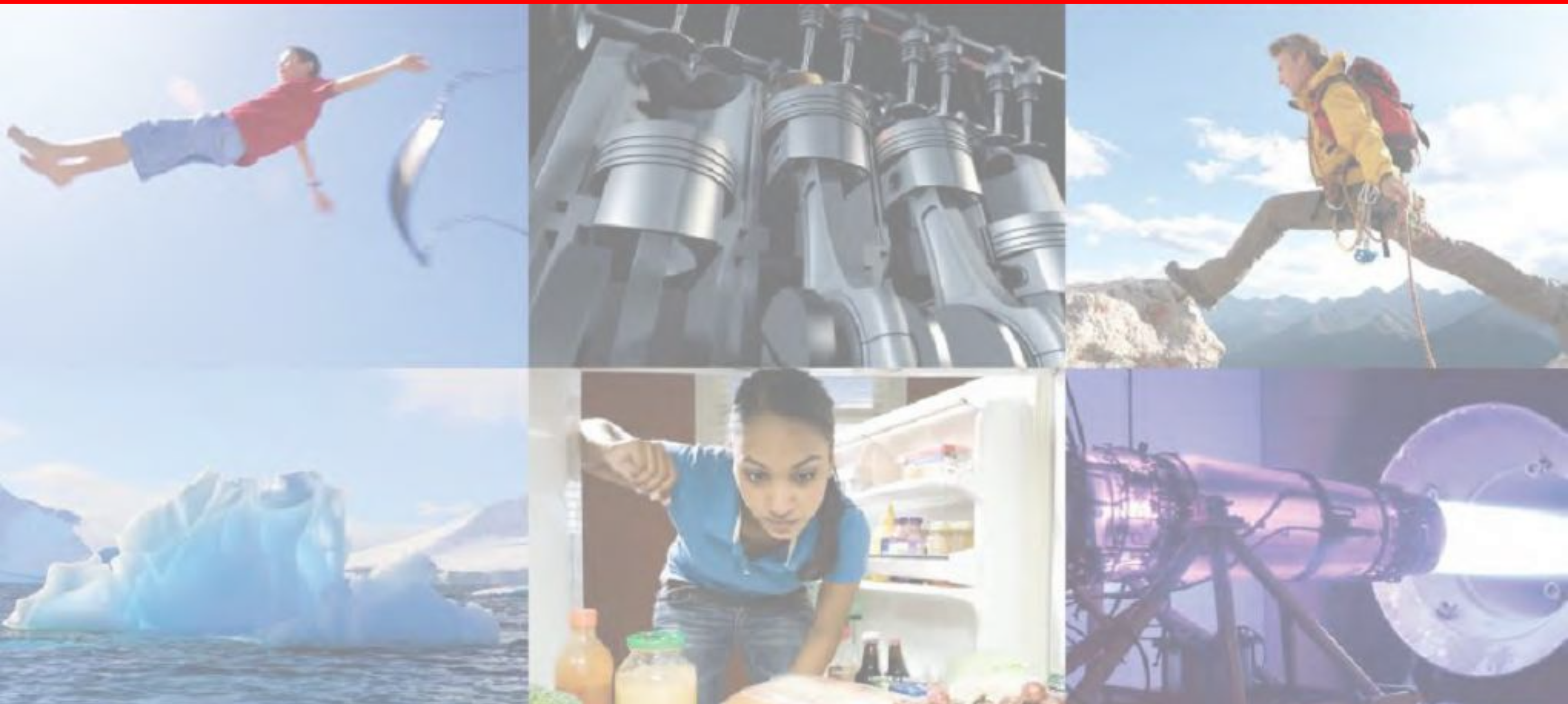


Refrigeration System

By Ertanto Vetra

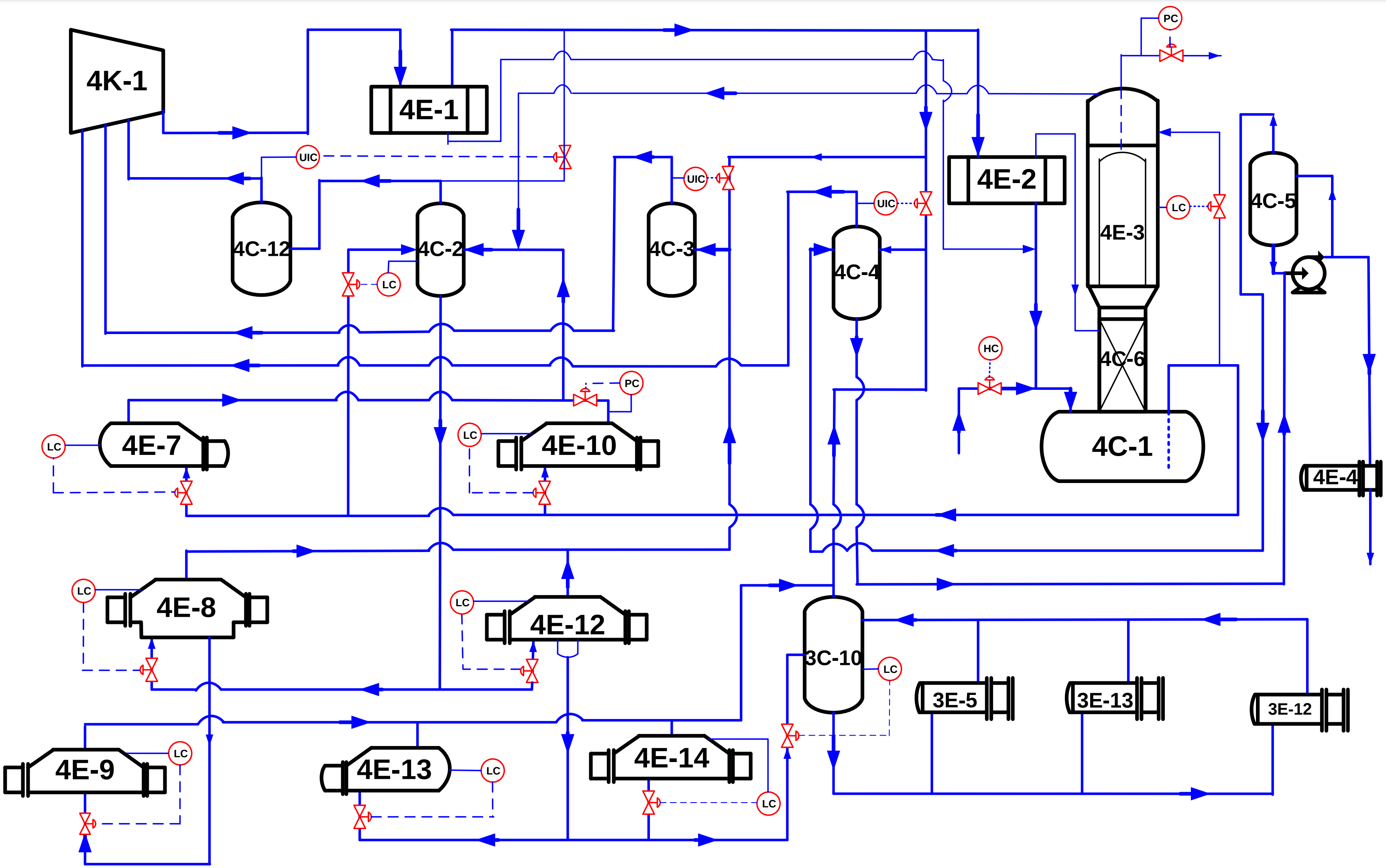
Outlines

- Introduction
- Overview
- Ideal Vapor Compression Refrigeration Cycle
- PH Diagram

