Energy Balances

One man's magic is another man's engineering.

Lazarus Long

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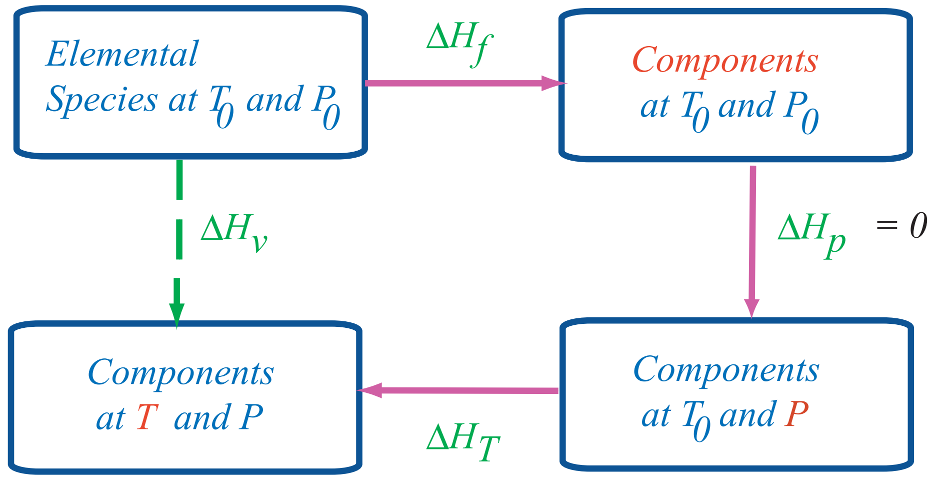
  3. Standard enthalpy reference ($\Delta H = 0$) is at $P_0 = 1\ atm$, $T_0 = 298\ K$ and elemental species.

Enthalpies of Vapor Streams



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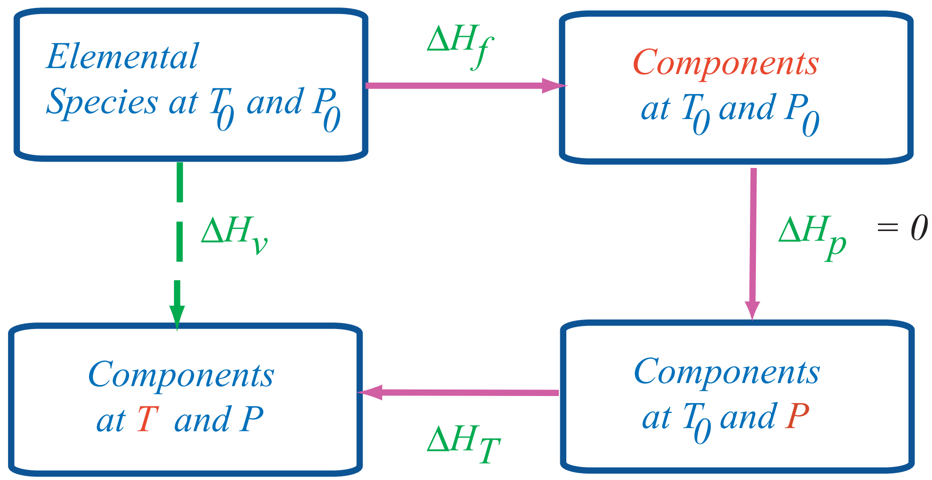

