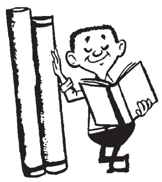
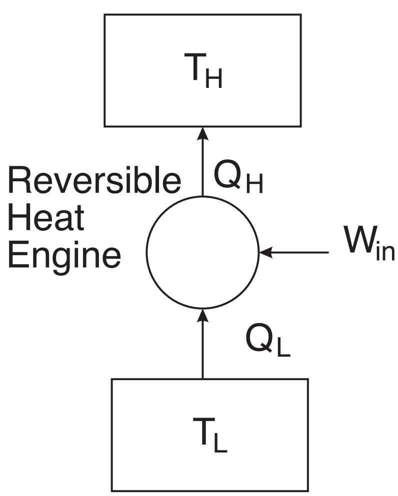
Refrigeration Cycle

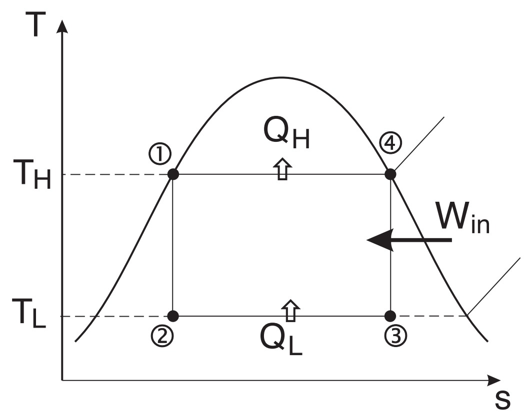


Reading	**Problems**
11-1 → 11-7, 11-9	11-11, 11-46, 11-49, 11-103

Definitions

- the 1st law of thermodynamics tells us that heat flow occurs from a hot source to a cooler sink, therefore, energy in the form of work must be added to the process to get heat to flow from a low temperature region to a hot temperature region.
- refrigeration cycles may be classified as
  - vapour compression
  - gas compression
- refrigerators and heat pumps have a great deal in common. The primary difference is in the manner in which heat is utilized.
  - ***Refrigerator*** $\underbrace{\downarrow C}_{takes\ heat\ from} \rightarrow \underbrace{H}_{transfers\ to}$
  - ***Heat Pump*** $\underbrace{C}_{takes\ heat\ from} \rightarrow \underbrace{H \uparrow}_{transfers\ to}$