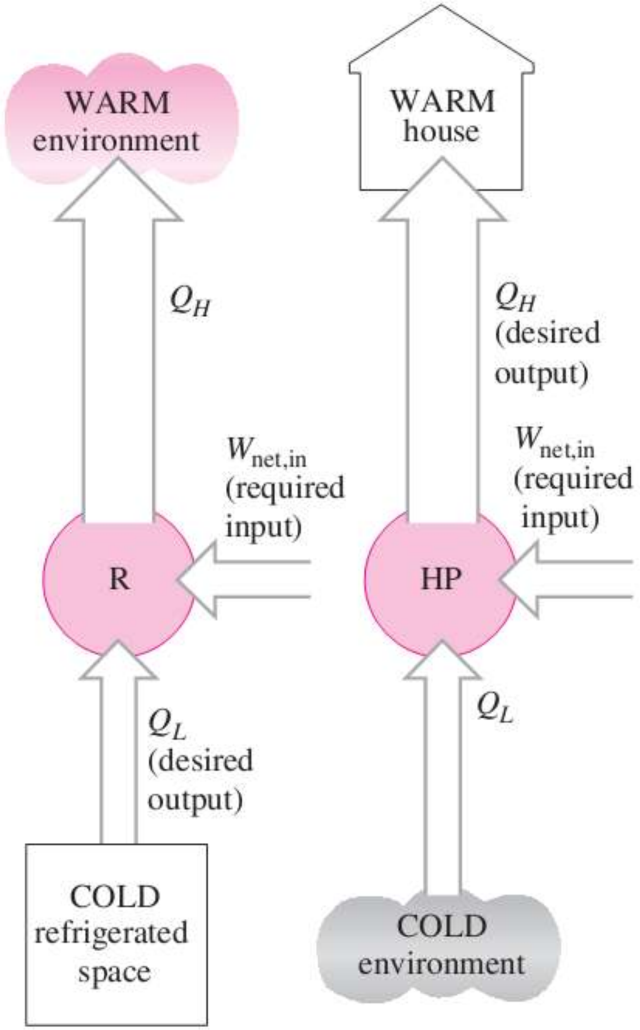
Introduction

Introduction

Introduction



Overview



(a) Refrigerator (b) Heat pump

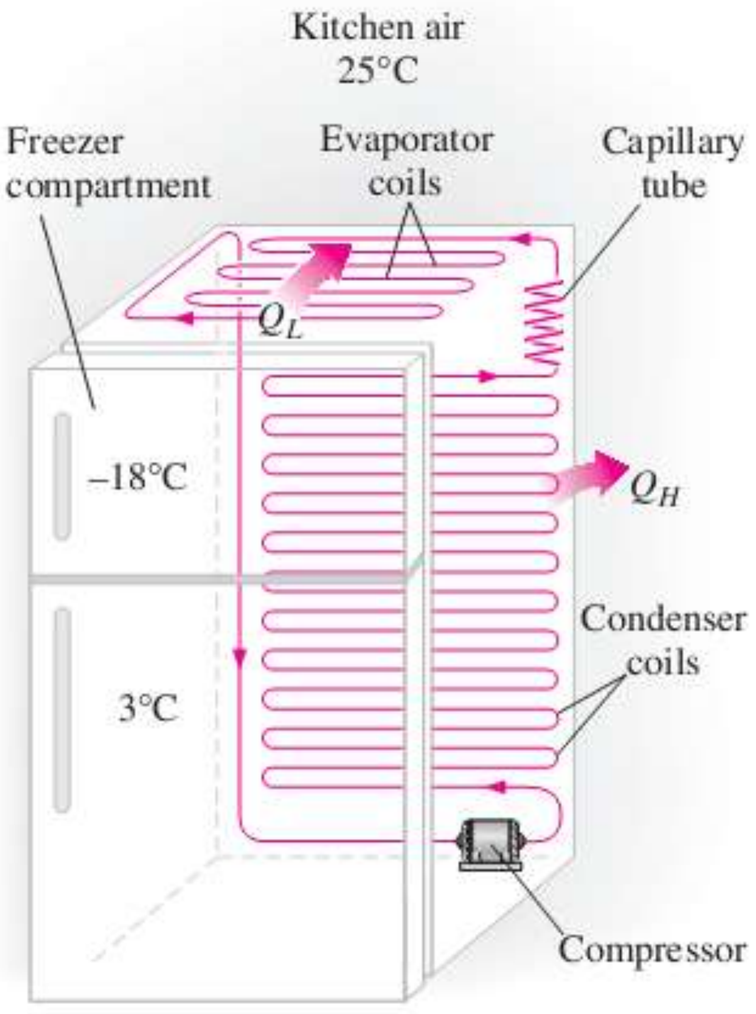
$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{net,in}}$$

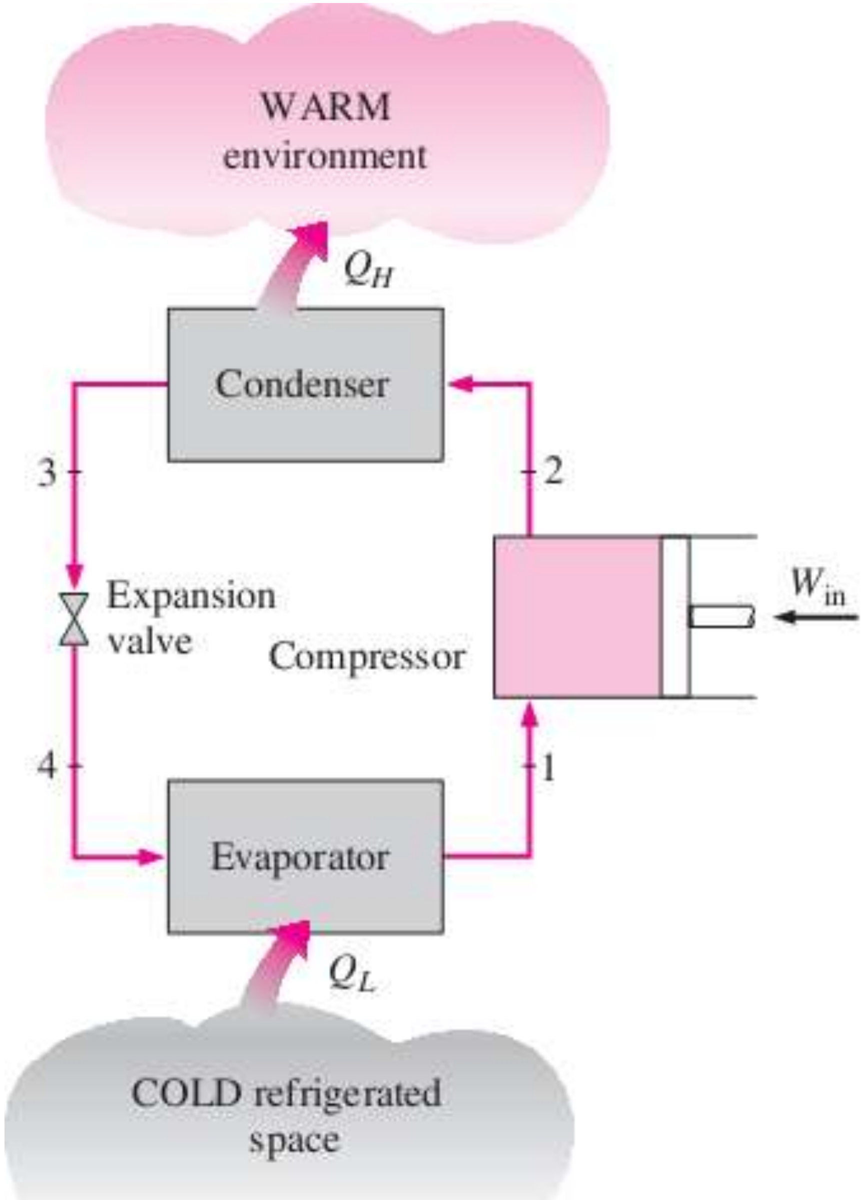
$$COP_{HP} = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Heating effect}}{\text{Work input}} = \frac{Q_H}{W_{net,in}}$$

