Vapor Compression Refrigeration Cycle

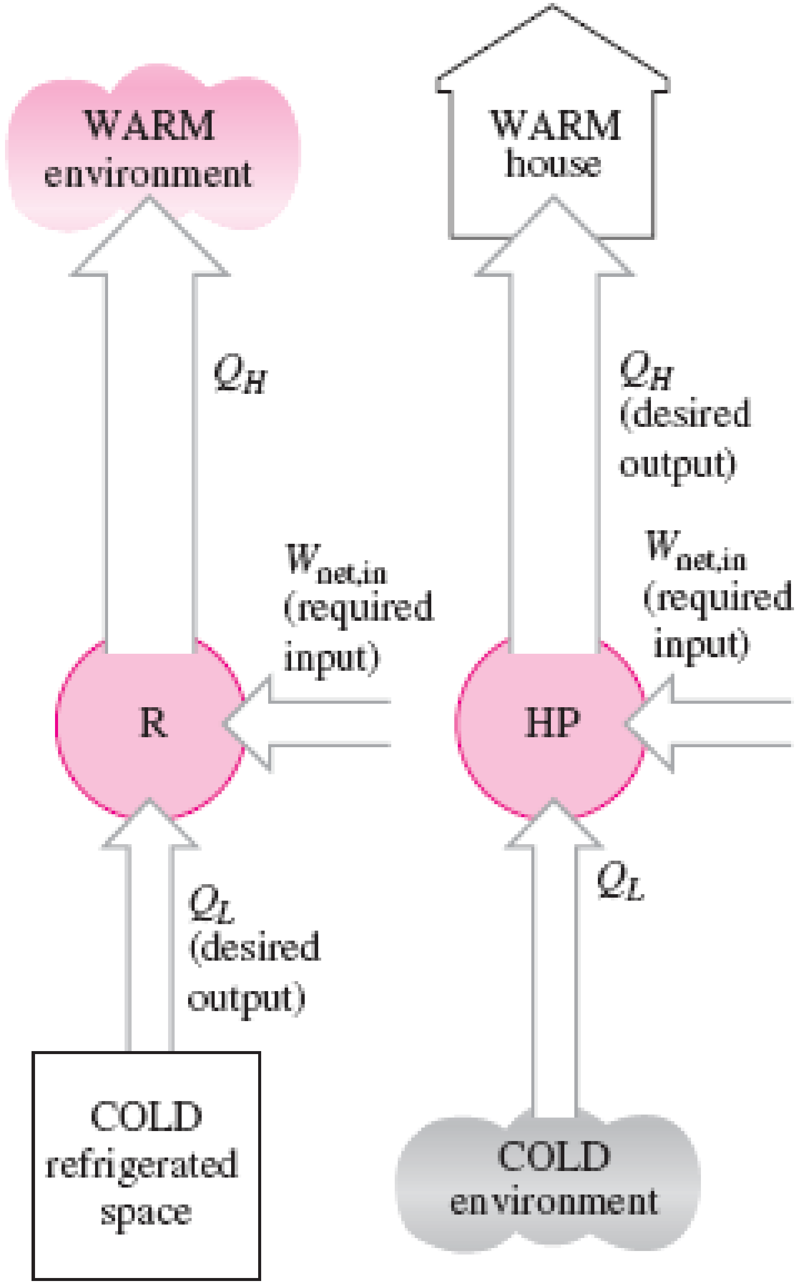
Ranjan Ganguly

Basic definitions

- $COP_{Ref} = Q_L/W_{net}$
- $COP_{HP} = Q_H/W_{net}$

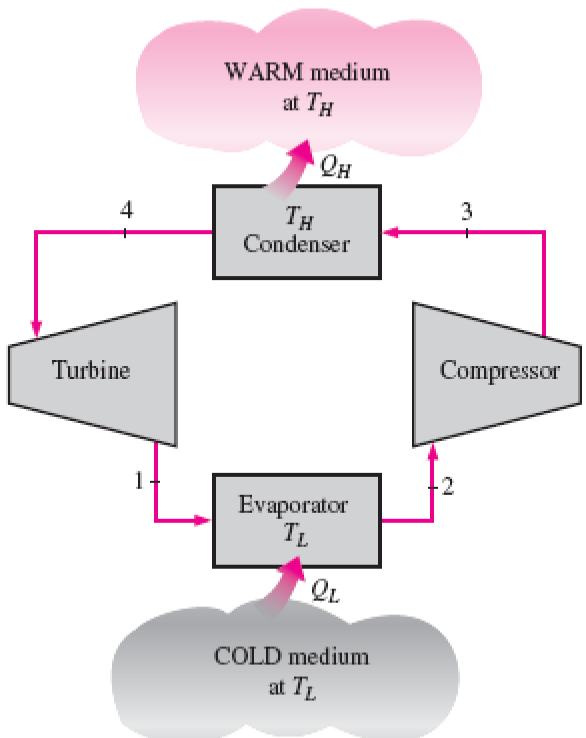
Refrigeration / cooling capacity is defined in terms of *<u>Ton of refrigeration</u>*
Definition: The capacity of a refrigeration system that can freeze 1 ton (964 kg) of liquid water at 0°C into ice at 0°C in 24 h

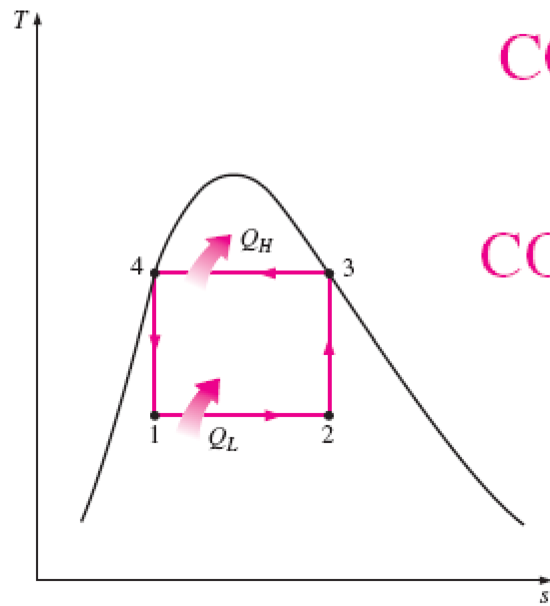
1 T $\cong$ 211 kJ/min = 3.52 kW



(a) Refrigerator (b) Heat pump