The coefficient of performance (COP) is given by

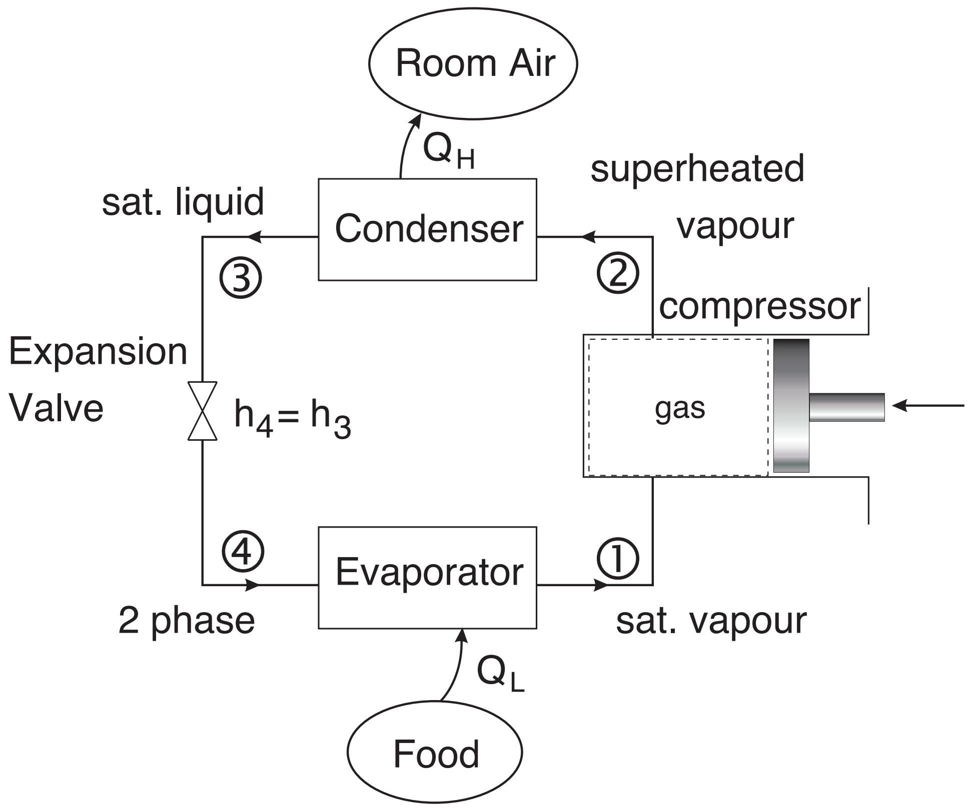
$$COP = \frac{benefit}{cost}$$

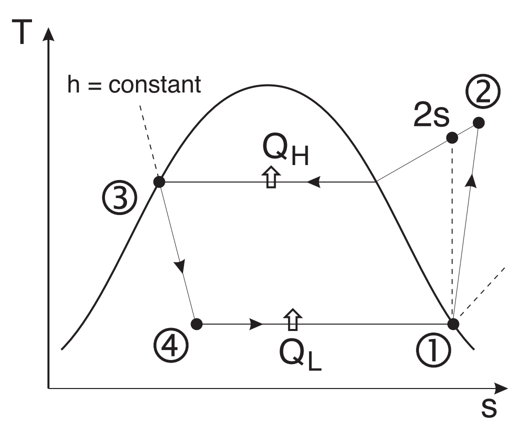
where the benefit for a refrigeration process is the cooling load given as Q_L. This is the net benefit, i.e. heat is removed from the cold space. For a heat pump, the benefit is the heat added to the hot space, i.e. Q_H.

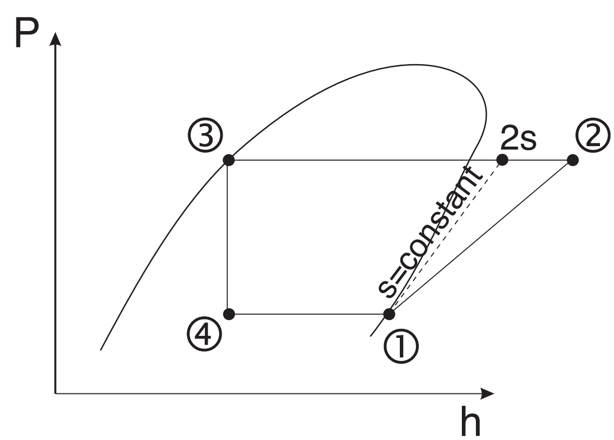
$$\begin{aligned} COP_{refrig} &= \frac{Q_L}{W_{in}} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\dfrac{Q_H}{Q_L} - 1} = \frac{1}{\dfrac{T_H(s_4 - s_1)}{T_L(s_3 - s_2)} - 1} \\ &= \frac{1}{\dfrac{T_H}{T_L} - 1} = \frac{T_L}{T_H - T_L} \end{aligned}$$

$$\begin{aligned} COP_{heat\ pump} &= \frac{Q_H}{W_{in}} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \dfrac{Q_L}{Q_H}} = \frac{1}{1 - \dfrac{T_L}{T_H}} \\ &= \frac{T_H}{T_H - T_L} \end{aligned}$$

Vapour Compression Refrigeration Cycle







Refrigeration Process

Process	Description
1-2s:	A reversible, adiabatic (isentropic) compression of the refrigerant. The saturated vapour at state 1 is superheated to state 2. $\Rightarrow \quad \boldsymbol{w_c = h_{2s} - h_1}$
2s-3:	An internally, reversible, constant pressure heat rejection in which the working substance is desuperheated and then condensed to a saturated liquid at 3. During his process, the working substance rejects most of its energy to the condenser cooling water. $\Rightarrow \quad \boldsymbol{q_H = h_{2s} - h_3}$
3-4	An irreversible throttling process in which the temperature and pressure decrease at constant enthalpy. $\Rightarrow \quad \boldsymbol{h_3 = h_4}$
4-1	An internally, reversible, constant pressure heat interaction in which the working fluid is evaporated to a saturated vapour at state point 1. The latent enthalpy necessary for evaporation is supplied by the refrigerated space surrounding the evaporator. The amount of heat transferred to the working fluid in the evaporator is called the refrigeration load. $\Rightarrow \quad \boldsymbol{q_L = h_1 - h_4}$