$$COP_{HP} = COP_R + 1$$

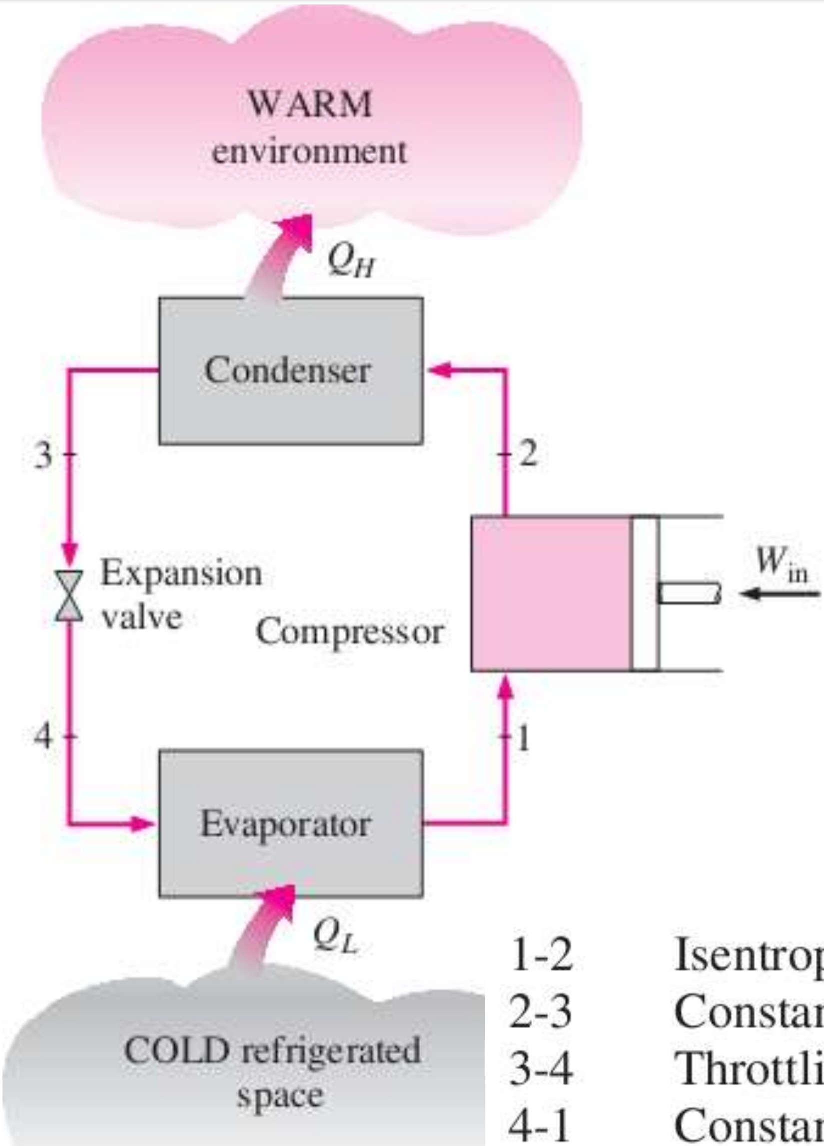
- Cooling capacity of a refrigeration system = the rate of heat removal from the refrigerated space (expressed in tons of refrigeration)
- The capacity of a refrigeration system that can freeze 1 ton (2000 lbm) of liquid water at 0°C (32°F) into ice at 0°C in 24 h is said to be 1 ton.
- One ton of refrigeration is equivalent to 211 kJ/min or 200 Btu/min.
- The cooling load of a typical 200-m2 residence is in the 3-ton (10-kW) range

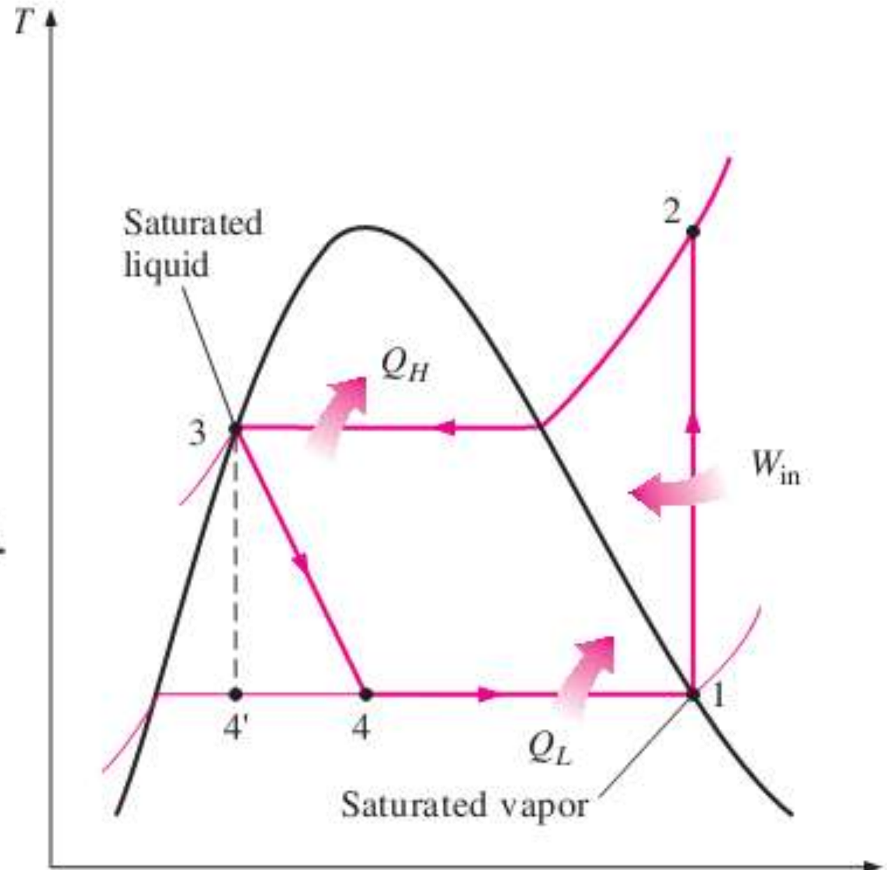
Ideal Vapor Compression Refrigeration Cycles





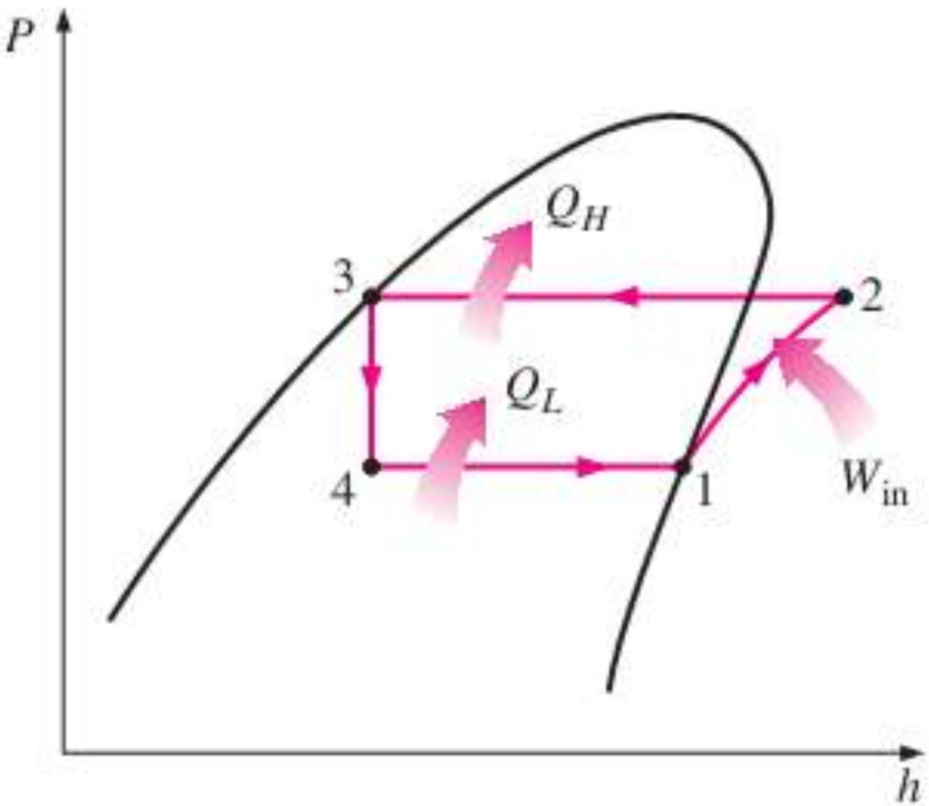
Ideal Vapor Compression Refrigeration Cycles