The reversed Carnot Cycle





$$\text{COP}_{\text{R,Carnot}} = \frac{1}{T_H/T_L - 1}$$

$$\text{COP}_{\text{HP,Carnot}} = \frac{1}{1 - T_L/T_H}$$

$$Q_H = (h_3 - h_4)$$

$$Q_L = (h_2 - h_1)$$

$$W_c = (h_3 - h_2)$$

$$W_{exp} = (h_4 - h_1)$$

Practical difficulties

(i) Problem associated with wet vapor compression (2—3) and expansion in a rotary expander (4—1).

(ii) Work output of the isentropic expansion (4—1) is too small to justify the cost of the expander.

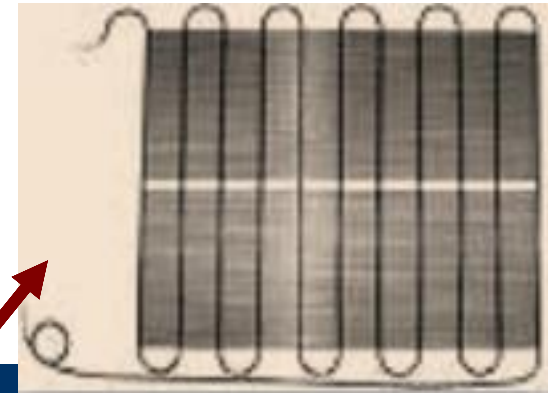
Improvements over the reversed Carnot cycle

