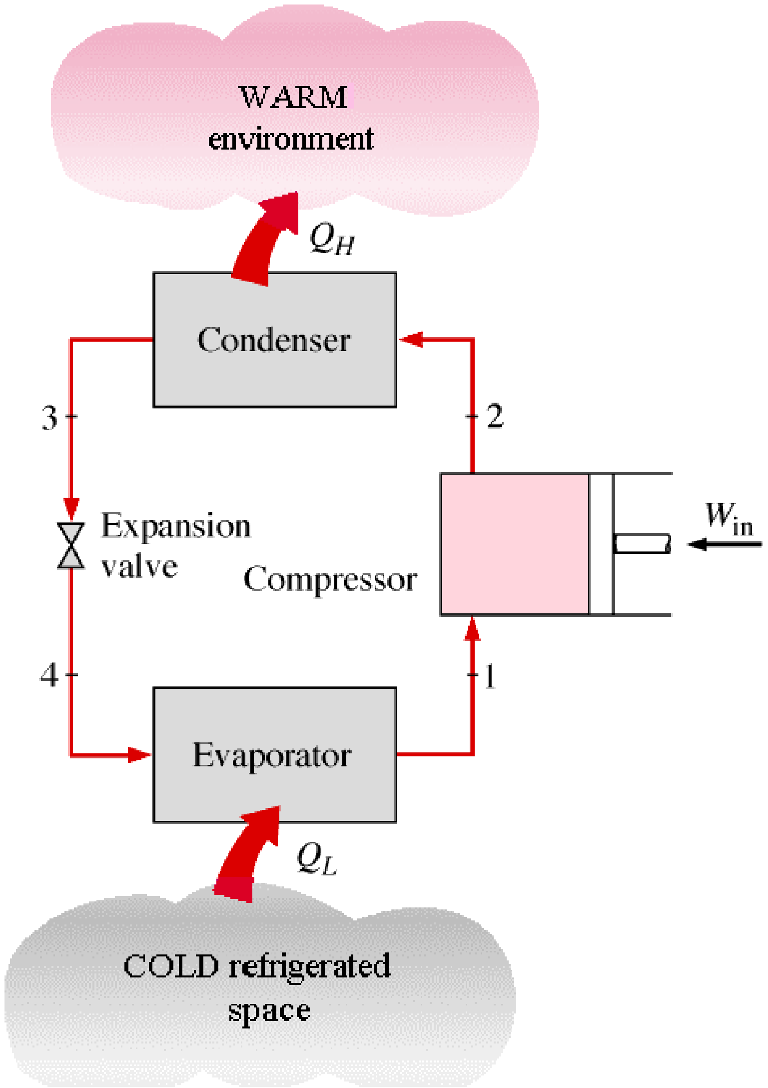
$$COP_{R,Carnot} = \frac{1}{T_H / T_L - 1} = \frac{T_L}{T_H - T_L}$$

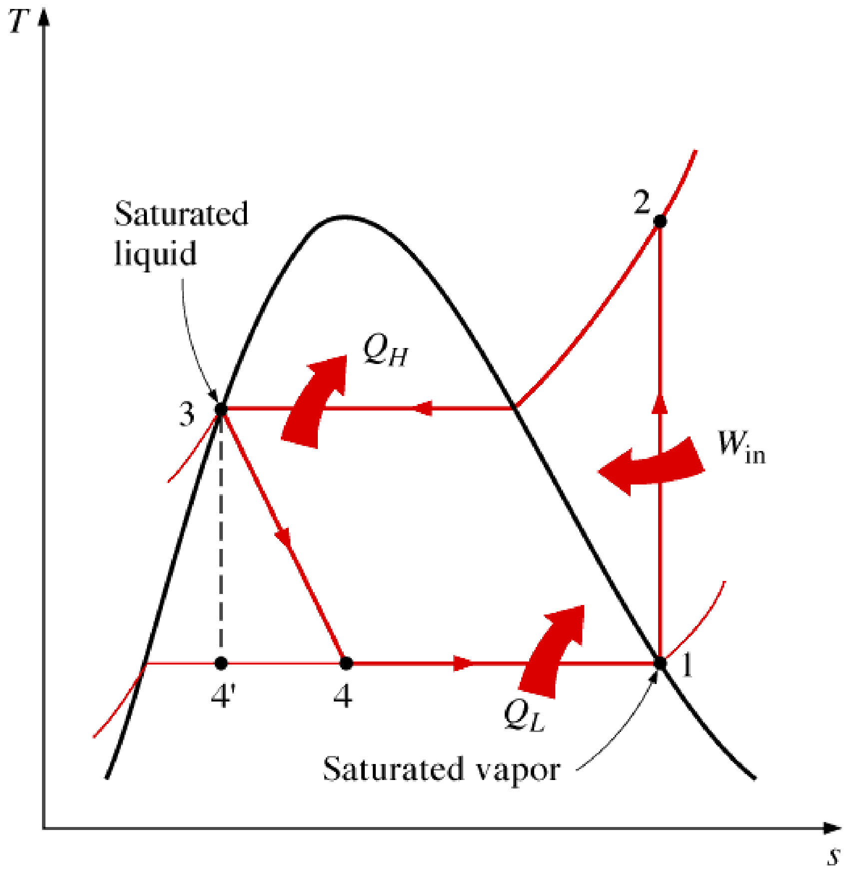
$$COP_{HP,Carnot} = \frac{1}{1 - T_L / T_H} = \frac{T_H}{T_H - T_L}$$