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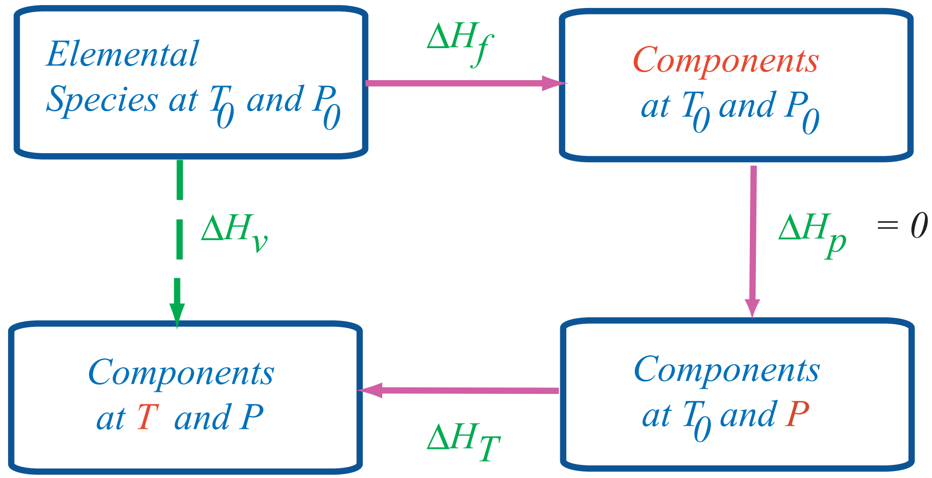

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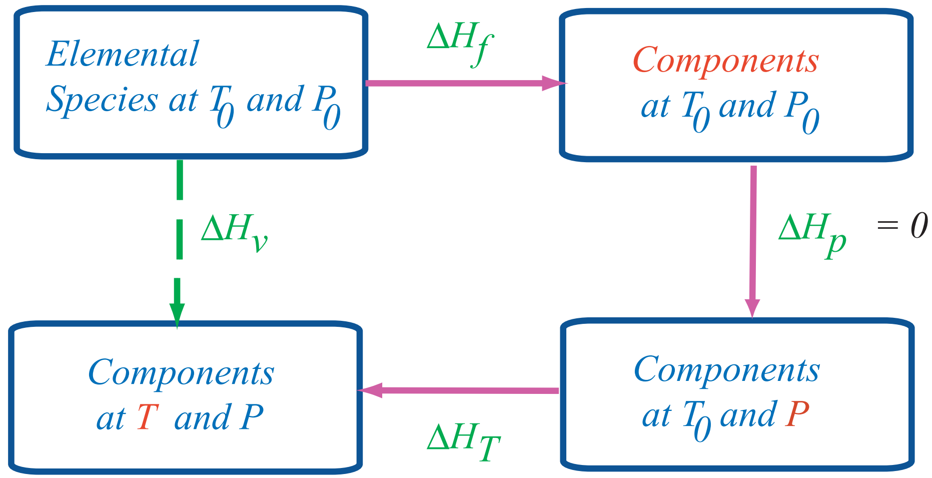

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$\Delta H_f = y_1 H_{f,1}(T_0) + ... + y_n H_{f,n}(T_0)$
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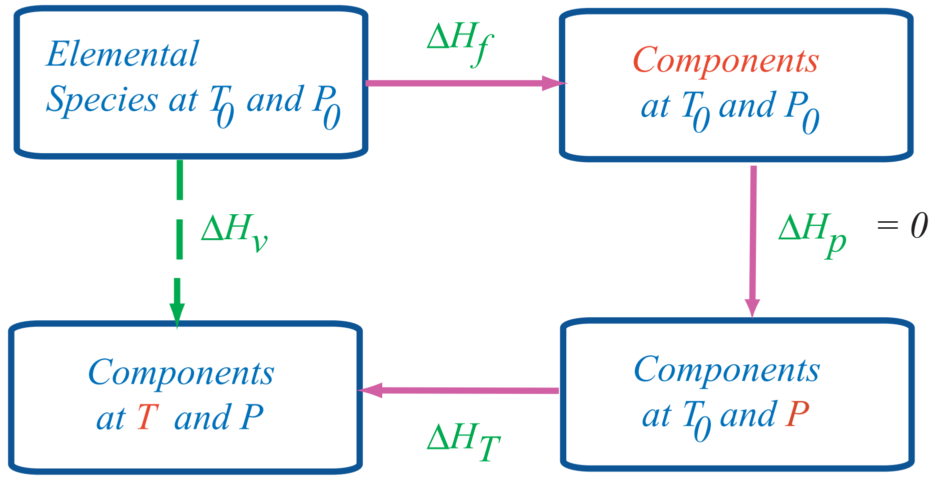