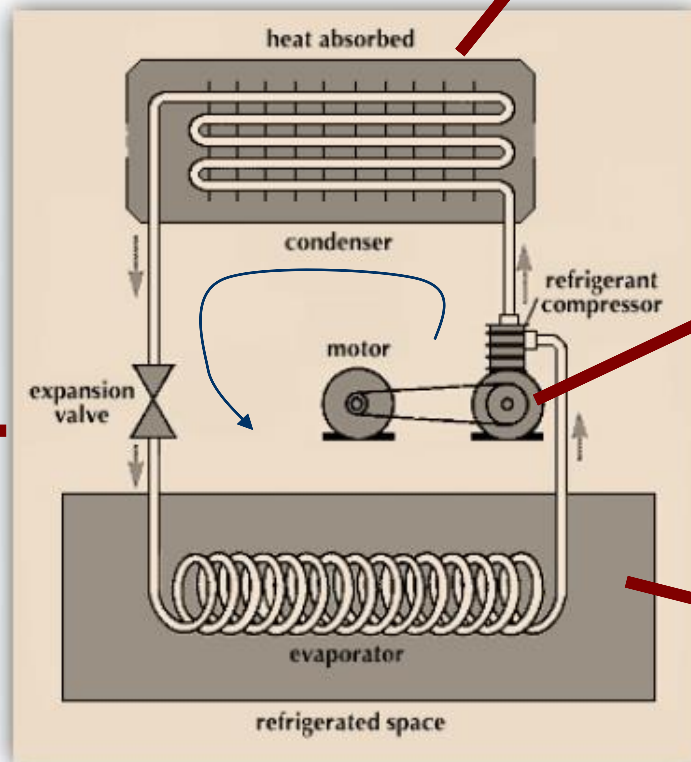
- In a basic vapor-compression refrigeration cycle, the refrigerant enters the compressor as a saturated vapor (and not wet) so that the compression in the compressor is trouble-free.

- An expansion valve replace the turbine and hence, the isentropic expansion is replaced with a throttling process.