Why not use the reversed Carnot Refrigeration Cycle

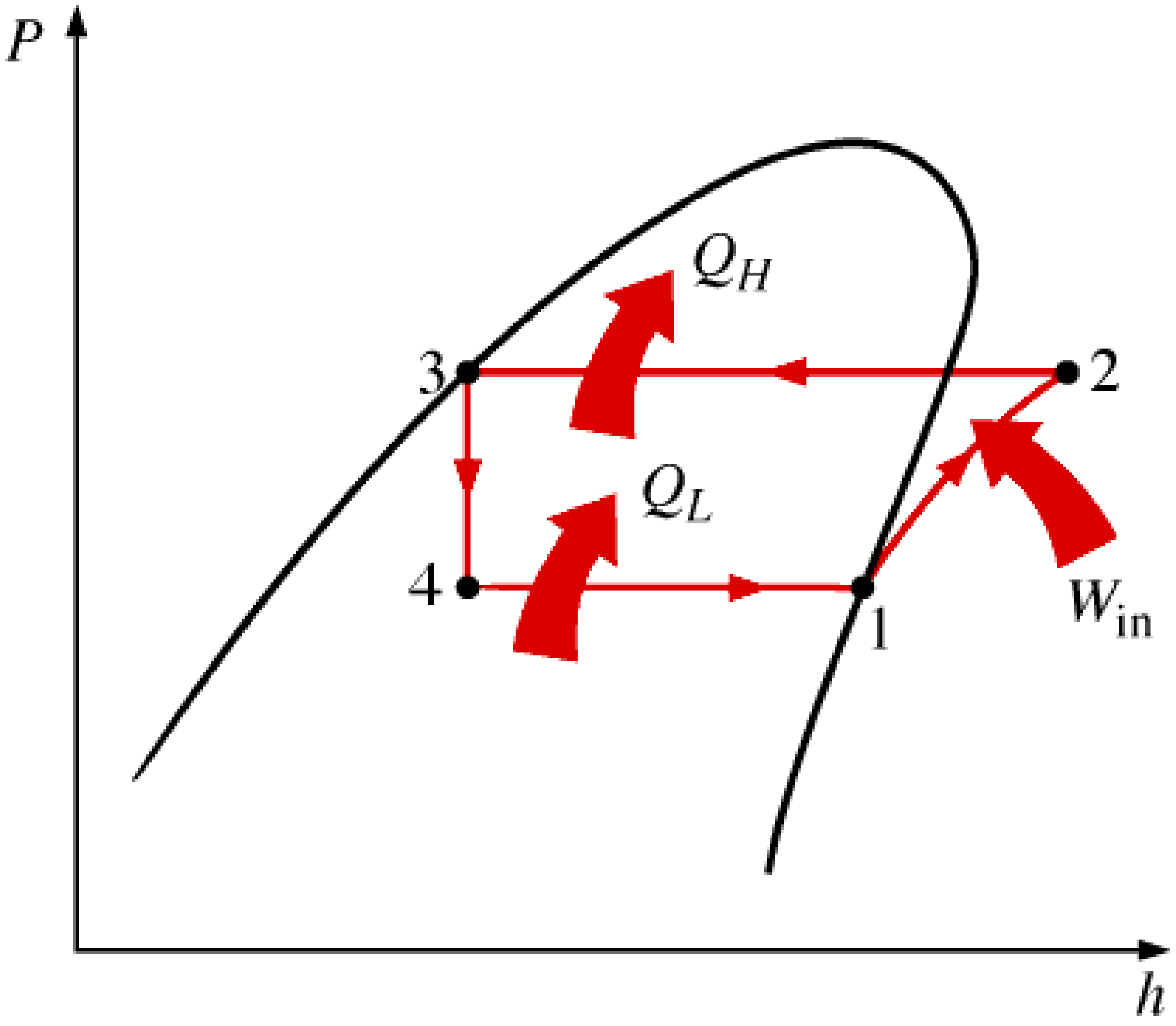
- Easier to compress vapor only and not liquid-vapor mixture
- Cheaper to have irreversible expansion through an expansion valve

Schmatic and *T-s* Diagram for Ideal Vapor-Compression Refrigeration Cycle

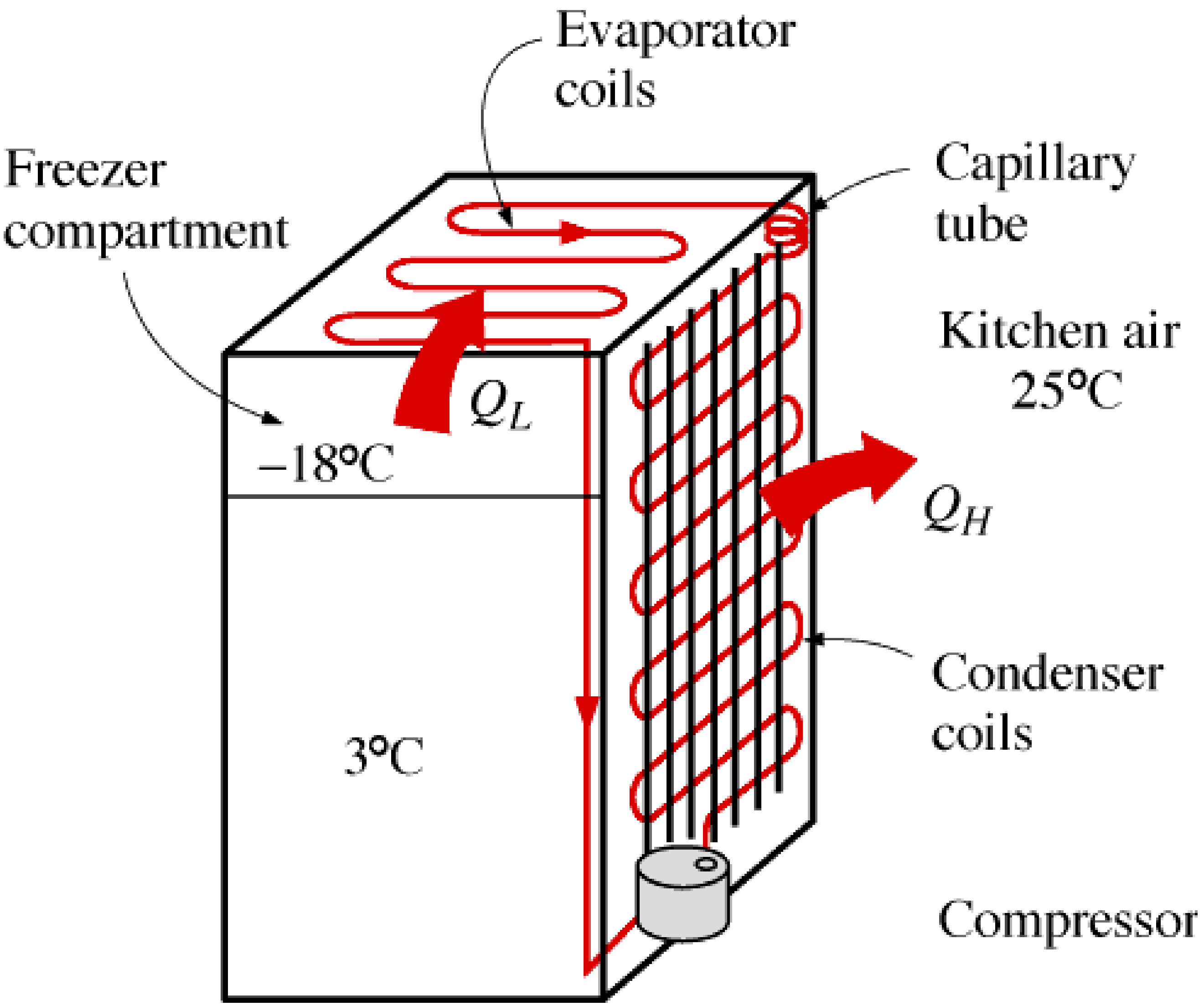




P-h Diagram of an Ideal Vapor-Compression Refrigeration Cycle



Ordinary Household Refrigerator



Four Processes of the Ideal Vapor-Compression Refrigeration Cycle

- The Ideal Vapor-Compression Refrigeration Cycle

Process	Description
1-2	Isentropic compression
2-3	Constant pressure heat rejection in the condenser
3-4	Throttling in an expansion valve
4-1	Constant pressure heat addition in the evaporator