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

Ideal Vapor Compression Refrigeration Cycles



Evaporator 4→1

$$\frac{\dot{Q}_{in}}{\dot{m}} = h_1 - h_4$$

Condenser 2→3

$$\frac{\dot{Q}_{out}}{\dot{m}} = h_2 - h_3$$

Compressor 1→2

$$\frac{\dot{W}_c}{\dot{m}} = h_2 - h_1$$

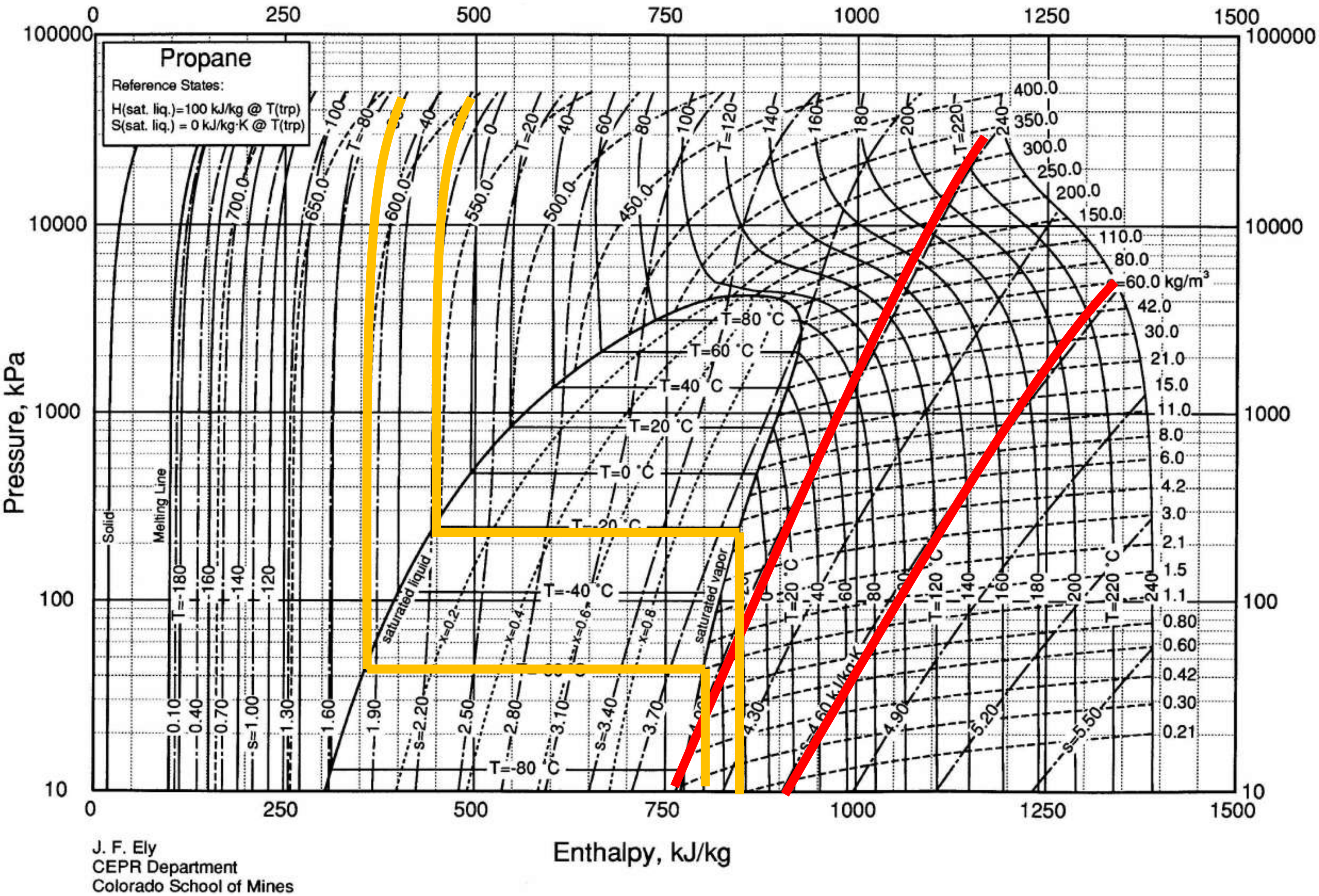
J-T Expansion 3→4

$$h_4 = h_3$$

$$\text{COP}_R = \frac{q_L}{w_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1} \qquad \text{COP}_{HP} = \frac{q_H}{w_{net,in}} = \frac{h_2 - h_3}{h_2 - h_1}$$

where $h_1 = h_{g\,@\,P_1}$ and $h_3 = h_{f\,@\,P_3}$ for the ideal case.

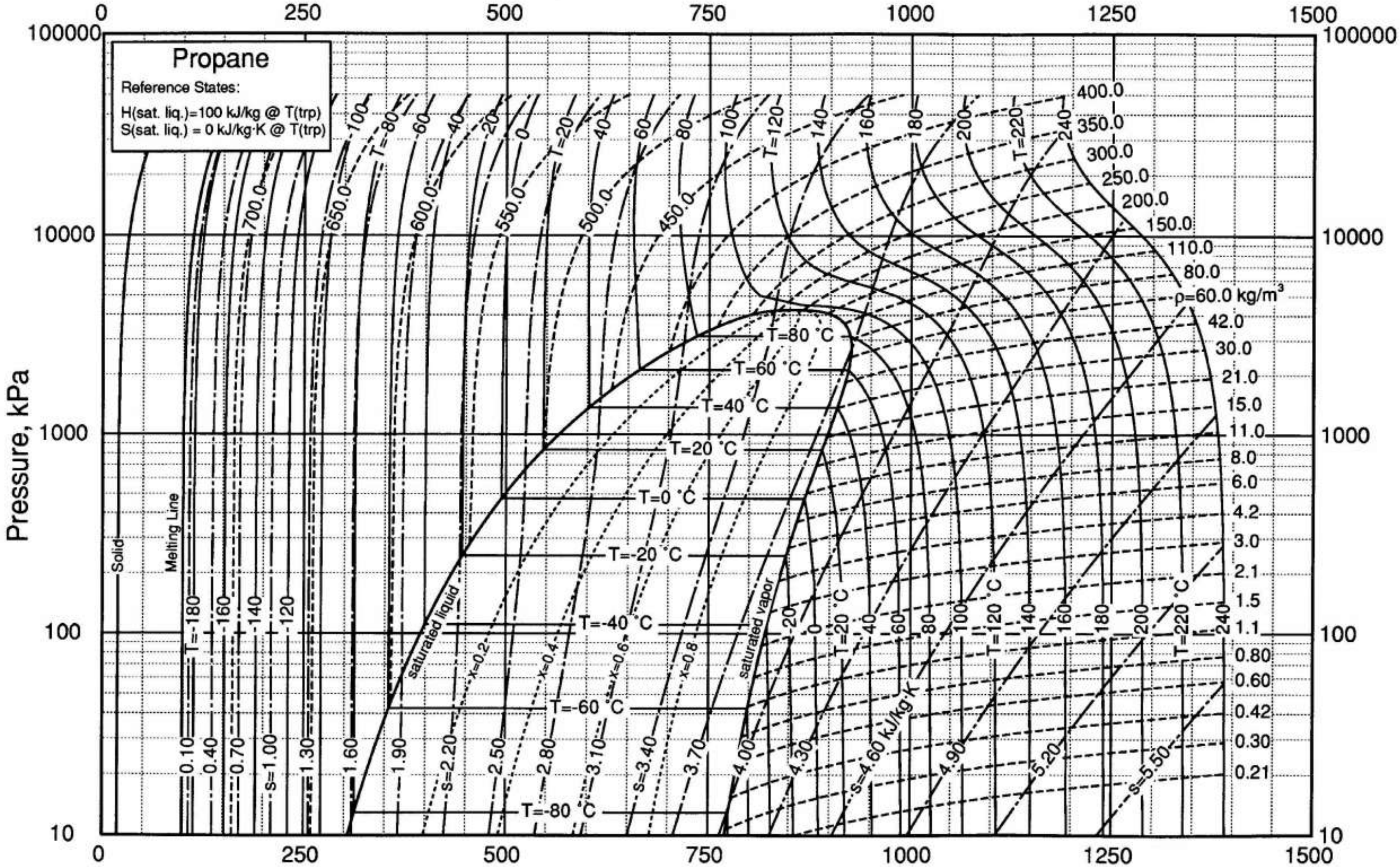
P-H Diagram (Propane)