Basic Components

Condenser



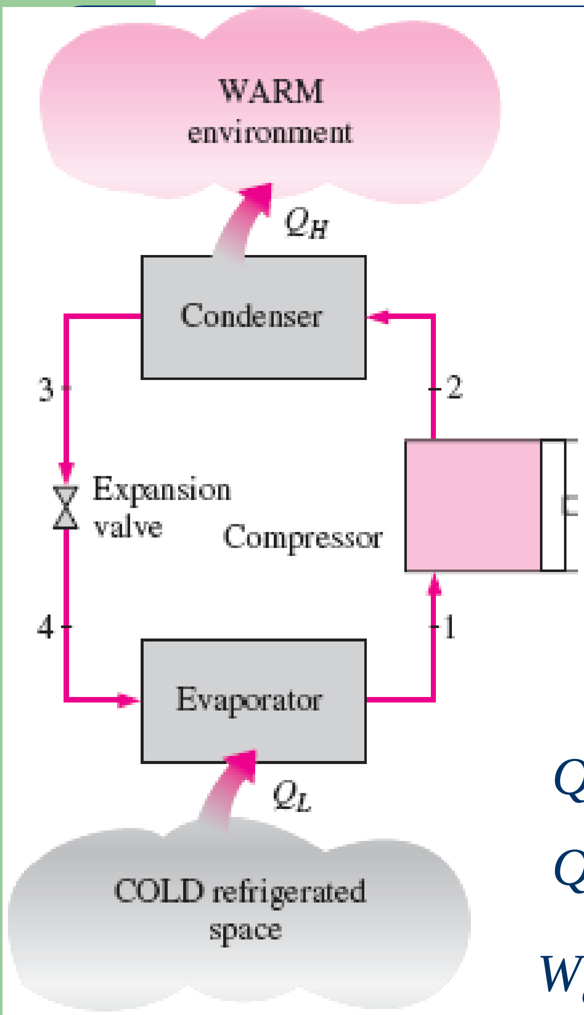


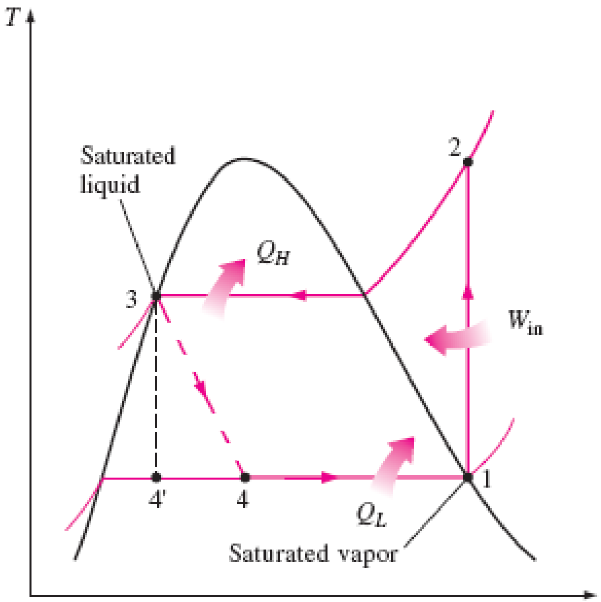
Compressor

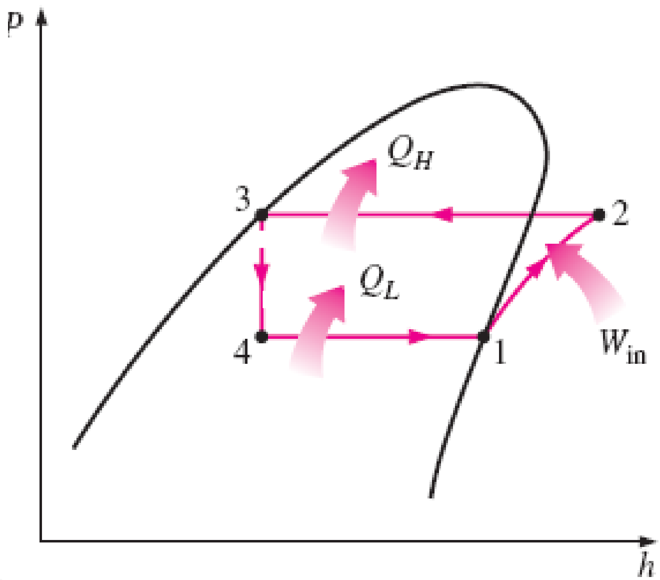
Expansion Valve

Evaporator

Ideal vapor compression refrigeration cycle







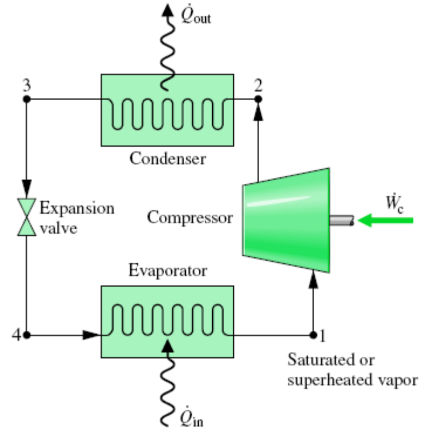
$$Q_H = (h_2 - h_3)$$

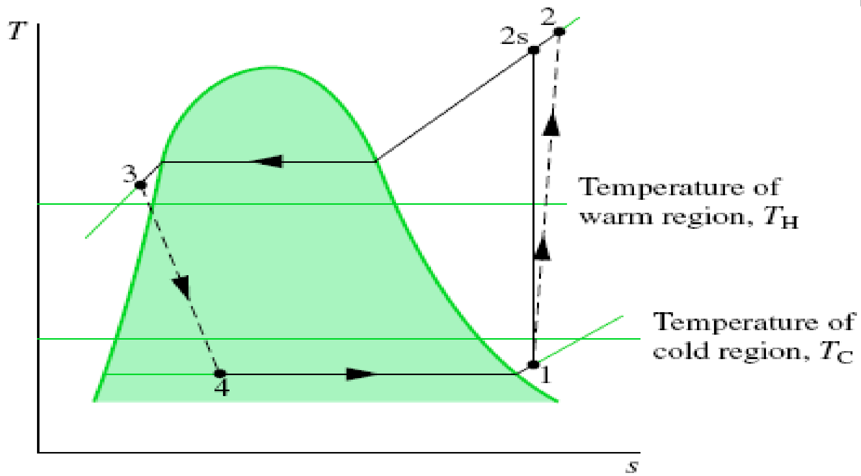