1^{st} and 2^{nd} Law Analysis of Ideal Vapor-Compression Refrigeration Cycle

- **Results of First and Second Law Analysis for Steady-Flow**

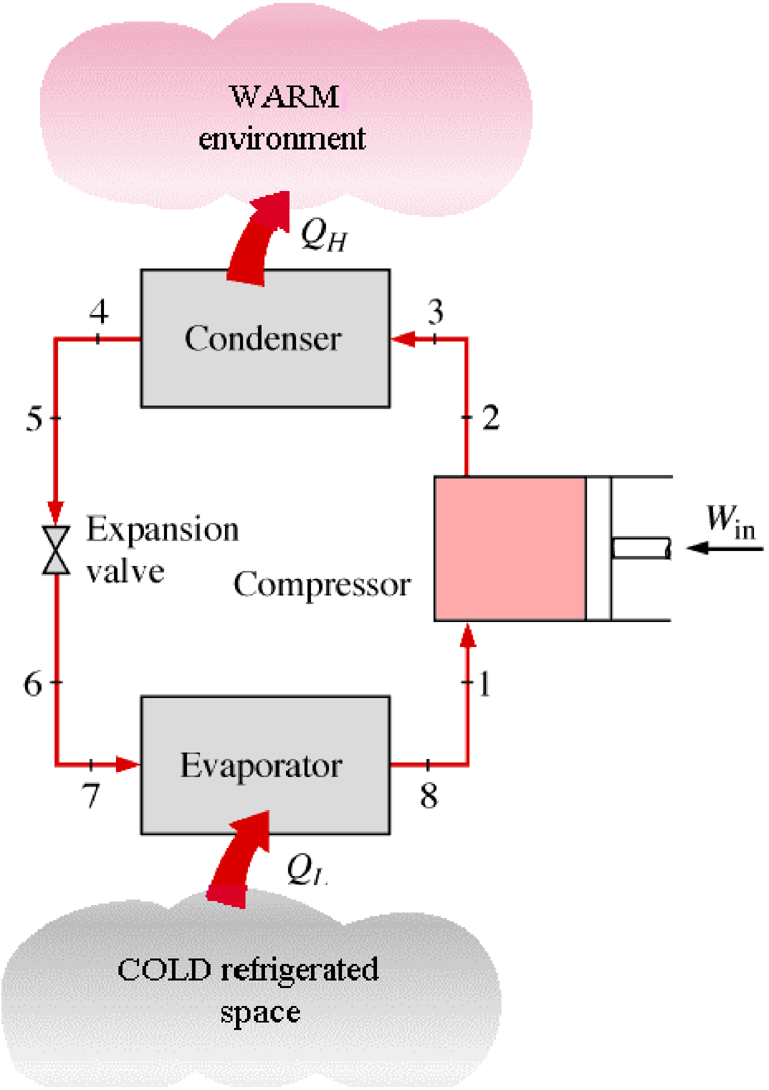
Component	Process	First Law Result
Compressor	s = Const.	$\dot{W}_{in} = \dot{m}(h_2 - h_1)$
Condenser	P = Const.	$\dot{Q}_H = \dot{m}(h_2 - h_3)$
Throttle Valve	Ds > 0	$h_4 = h_3$
Evaporator	P = Const.	$\dot{Q}_L = \dot{m}(h_1 - h_4)$

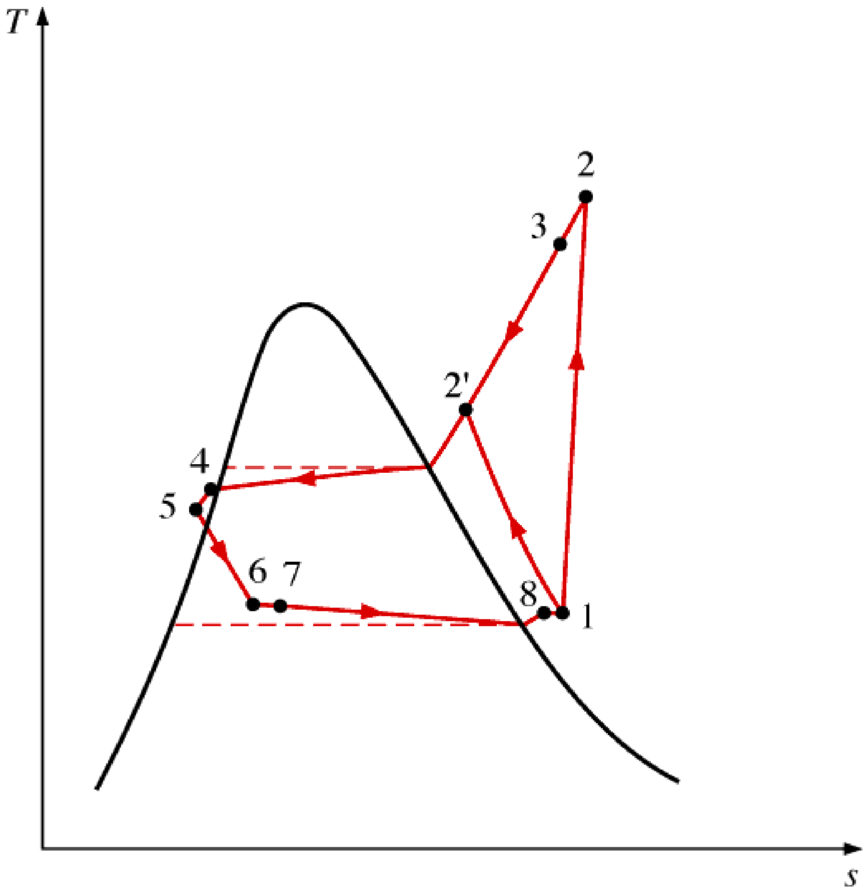
COP of An Ideal Vapor-Compression Refrigeration Cycle

$$COP_R = \frac{\dot{Q}_L}{\dot{W}_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP_{HP} = \frac{\dot{Q}_H}{\dot{W}_{net,in}} = \frac{h_2 - h_3}{h_2 - h_1}$$