Common Refrigerants

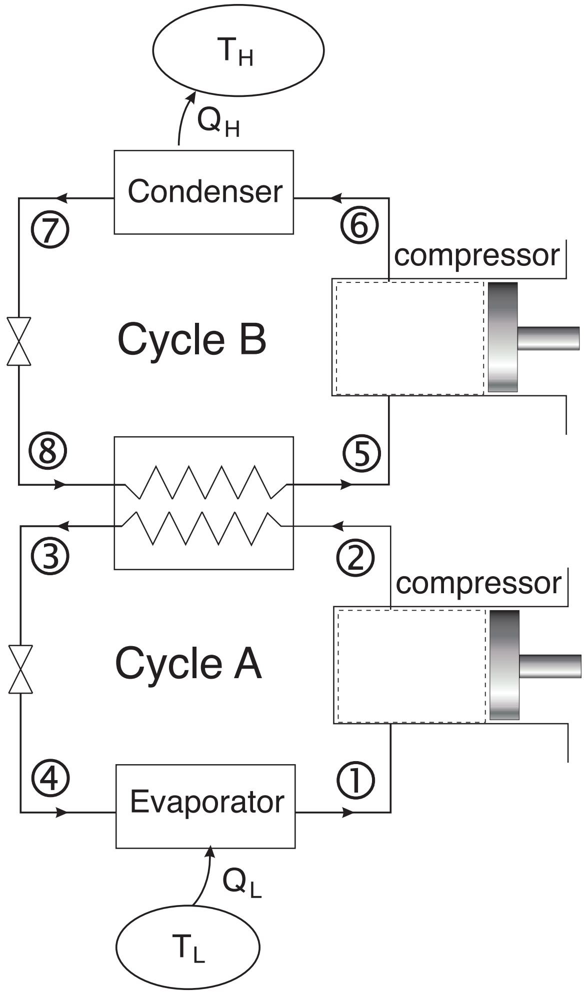
There are several fluorocarbon refrigerants that have been developed for use in VCRC.

R11		
R12	CCl_2F_2	dichlorofluoromethane - used for refrigeration systems at higher temperature levels - typically, water chillers and air conditioning
R22	$CHClF_2$	has less chlorine, a little better for the environment than R12 - used for lower temperature applications
R134a	CFH_2CF3	tetrafluorethane - no chlorine - went into production in 1991 - replacement for R12
R141b	$C_2H_3FCl_2$	dichlorofluoroethane
Ammonia	NH_3	corrosive and toxic - used in absorption systems
R744	CO_2	behaves in the supercritical region - low efficiency
R290	**propane**	combustible

Designation	Chemical Formula	Ozone Depletion Potential[1]	Global Warming Potential[2]
Ozone Depleting & Global Warming Chemicals			
CFC-11	CCl_3F	1	3,400
CFC-12	CCl_2F_2	0.89	7,100
CFC-13	$CClF_3$		13,000
CFC-113	$C_2F_3Cl_3$	0.81	4,500
CFC-114	$C_2F_4Cl_2$	0.69	7,000
CFC-115	$C_2F_5Cl_1$	0.32	7,000
Halon-1211	CF_2ClBr	2.2-3.5	
Halon-1301	CF_3Br	8-16	4,900
Halon-2402	$C_2F_4Br_2$	5-6.2	
carbon tetrachloride	CCl_4	1.13	1,300
methyl chloroform	CH_3CCl_3	0.14	
nitrous oxide	N_2O		270
Ozone Depleting & Global Warming Chemicals - Class 2			
HCFC-22	CHF_2Cl	0.048	1,600
HCFC-123	$C_2HF_3Cl_2$	0.017	90
HCFC-124	C_2HF_4Cl	0.019	440
HCFC-125	C_2HF_5	0.000	3,400
HCFC-141b	$C_2H_3FCl_2$	0.090	580
HCFC-142b	$C_2H_3F_2Cl$	0.054	1800
Global Warming, non-Ozone Depleting Chemicals			
carbon dioxide	CO_2	0	1
methane	CH_4	0	11
HFC-125	CHF_2CF_3	0	90
HFC-134a	CFH_2CF_3	0	1,000
HFC-152a	CH_3CHF_2	0	2,400
perfluorobutane	C_4F_{10}	0	5,500
perfluoropentane	C_5F_{12}	0	5,500
perfluorohexane	C_6F_{14}	0	5,100
perfluorotributylamine	$N(C_4F_9)_3$	0	4,300