$$Q_L = (h_1 - h_4)$$

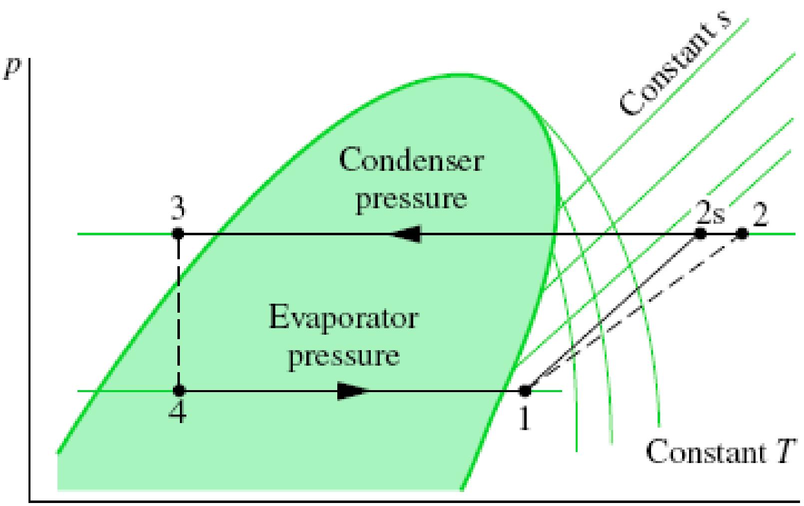
$$W_c = (h_2 - h_1); \quad W_{exp} = 0$$

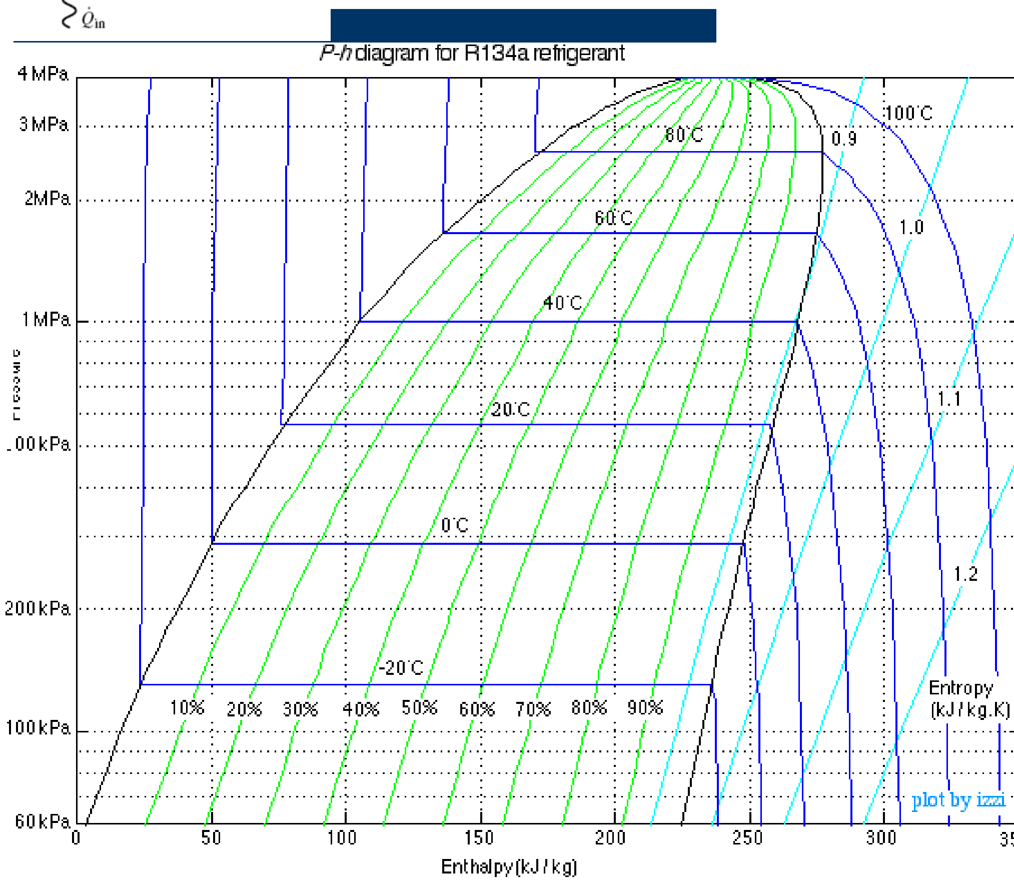
1-2	Isentropic compression in a compressor
2-3	Constant-pressure heat rejection in a condenser
3-4	Throttling in an expansion device
4-1	Constant-pressure heat absorption in an evaporator