Schmatic and *T-s* Diagram for Actual Vapor-Compression Refrigeration Cycle

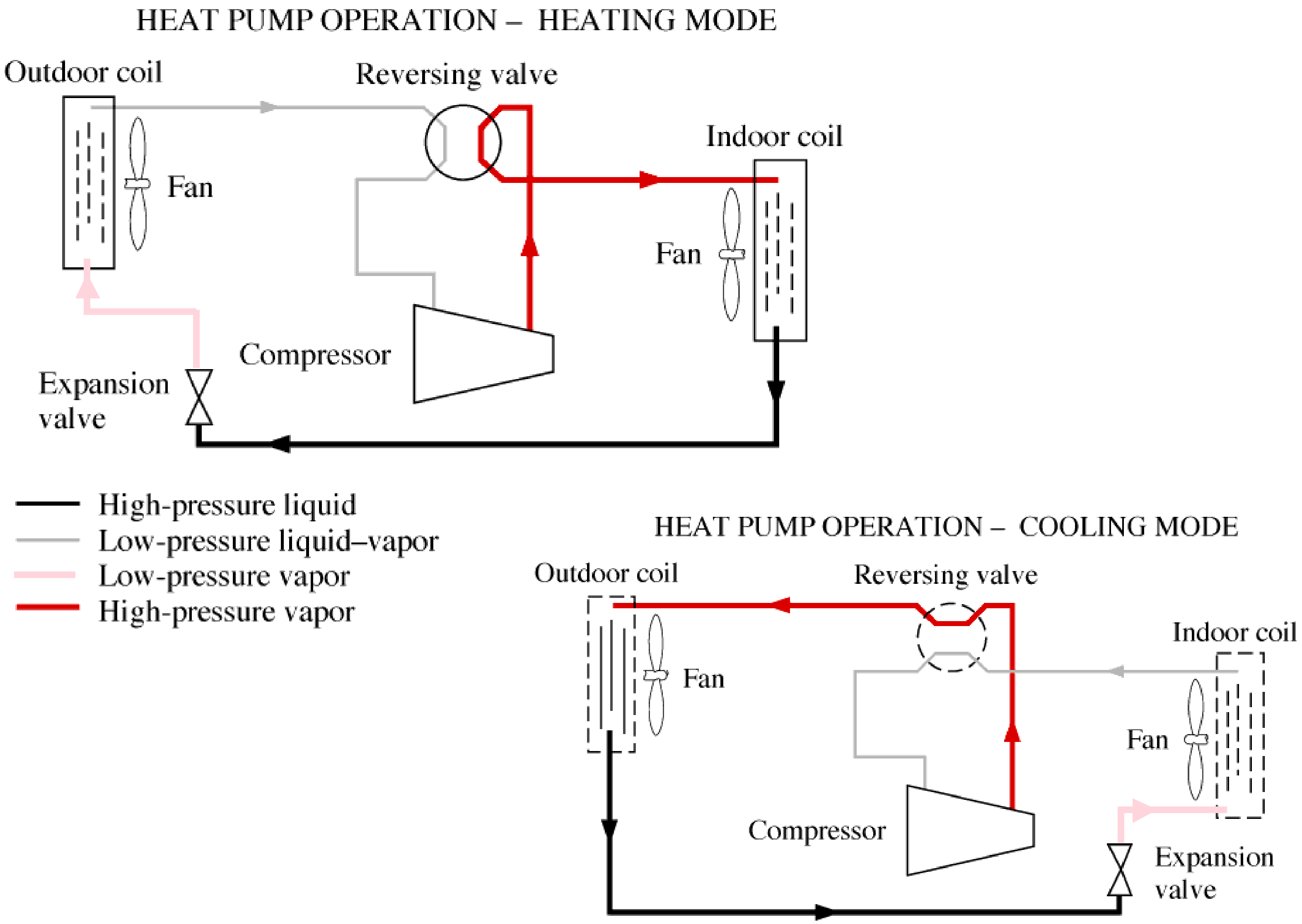




Practice Problem 10.1

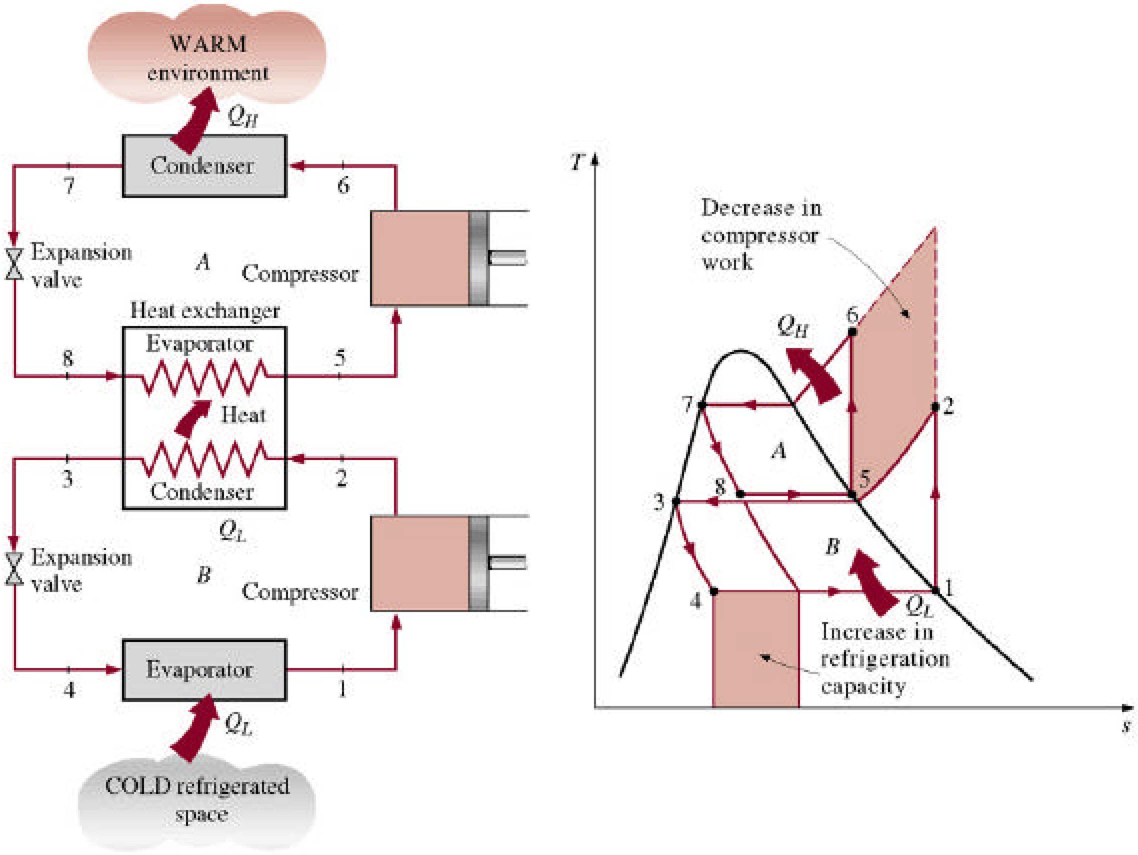
Refrigerant-134a is the working fluid in an ideal compression refrigeration cycle. The refrigerant leaves the evaporator -20°C and has a condenser pressure of 0.9 MPa. The mass flow rate is 3 kg/min. Find COP_R , $COP_{R, Carnot}$ for same T_{max} and T_{min} , and the tons of refrigeration. (One ton of refrigeration is equivalent to 12,000 Btu/hr or 211 kJ/min.)