PH Diagram Exercise

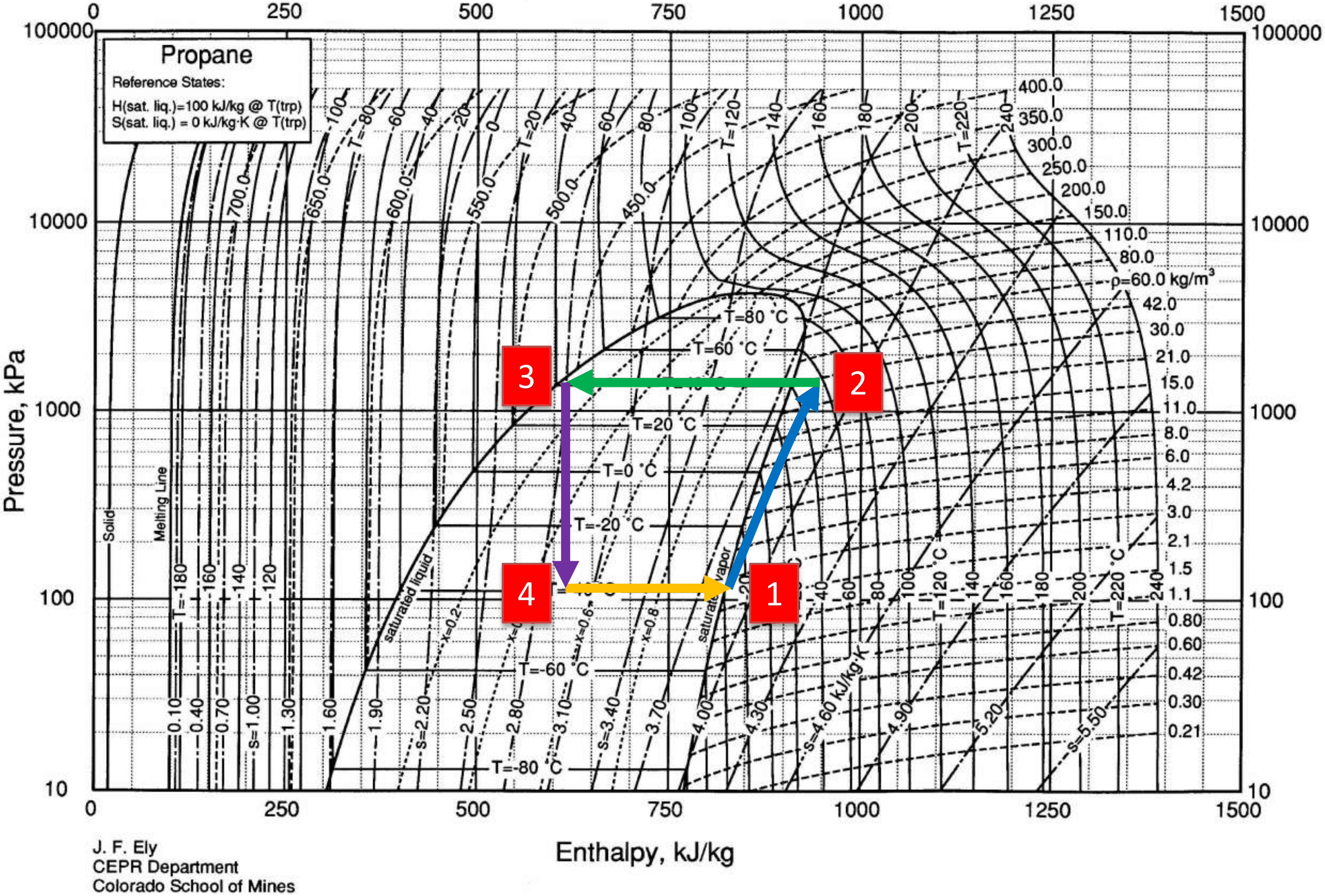
An ideal Propane Refrigeration Cycle is used to cool a process stream from 5°C to -35°C. The cycle rejects heat to the environment using a cooling water with the inlet CW temp = 35 °C. If it is assumed that the minimum temperature approach in the exchanger is 5 °C. Determine:

- P-H Diagram Plot
- The Operating Pressure of Propane Evaporator & Condenser
- Duty of Propane Evaporator, Condenser, Compressor, and cycle COP
  – Compare with the results obtained by using property tables (A16 to A18)



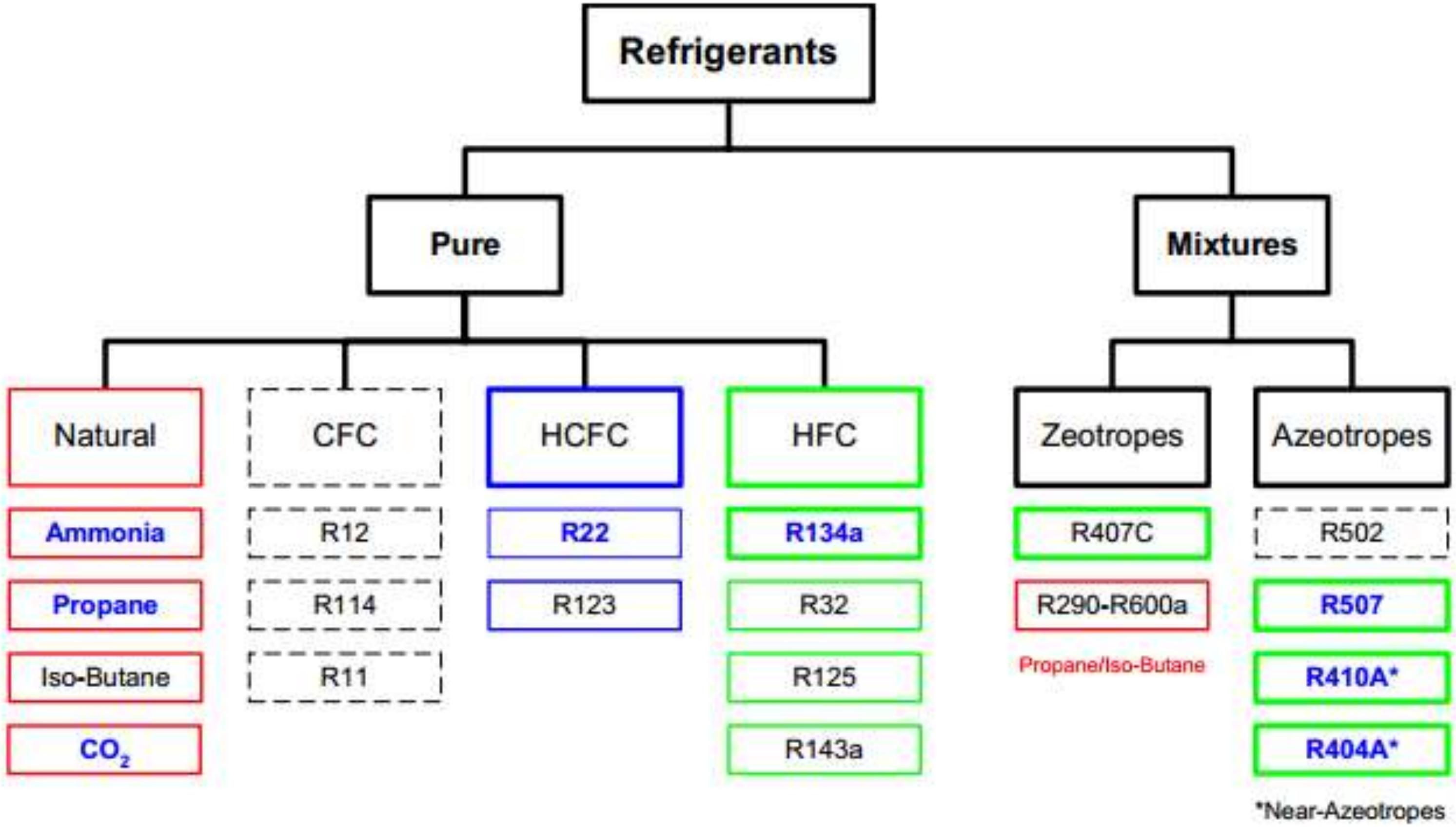
Propane
Reference States:
H(sat. liq.)=100 kJ/kg @ T(trp)
S(sat. liq.) = 0 kJ/kg·K @ T(trp)
Pressure, kPa
saturated liquid
saturated vapor
Solid
Melting Line
ρ=60.0 kg/m³
s=4.60 kJ/kg·K
T=80 °C
T=60 °C
T=40 °C
T=20 °C
T=0 °C
T=-20 °C
T=-40 °C
T=-60 °C
T=-80 °C
x=0.2
x=0.4
x=0.6
x=0.8

P-H Diagram (Propane)