P-h diagram









p-h diagram for R134a

A typical **actual** refrigeration cycle on T-s and p-h diagrams

Ideal properties of a refrigerant

- Low boiling point and low freezing point
- Low specific heat
- High latent heat
- p_{sat} in the evaporator and condenser should be low (to reduce the material cost) and must be positive (to avoid leakage of air into the system)
- Critical pr. and temp well above the max operating p and t
- Low specific volume
- High thermal conductivity
- Chemical stability: must not react with the metal or lubricant
- Non-flammable, non-explosive, non-toxic and non-corrosive
- Environment friendly
- Cheap and easily available

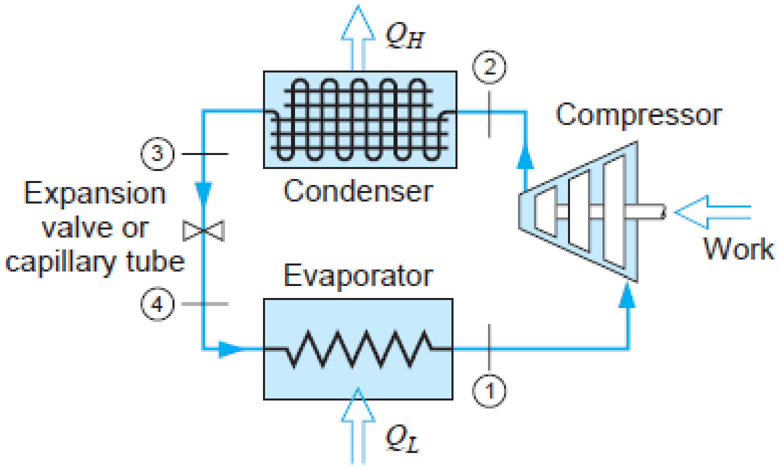
BANNED!

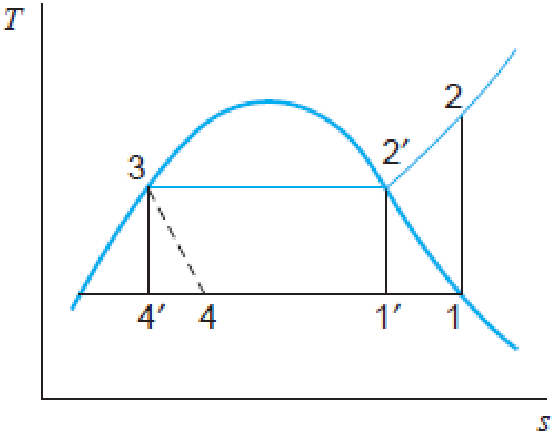
Typical Refrigerant fluids

Ammonia (NH_3)(R-717); Dichloro–Difluoro methane (Freon–12) (R-12) [CCl_2F_2];
Carbon Dioxide (R744); Refrigerant 134a (CF_3CH_2F)