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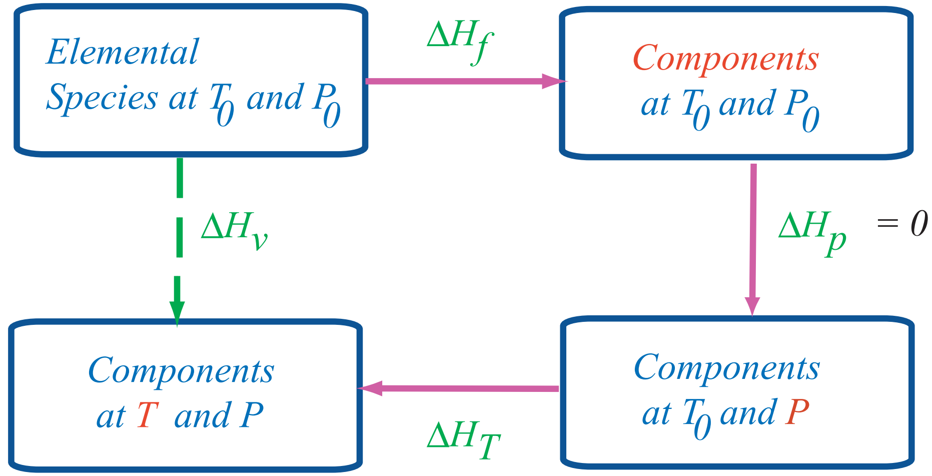

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$$\Delta H_T = y_1 \int_{T_0}^{T} c_{p,1}^0 dT + ... + y_n \int_{T_0}^{T} c_{p,n}^0 dT$$

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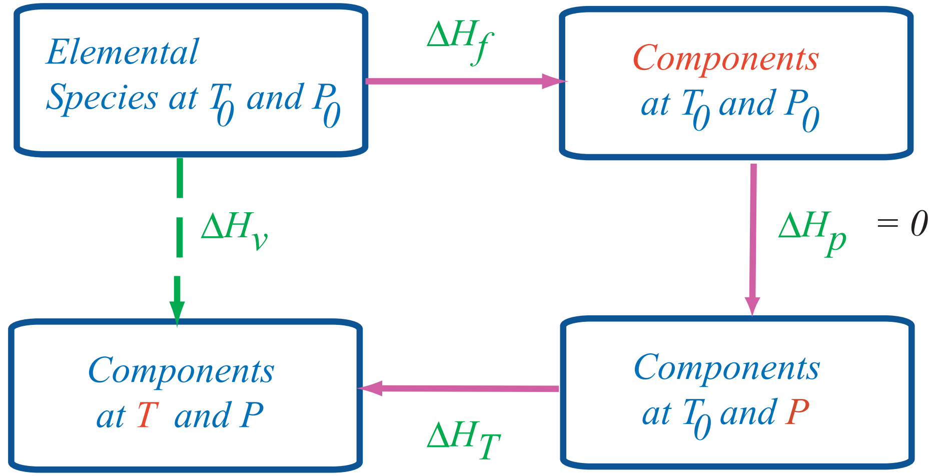

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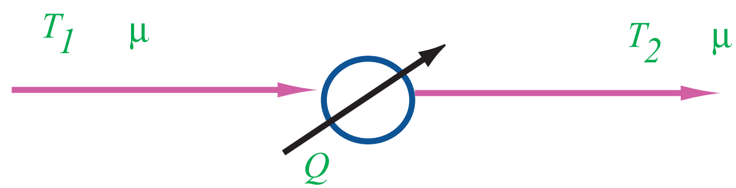
Heat Exchanger Calculation

Consider a heat exchanger with no phase change.