Heat Pump Heats a House in Winter and Cools it in Summer

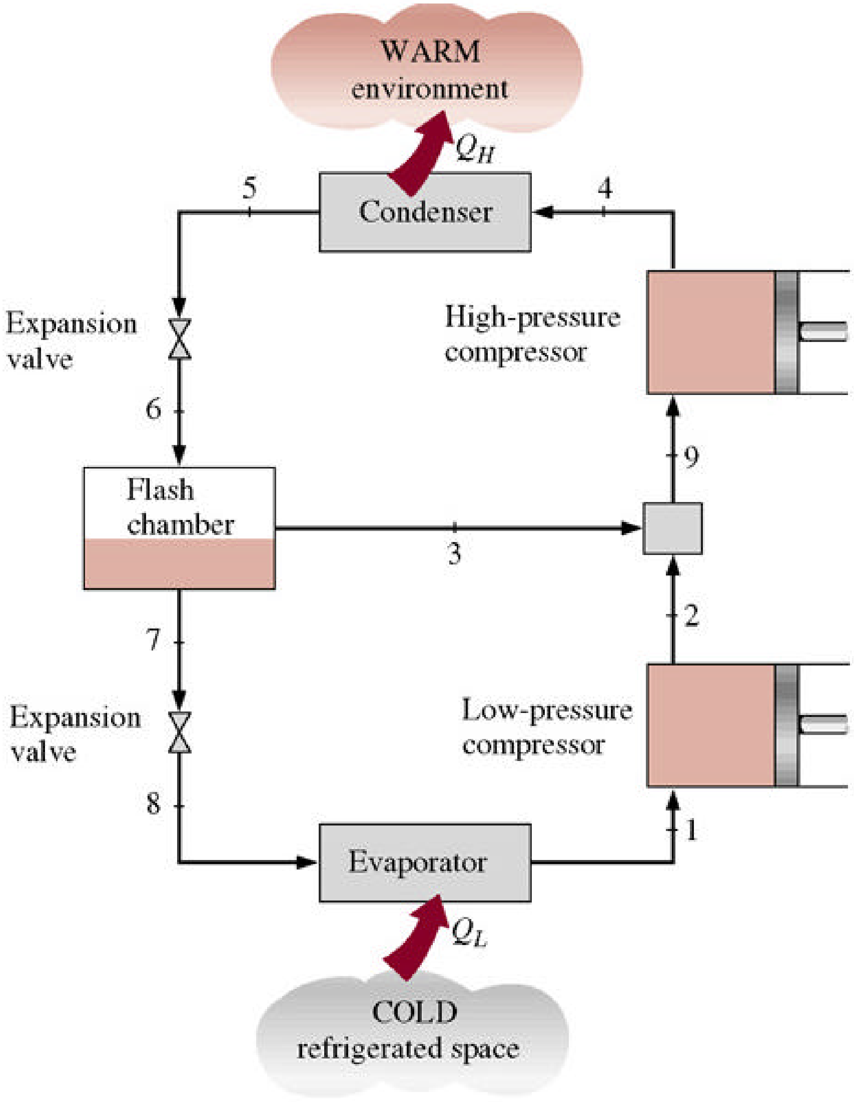


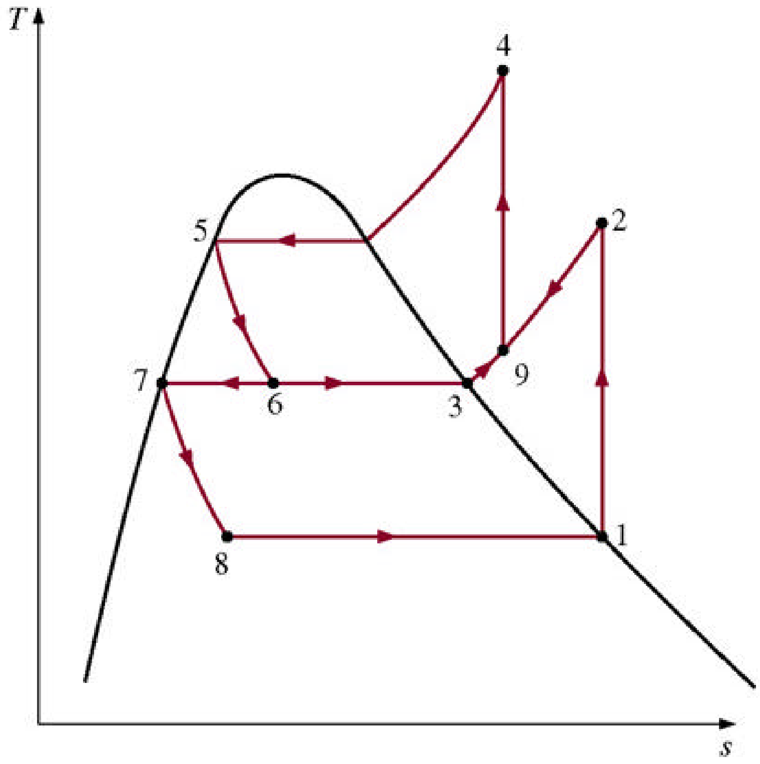
A Two-Stage Cascade Regrigeration System

Objecitve: To achieve a larger temperature range (cooler temperautre) without requiring a large pressure range in the compressor