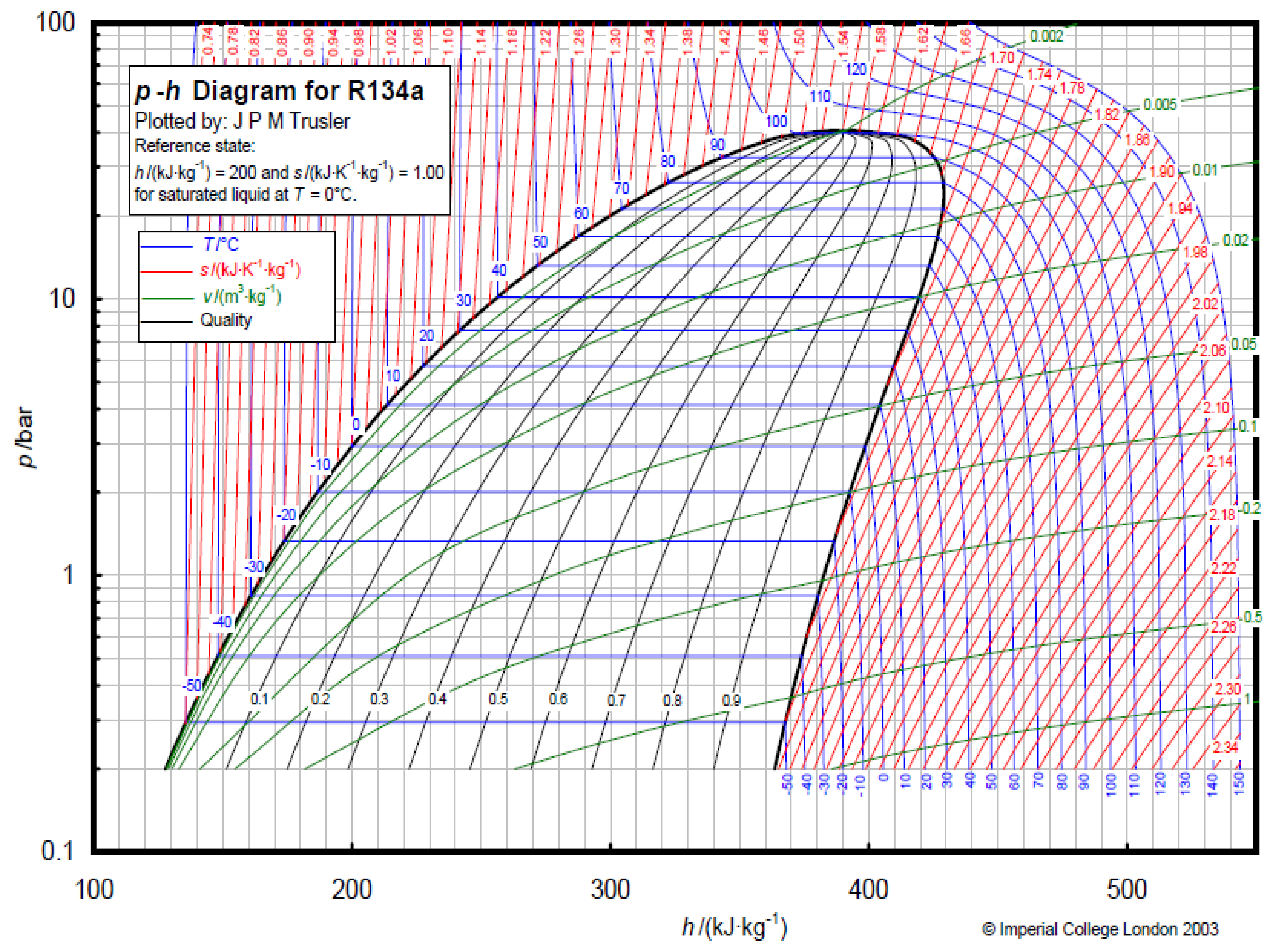
Sample problem

A refrigerator with R-134a as the working fluid has a minimum temperature of −10◦C and a maximum pressure of 1 MPa. Assume an ideal refrigeration cycle. Find the specific heat transfer from the cold space and that to the hot space, and determine the COP.





Also, calculate the COP of the Carnot refrigeration cycle operating between the two pressures