Refrigerant Selection

Refrigerant Classification



Used in or considered for Refrigeration

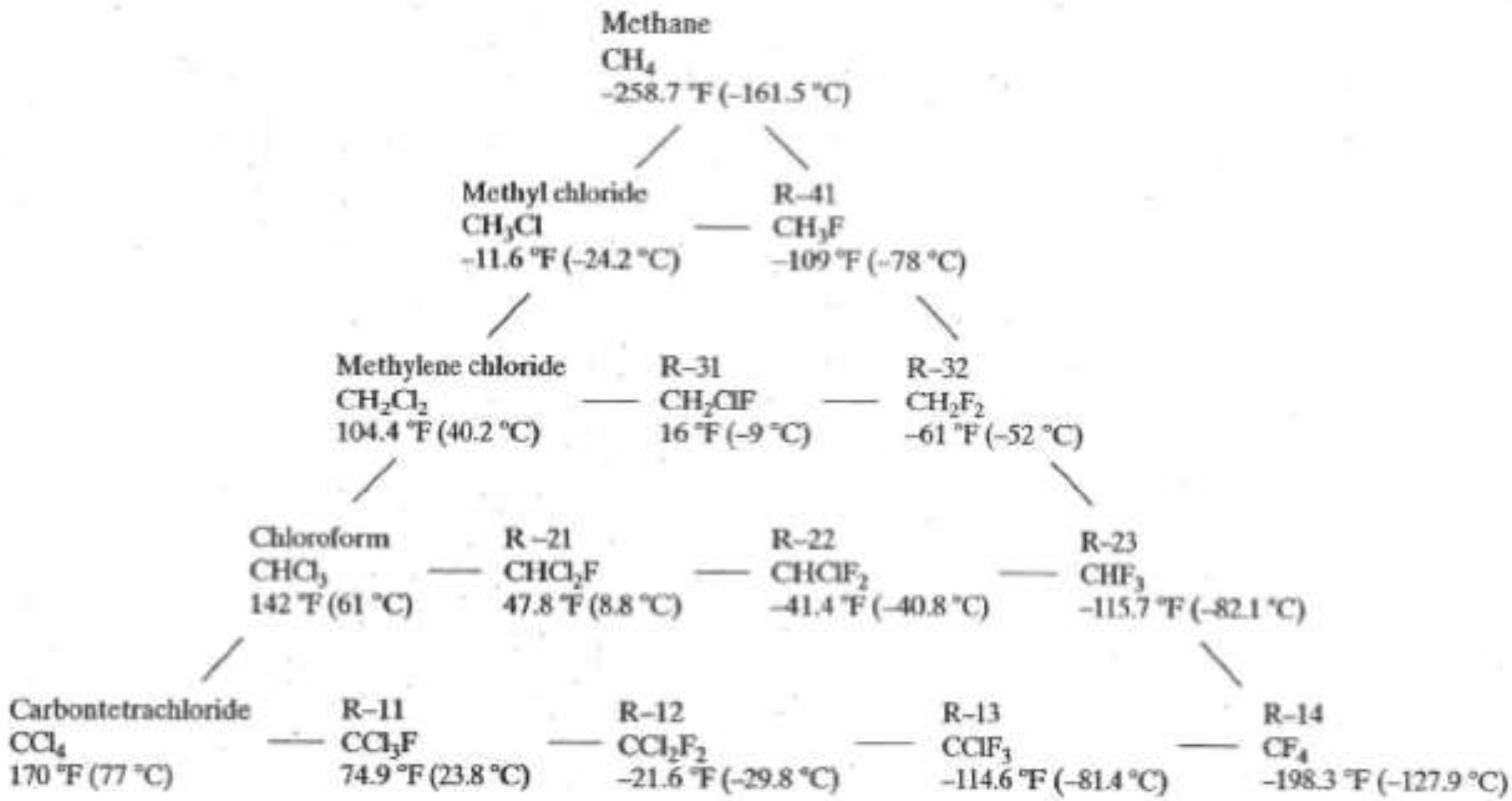
ASHRAE Refrigerant Safety Classification

	Low/No Toxicity	High Toxicity
No Flammability	A1 R11, R12, R22, R125, R134a, R407C, R507, R404A, R410A, R744	B1 R123, R764, R21
Low Flammability	A2 R32, R142b, R143a, R152a	B2 NH_3
High Flammability	A3 R170, R290, R600a, R1150	B3 R1140

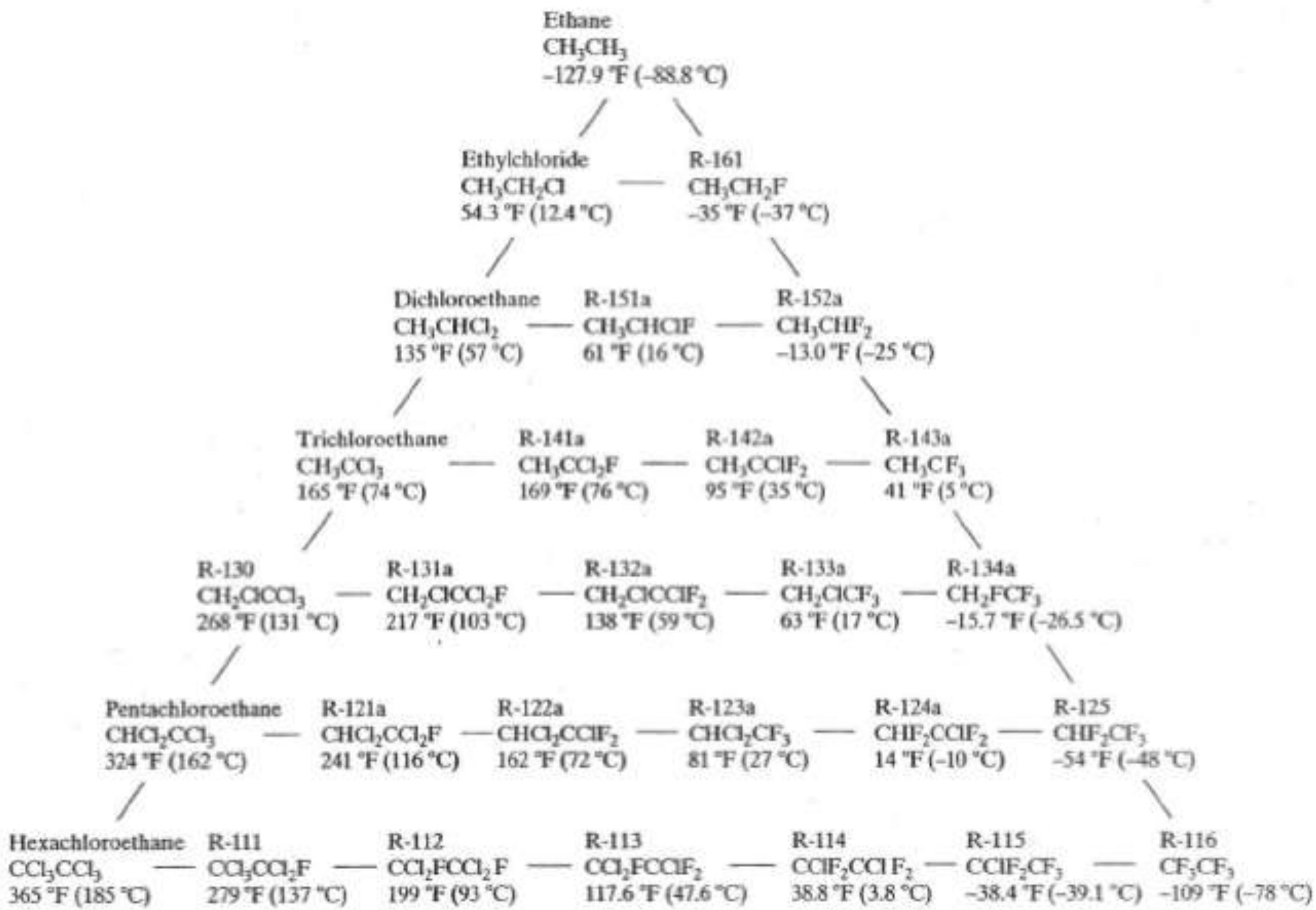
Refrigerants marked in Red are ozone depleting substances that are no longer used in new equipment.

Refrigerants marked in Green are natural refrigerants that have low GWP, as well as no ODP.

Refrigerants: Methane Group



Refrigerants: Ethane Group



ODP and GWP for Various Refrigerants

Refrigerant	ODP	GWP	Refrigerant	ODP	GWP
CFC-11	1.0	1.0	HFC-125	0.0	0.84
CFC-12	1.0	3.05	HFC-134	0.0	0.25
CFC-13	N/A	N/A	HFC-134a	0.0	0.25
HCFC-22	0.051	0.370	HFC-143a	0.0	1.2
HFC-23	0.0	N/A	HFC-152a	0.0	0.029
HFC-32	0.0	0.130	R500	0.78	2.39
CFC-113	0.87	1.300	R502	0.245	5.10
CFC-114	0.74	4.150	R503	N/A	N/A
HCFC-123	0.016	0.019	R410A	0.0	0.49
HCFC-123a	0.016	0.019	R507	0.0	0.96
HCFC-124	0.018	0.095			

ODP (Ozone Depletion Potential), and GWP (Greenhouse Warming Potential) are calculated relative to CFC R11.

Refrigerant Comparison

Refrigerant	CO_2	R12	R22	R134a	R404A	R410A	C_3H_8	NH_3
Natural?	Yes	No	No	No	No	No	Yes	Yes
Flammable?	No	No	No	No	No	No	Yes	Yes
Toxic?	No	No	No	No	No	No	No	Yes
Relative Cost	0.1	-	(1.0)	4.0	5.0	5.0	0.3	0.2
Volum. Capacity	4.8	0.6	(1.0)	0.7	1.2	1.5	0.9	1.0
Critical Temp.(F)	88	234	205	214	163	158	206	270
P @ 70F (psia)	852	85	136	86	165	216	125	129
ODP	0	1.0	0.05	0	0	0	0	0
GWP (100yr)	(1.0)	7100	1500	1300	3750	1730	3	0

(1.0) means reference value

Refrigerant Selection

- Two important parameters that need to be considered are ***the temperatures of the two media (the refrigerated space and the environment)*** with which the refrigerant exchanges heat.

- To have heat transfer at a reasonable rate, a temperature difference of 5 to 10°C should be maintained between the refrigerant and the medium with which it is exchanging heat.