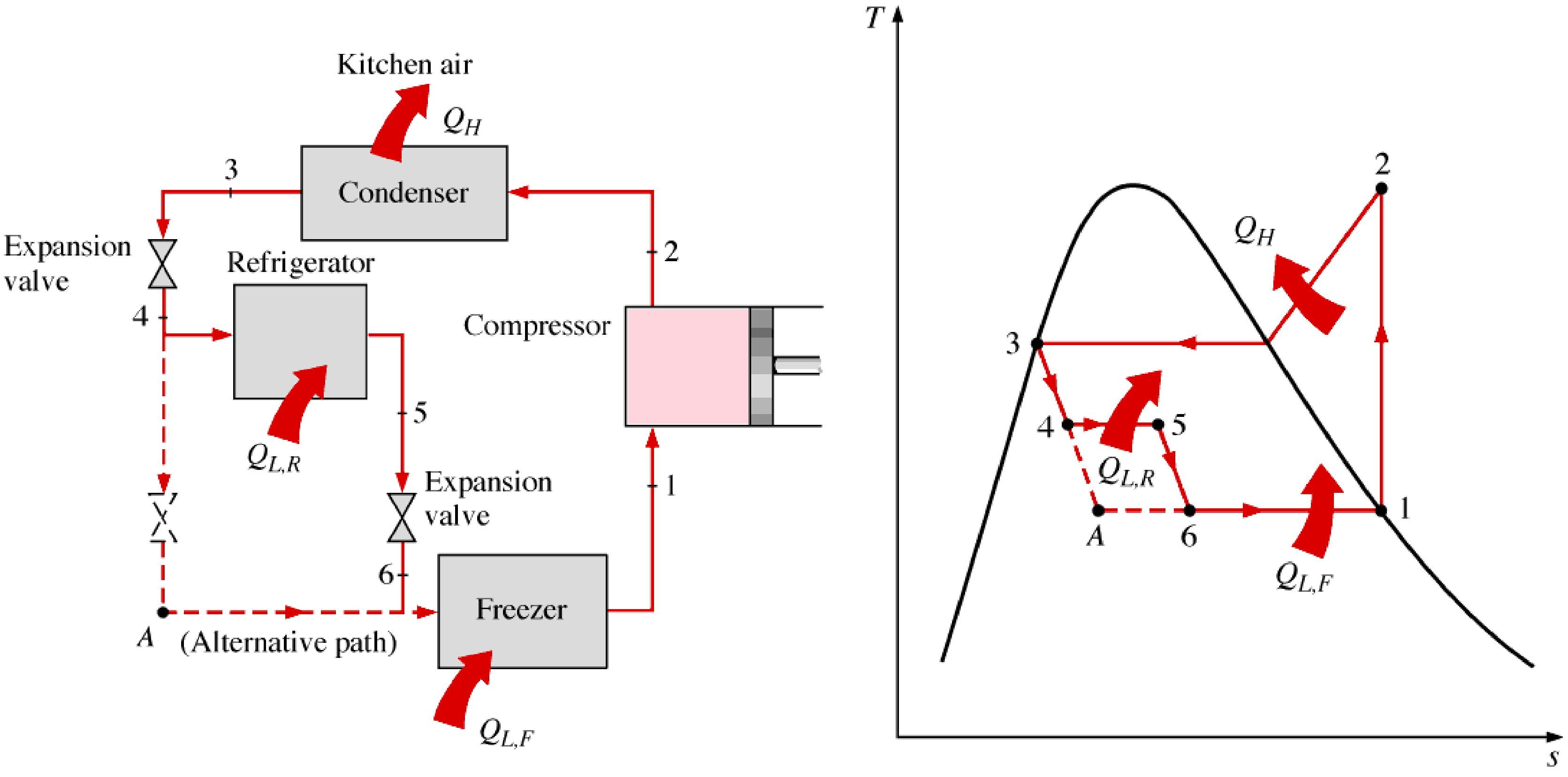


A Two-Stage Cascade Regrigeration System with a flash chamber

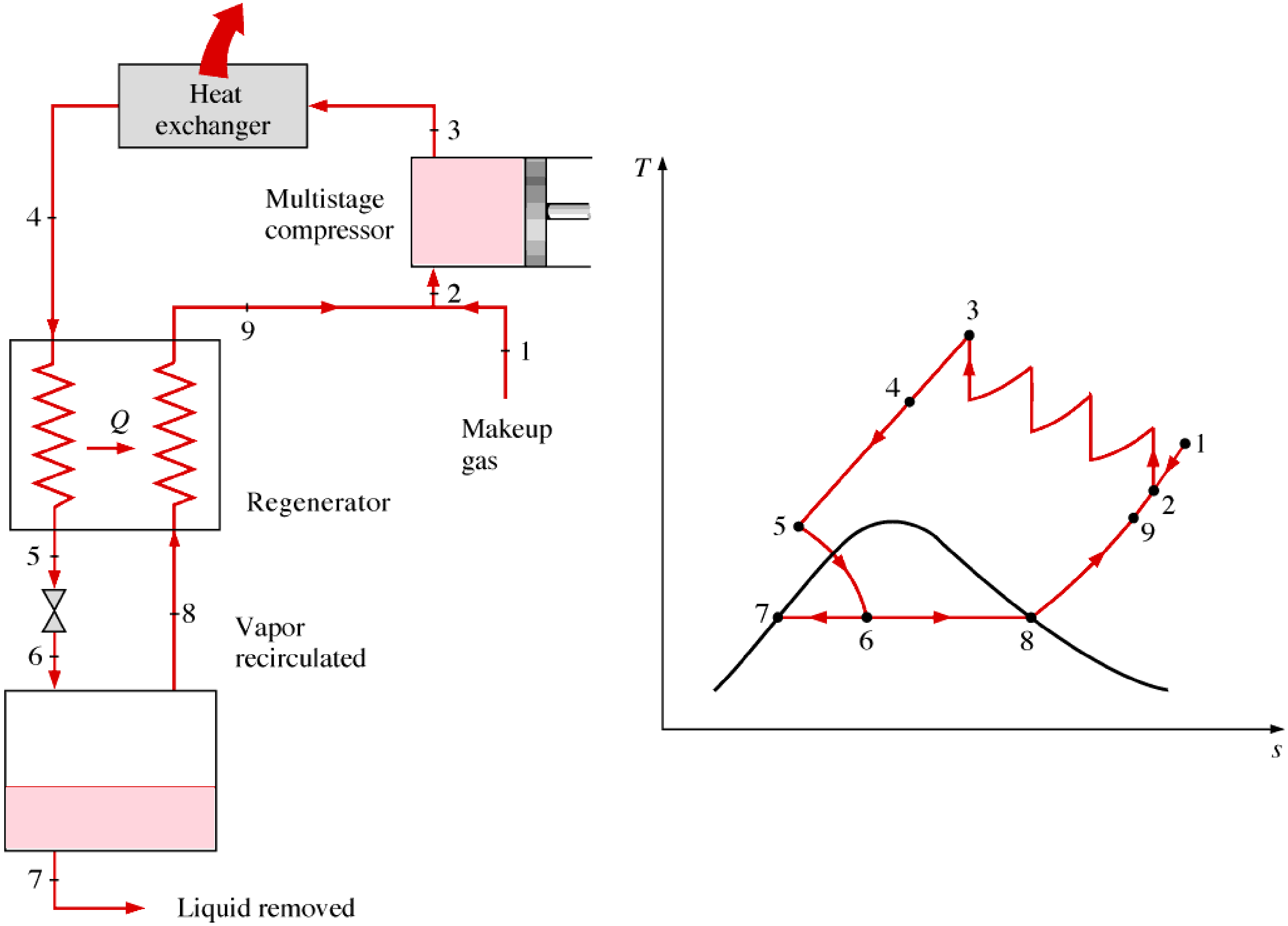




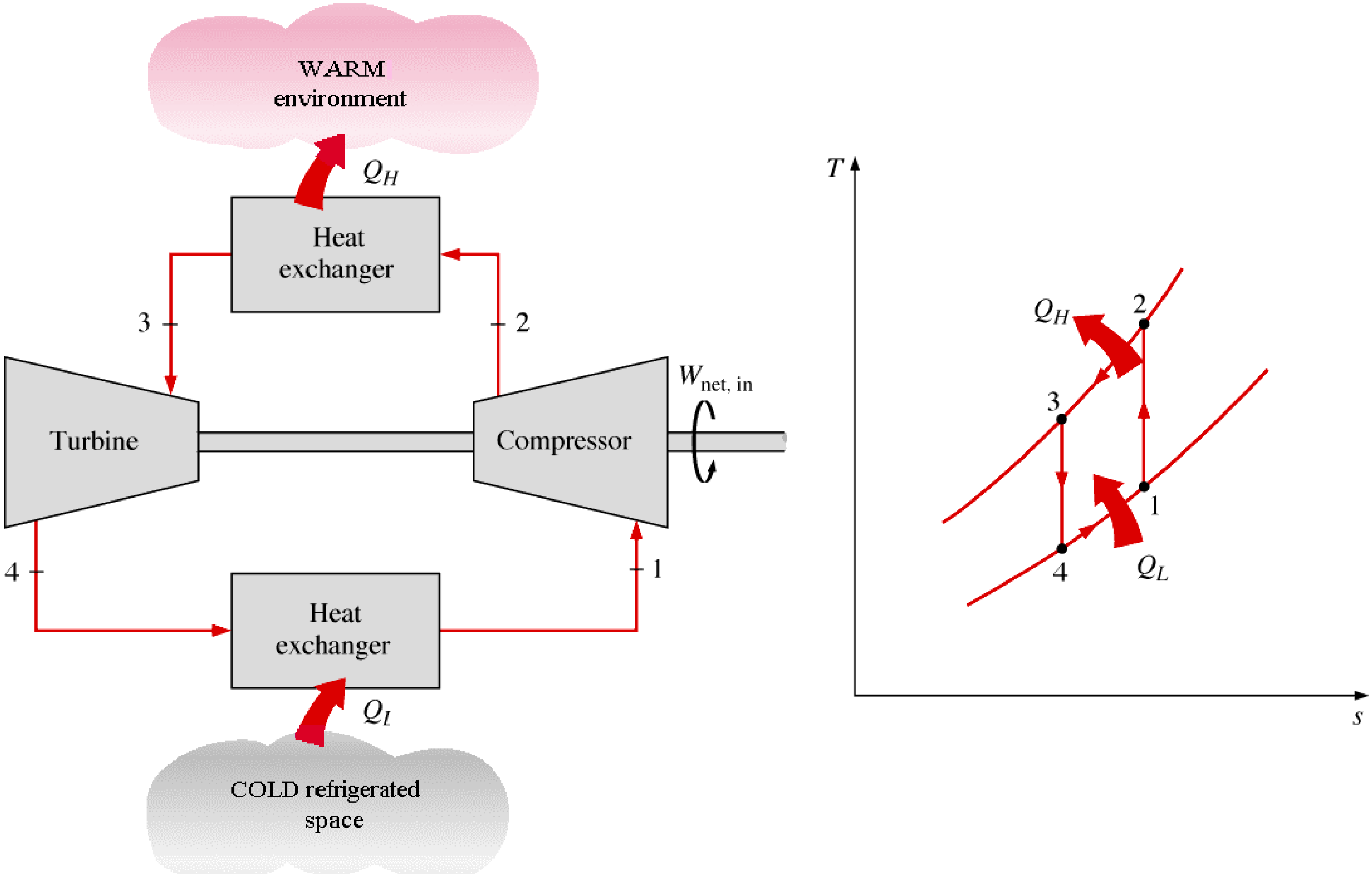
Schmatic and *T-s* Diagram for Refrigerator-Freezer Unit with One Compressor



Linde-Hampson System for Liquefying Gases



Simple Gas Refrigeration Cycle (Reversed Brayton Cycle)