p -h Diagram for R134a
Plotted by: J P M Trusler
Reference state:
h /(kJ·kg-1) = 200 and s /(kJ·K-1·kg-1) = 1.00
for saturated liquid at T = 0°C.
T /°C
s /(kJ·K-1·kg-1)
v /(m3·kg-1)
Quality
p /bar
100
10
1
0.1
h /(kJ·kg-1)
100
200
300
400
500
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
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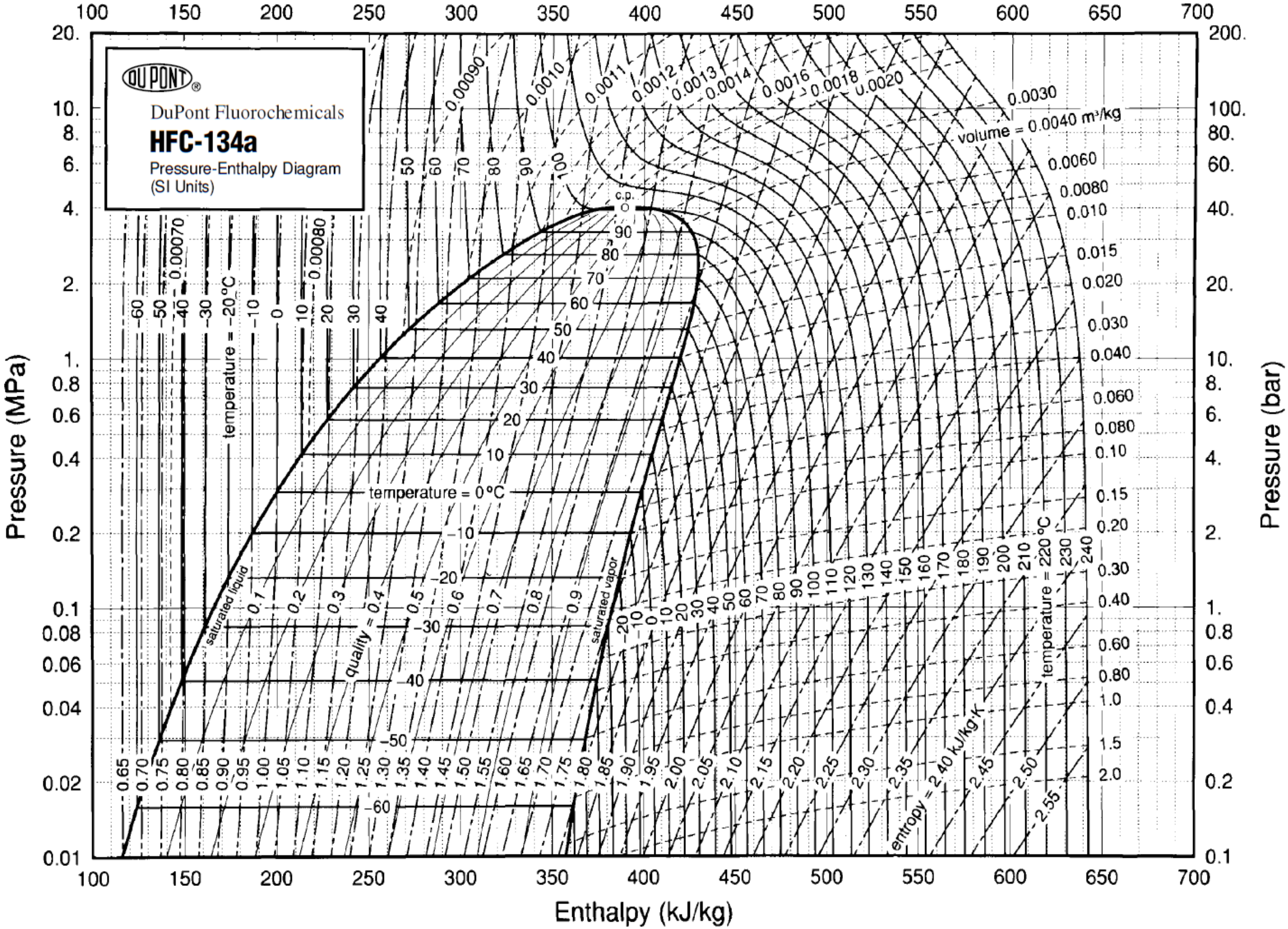

DUPONT®
DuPont Fluorochemicals
HFC-134a
Pressure-Enthalpy Diagram
(SI Units)
Pressure (MPa)
Pressure (bar)
Enthalpy (kJ/kg)
100 150 200 250 300 350 400 450 500 550 600 650 700
20. 10. 8. 6. 4. 2. 1. 0.8 0.6 0.4 0.2 0.1 0.08 0.06 0.04 0.02 0.01
200. 100. 80. 60. 40. 20. 10. 8. 6. 4. 2. 1. 0.8 0.6 0.4 0.2 0.1
c.p.
saturated liquid
saturated vapor
quality = 0.4
temperature = 0 °C
temperature = −20 °C
temperature = 220 °C
volume = 0.0040 m³/kg
entropy = 2.40 kJ/kg·K