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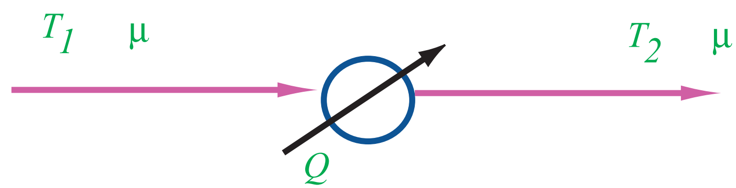

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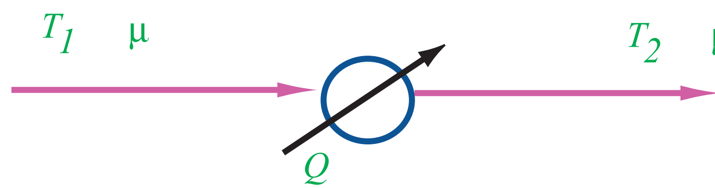

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Since composition does not change, ΔH_f at T_0 is the same on both sides of heat balance and thus cancels out.

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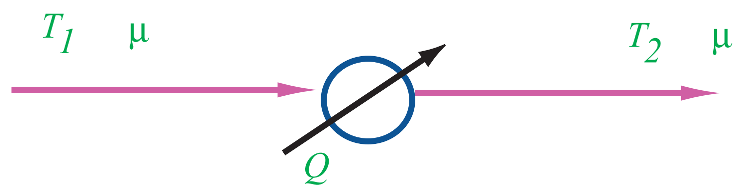

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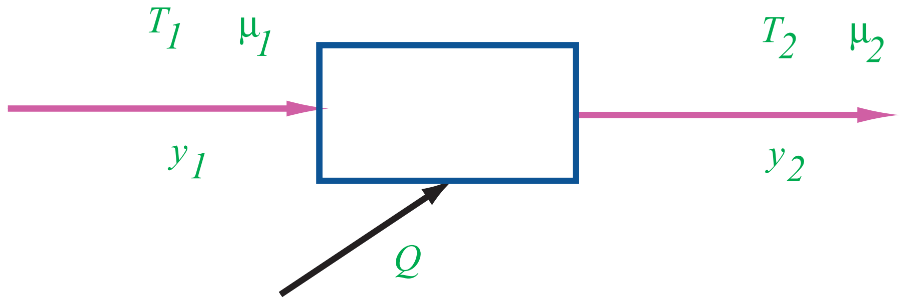
This implies:

$$Q = \mu \left(y_1 \int_{T_1}^{T_2} c_{p,1}^0 dT + ... + y_n \int_{T_1}^{T_2} c_{p,n}^0 dT \right)$$

Reactor Calculation

Consider a gas phase reactor.



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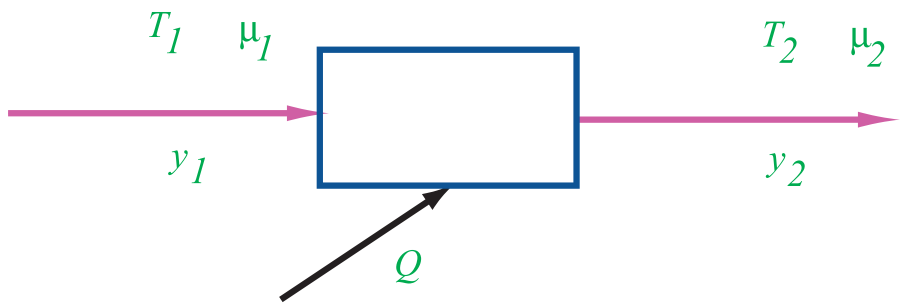

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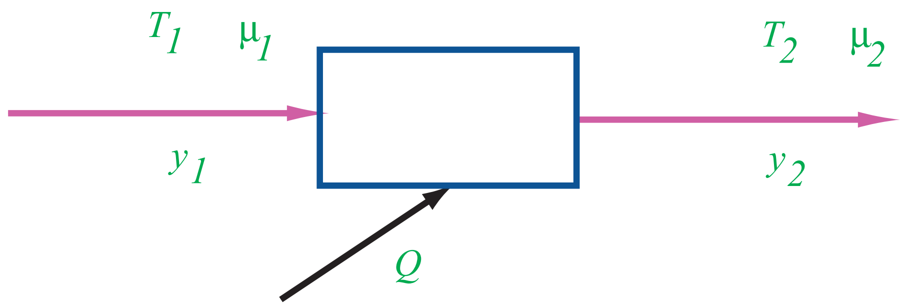