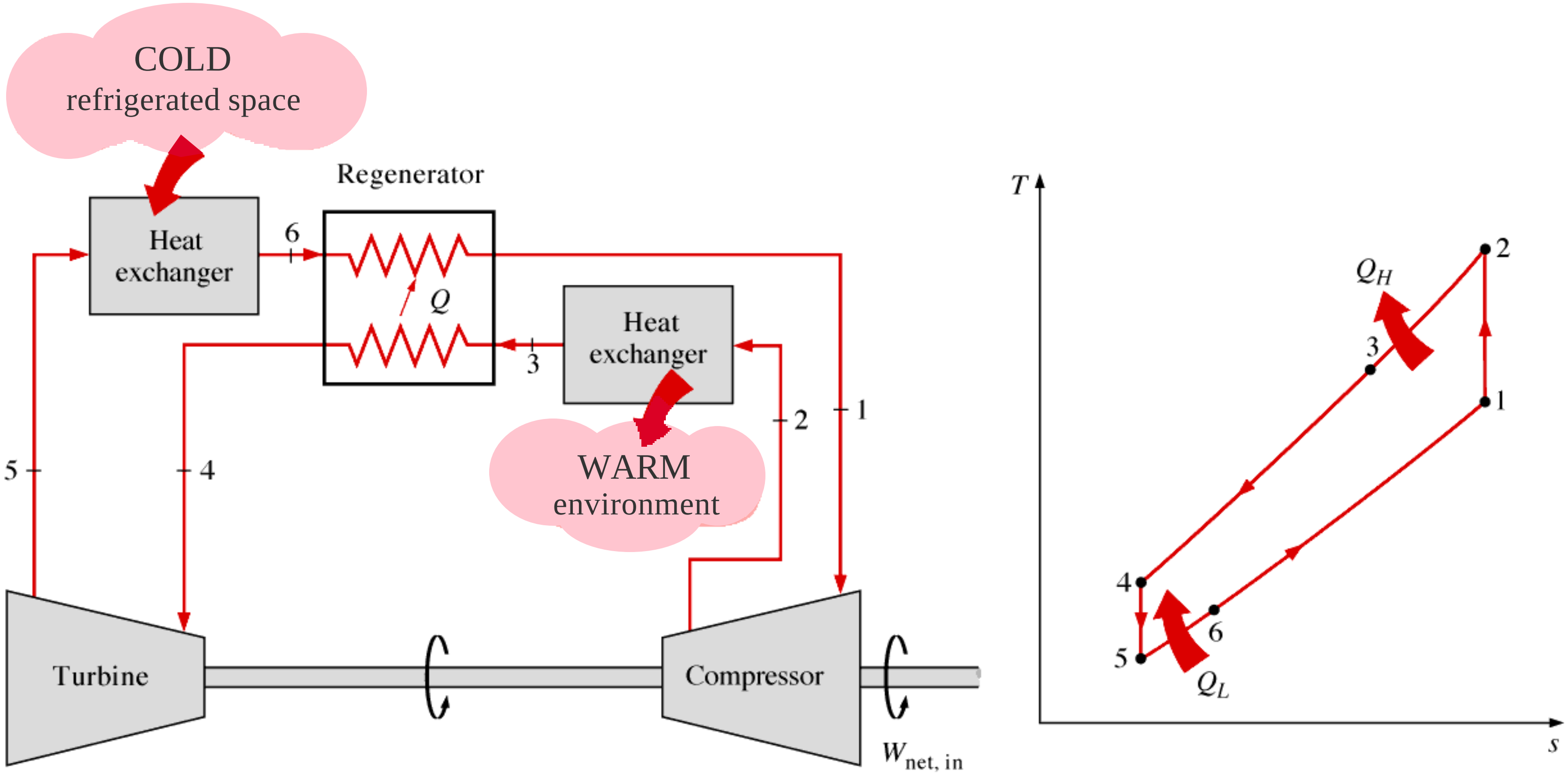


Objective and COP of Gas Refrigeration Cycle

- Objective: to cool aircraft and to obtain very low (cryogenic) temperatures after it is modified with regeneration. The work output of the turbine can be used to reduce the work input requirements to the compressor.

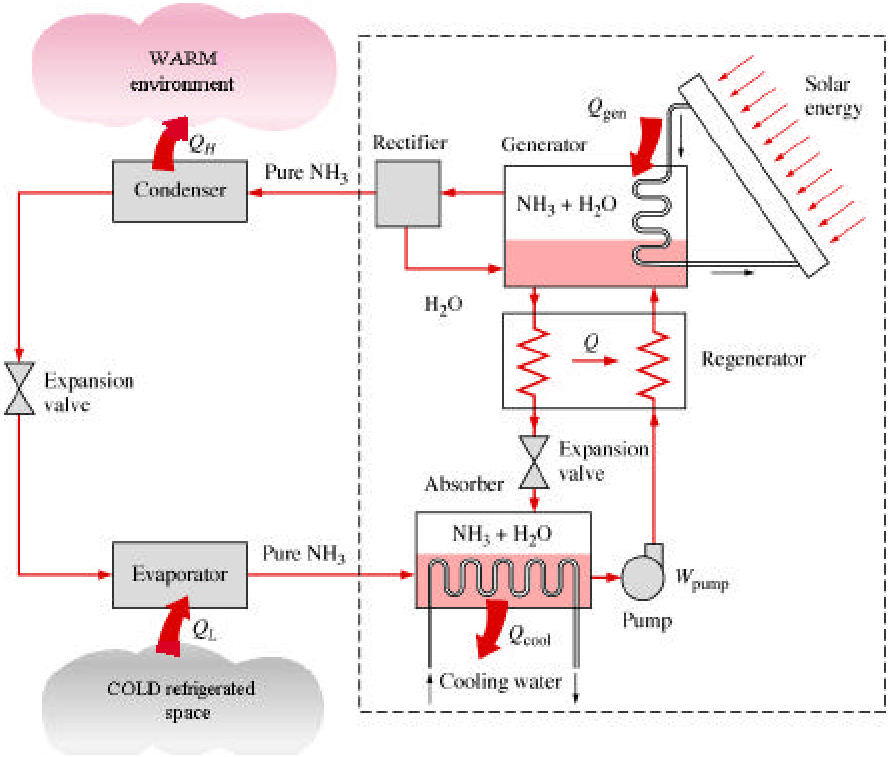
$$COP_R = \frac{q_L}{w_{net,in}} = \frac{q_L}{w_{comp,in} - w_{turb,out}}$$

Gas Refrigeration Cycle With Regeneration

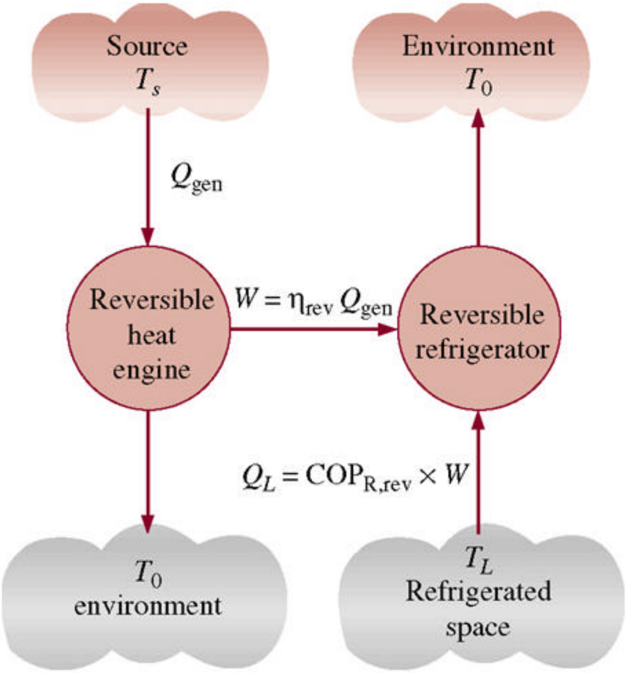


Ammonia Absorption Refrigeration Cycle

- Useful when inexpensive thermal energy is available at 200 to 200 C
- Pump work is typically small because a liquid is being compressed



COP for an Ammonia Absorption Refrigeration Cycle



$$W = \eta_{\text{rev}}\, Q_{\text{gen}} = \left(1 - \frac{T_0}{T_s}\right) Q_{\text{gen}}$$

$$Q_L = \text{COP}_{\text{R,rev}} W = \left(\frac{T_L}{T_0 - T_L}\right) W$$

$$\text{COP}_{\text{rev, absorption}} = \frac{Q_L}{Q_{\text{gen}}} = \left(1 - \frac{T_0}{T_s}\right)\left(\frac{T_L}{T_0 - T_L}\right)$$