1 - relative to R11
2 - relative to CO_2

Cascade Refrigeration System

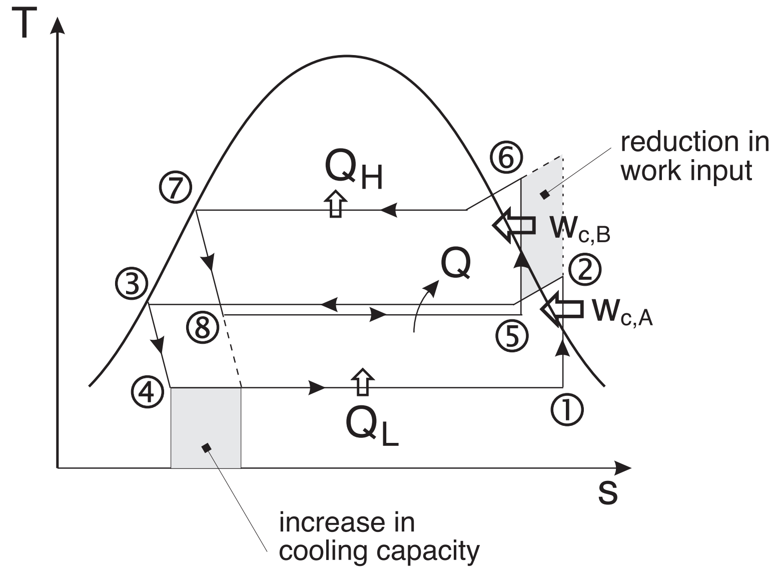


- two or more vapour compression refrigeration cycles are combined
- used where a very wide range of temperature between T_L and T_H is required

Advantages

- the refrigerants can be selected to have reasonable evaporator and condenser pressures in the two or more temperature ranges

$$COP = \frac{Q_L(\uparrow)}{W_{net}(\downarrow)} \ overall(\uparrow)$$

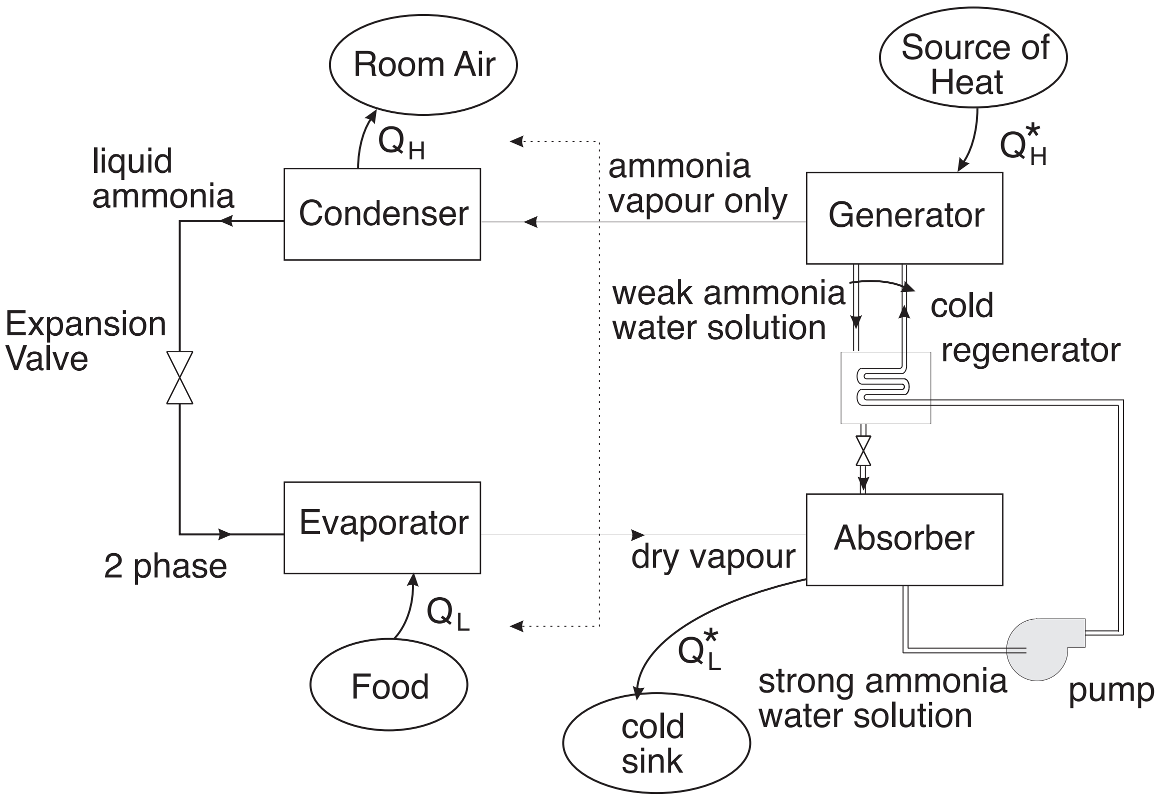


Absorption Refrigeration System

Differences between an absorption refrigeration system and a VCRC

VCRC	Absorption RS
● vapour is compressed between the evaporator and the condenser	● the refrigerant is absorbed by an absorbent material to form a liquid solution
● process is driven by work	● heat is added to the process to retrieve the refrigerant vapour from the liquid solution
	● process is driven by heat

Process


Room Air
Source of Heat
Q_H
Q_H^*
liquid ammonia
Condenser
ammonia vapour only
Generator
weak ammonia water solution
cold
regenerator
Expansion Valve
Evaporator
dry vapour
Absorber
2 phase
Q_L
Q_L^*
Food
strong ammonia water solution
pump
cold sink