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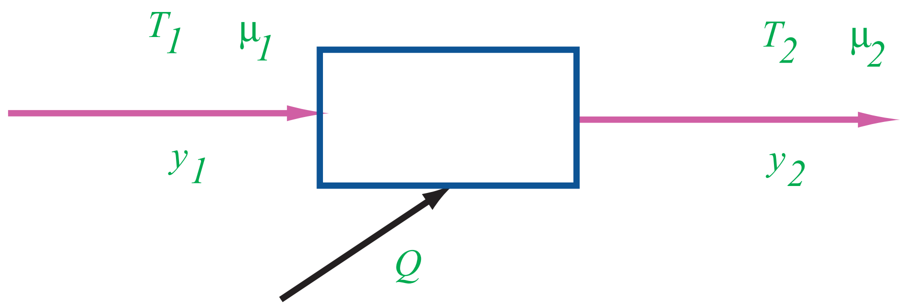

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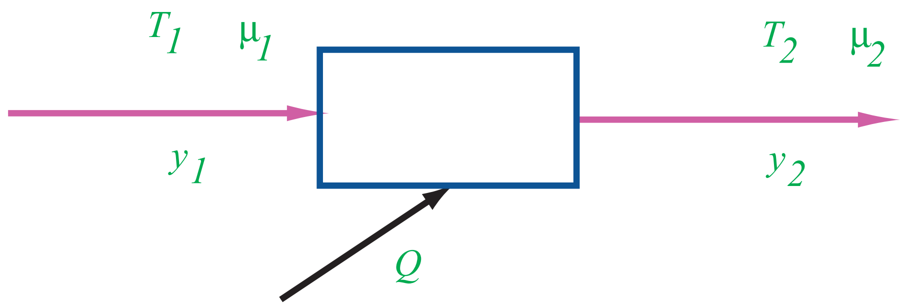

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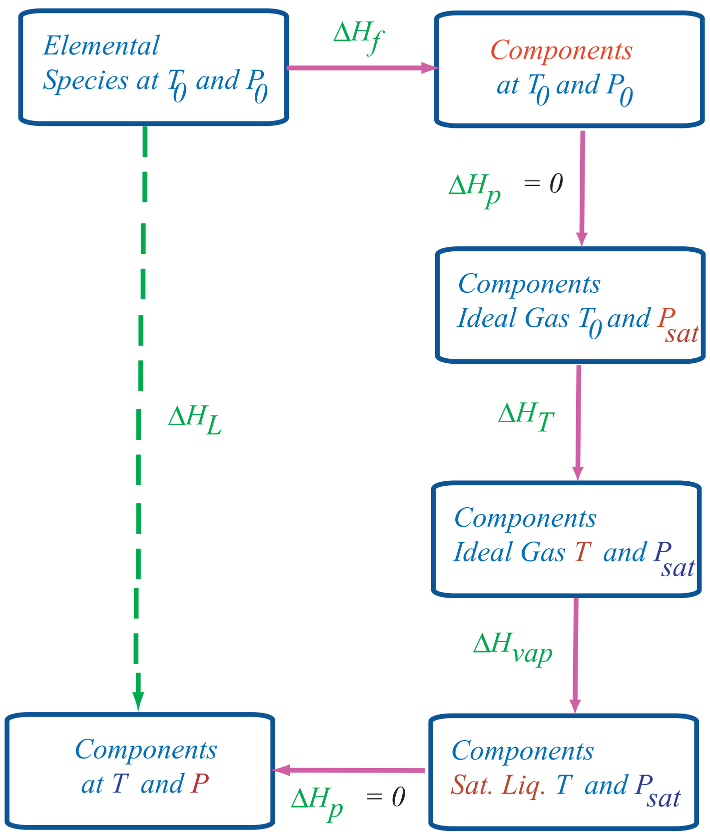