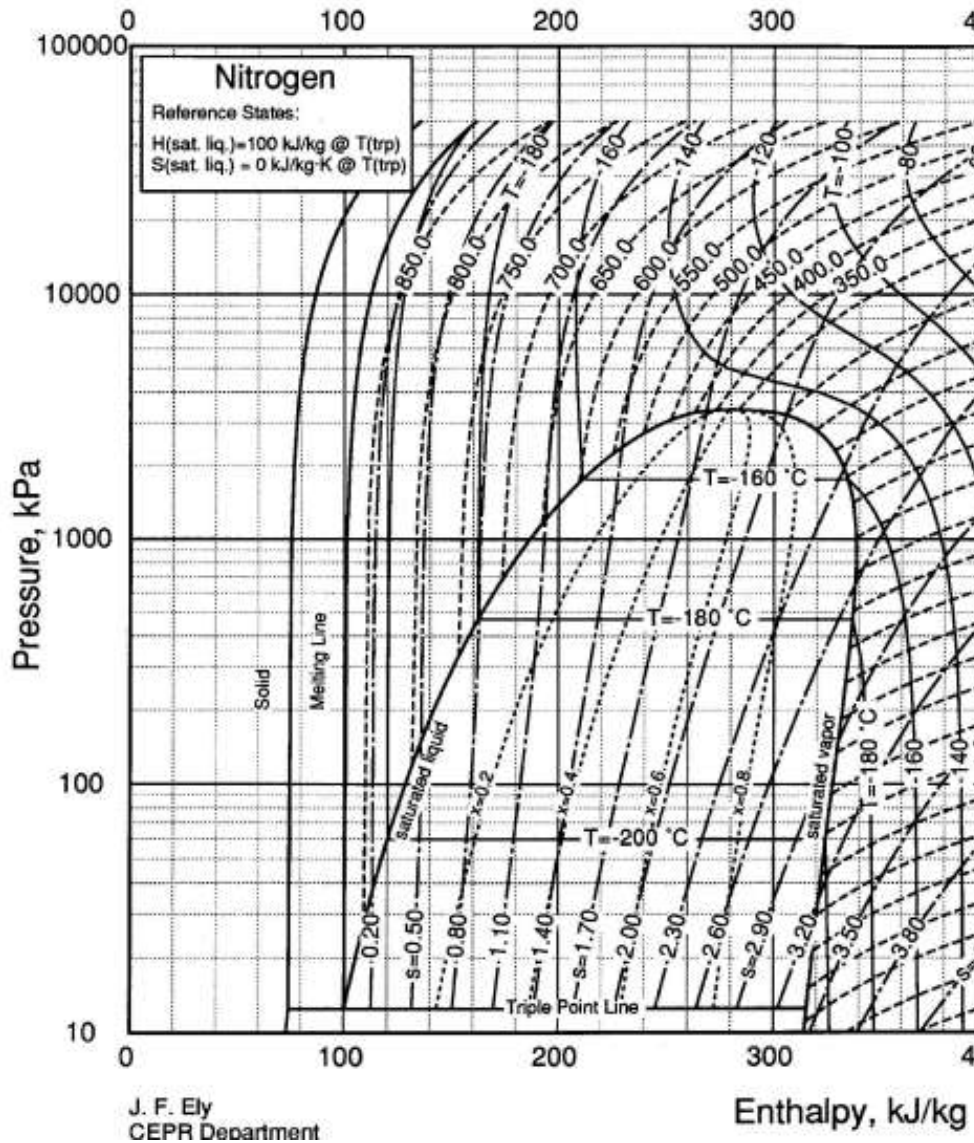
- If a refrigerated space is to be maintained at -10°C, for example, the temperature of the refrigerant should remain at about -20°C while it absorbs heat in the evaporator.

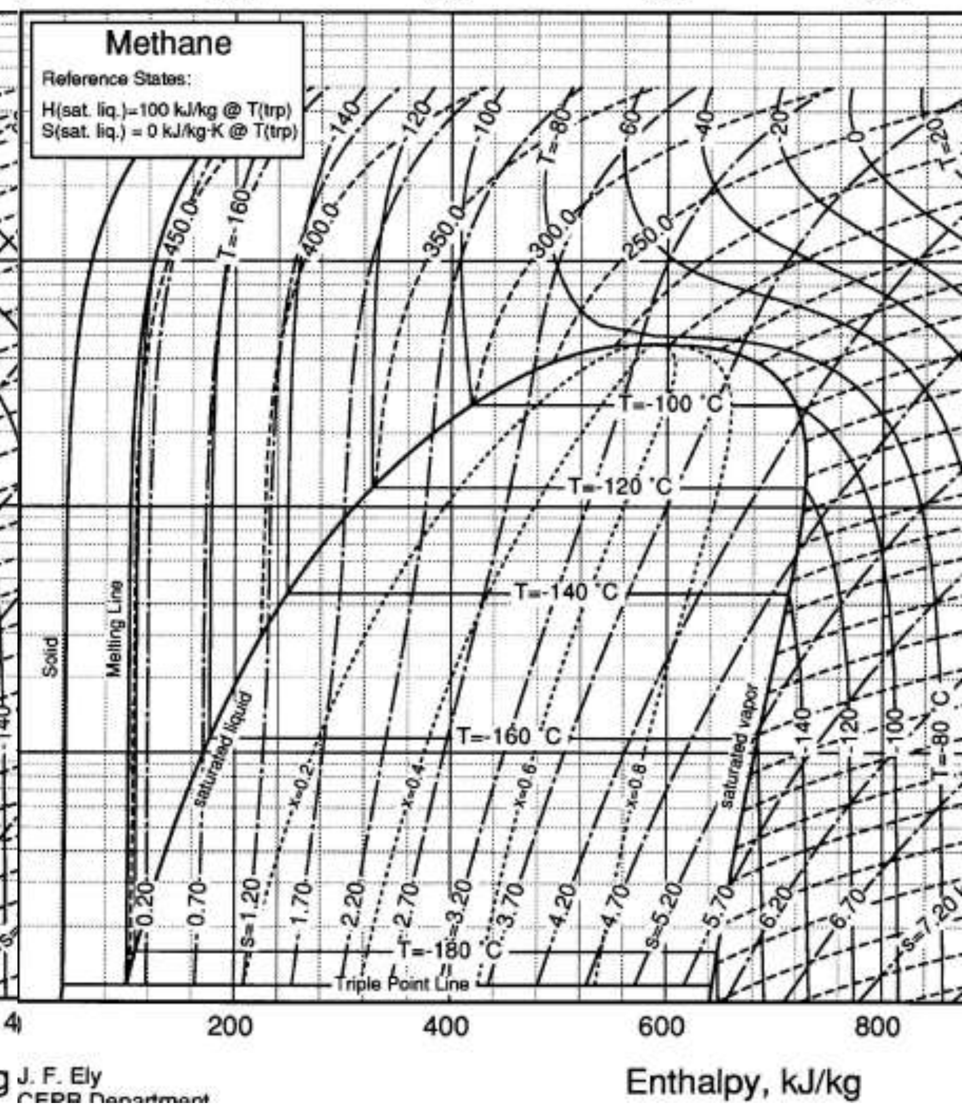
Refrigerant Selection

- **Freezing point**
  Evaporator T should be well above freezing T at operating P
- **Vacuum operation**
  Evaporator P below atm P should be avoided. (however in some cases is still possible with some precautions)
- **Latent heat of vaporization**
  Higher latent heat → lower flow rate of refrigerant, reduces the compression power

Refrigerant	Freezing point at atmospheric pressure (°C)	Boiling point at atmospheric pressure (°C)
Ammonia	−78	−33
Chlorine	−101	−34
n-butane	−138	0
i-butane	−160	−12
Ethylene	−169	−104
Ethane	−183	−89
Methane	−182	−161
Propane	−182	−42
Propylene	−185	−48
Nitrogen	−210	−196

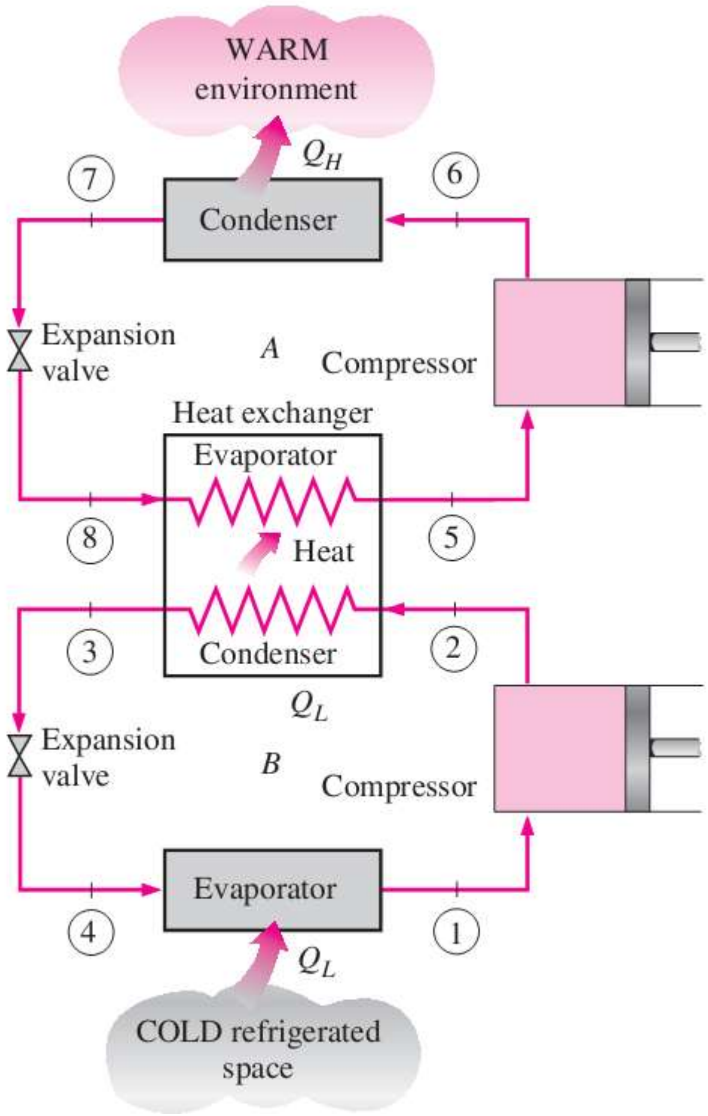
- **General considerations**
  Always available, nontoxic, non flammable,non corrosive & have a low GHG emission.
  - NG processing using C1,C2,or C3 refrigerant
  - Olefins plant using ethylene, propylene
  - Halocarbons refrigerant are nonflammable

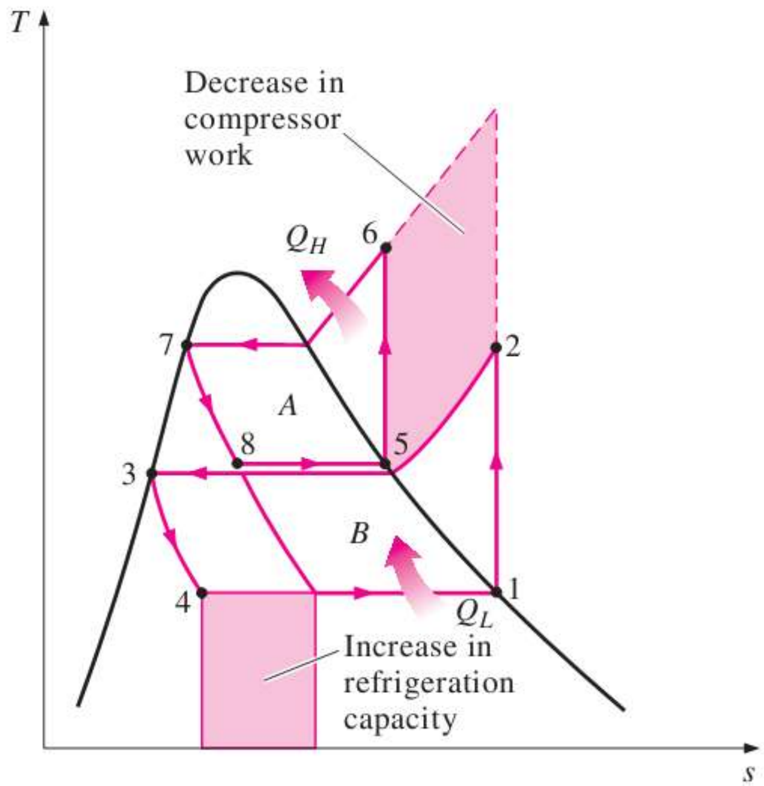




Analyze These…

Cascade Cycle

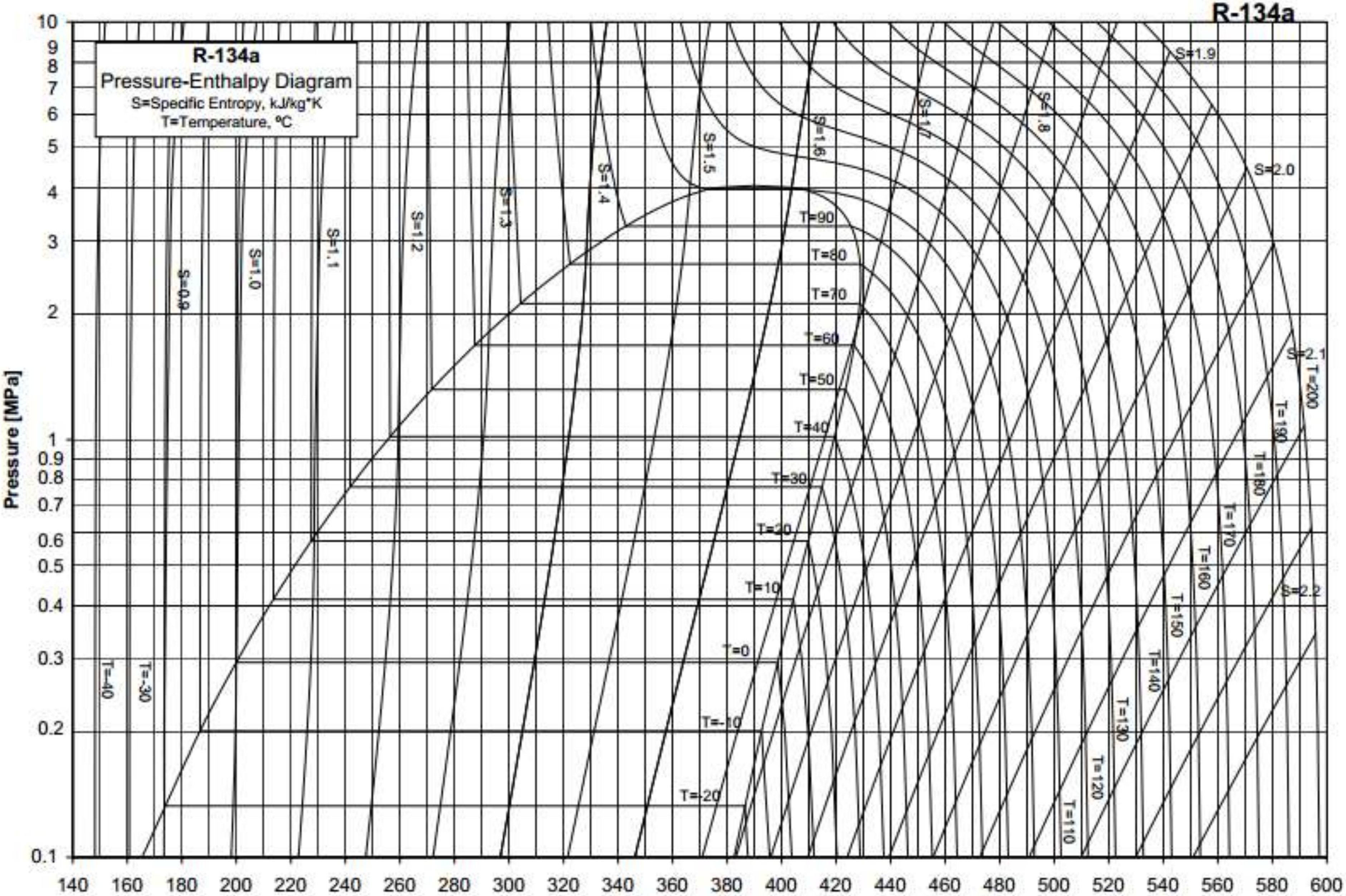




Exercise – Cascade Cycle

Consider a two-stage cascade refrigeration system operating between the pressure limits of 0.8 and 0.14 MPa. Each stage operates on an ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid. Heat rejection from the lower cycle to the upper cycle takes place in an adiabatic counter-flow heat exchanger where both streams enter at about 0.32 MPa. If the mass flow rate of the refrigerant through the upper cycle is 0.05 kg/s, determine

1. The mass flow rate of the refrigerant through the lower cycle,
2. The rate of heat removal from the refrigerated space and the power input to the compressor, and
3. The coefficient of performance of this cascade refrigerator.



Produced by E. Hansen and I. Aartun, NTNU 1999. Based on the program Allprops, Center for Applied Thermodynamic studies, University of Idaho.

Multistage Compression with Intercooling