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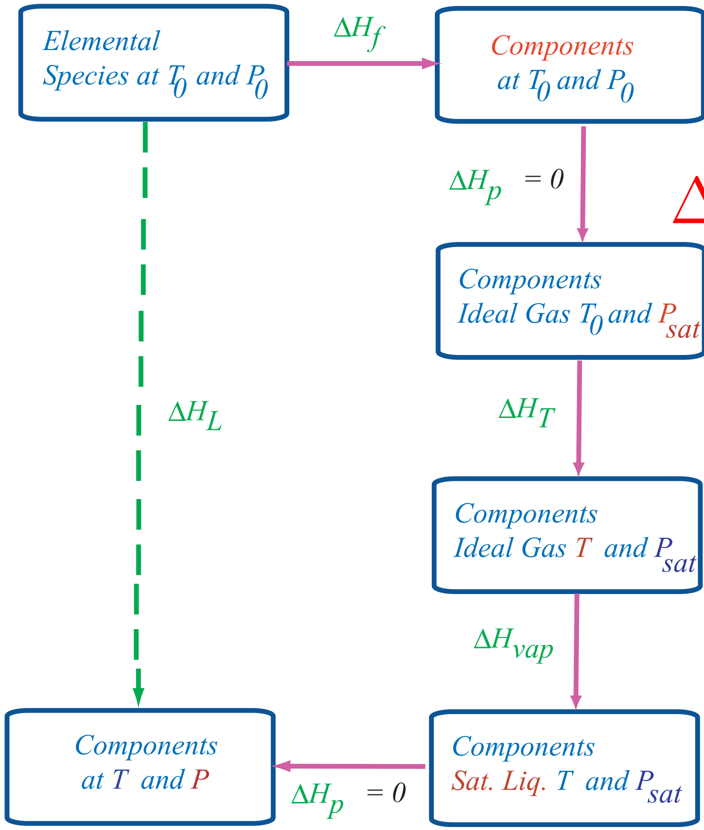

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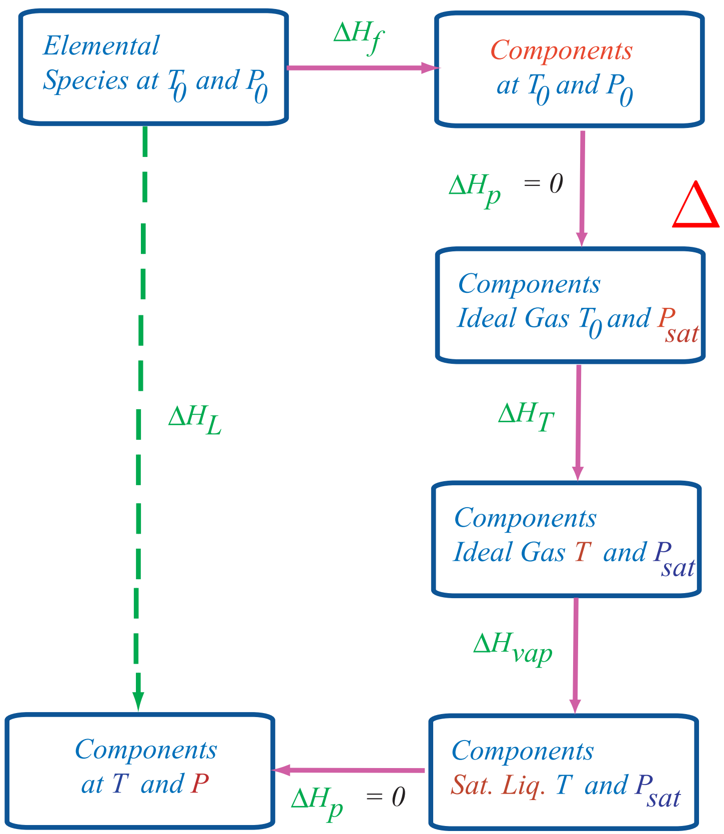

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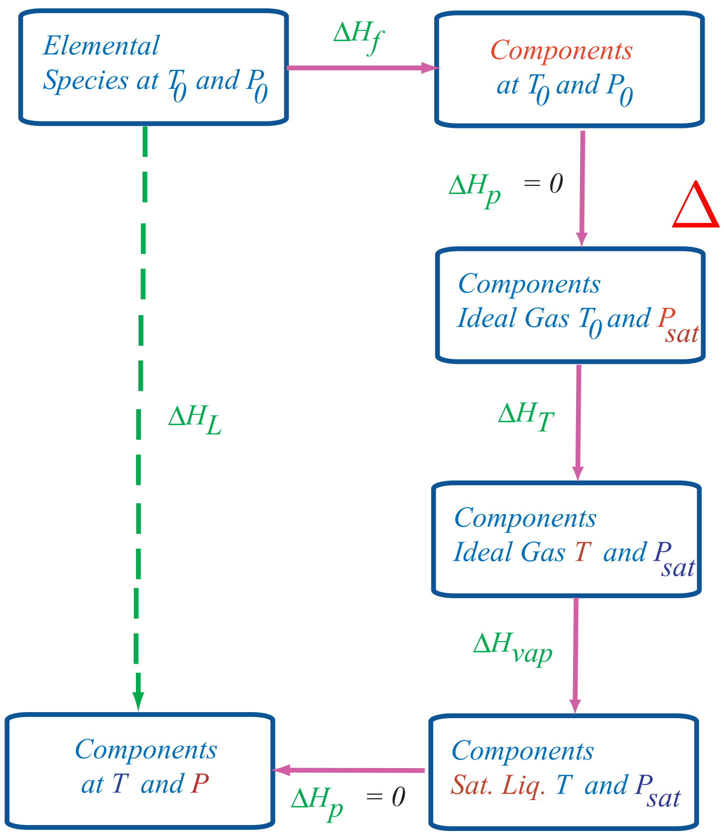

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$$\Delta H^k_{vap}(T) = \Delta H^k_{vap}(T_b)\left[\frac{(T^k_c - T)}{(T^k_c - T_b)}\right]^{0.38}$$

T^k_c : critical temperature

T^k_b : boiling point at 1 atm

$\Delta H^k_{vap}(T_b)$ heat of vaporization at T^k_b

Liquid Mixtures and Two Phase Mixtures

- The specific stream enthalpy for liquid mixtures is estimated as a weighted sum of respective mole fractions.
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- For a vapor-liquid mixture with vapor fraction ϕ, the stream enthalpy is given by the weighted sum of the liquid and vapor enthalpies.
  $\Delta H_L(T, x) = \phi \Delta H_V(T, y) + (1 - \phi) \Delta H_L(T, x)$

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$V/F = 0,\ P_L$ specified	Bubble point temperature
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T_L specified, $V/F = 0$	Bubble point pressure
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We did not consider the flash calculations that involved energy balance. We will consider the adiabatic flash now.

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<u>Scenario</u>: Heat is added to a liquid mixture stream due to which part of it vaporizes. What is the flash temperature and what are the compositions of the liquid and vapor streams if the pressure is specified?

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- If $\Delta H_{dew} \geq \Delta H_{spec} \geq \Delta H_{bub}$, guess ξ_n (or ϕ).

- Perform a flash calculation with ξ_n (or ϕ) and P specified to obtain y_k, x_k and T.
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  Calculate $\Delta H(T) = \phi \Delta H_v + (1-\phi)\Delta H_L$
- If $f = \Delta H_{spec} - \Delta H(T) = 0$ STOP. Otherwise, if $f > 0$ reguess a higher ξ_n (or ϕ), else guess a lower ξ_n (or ϕ) and go back to previous step.

Illustrative Example

Consider a 50-50 liquid mixture of benzene and toluene flowing at $100\ gmol/s$ at $300\ K$ and $1\ bar$. If heat is added to this stream at the rate of $860.42\ kcal/s$, what is the temperature of the mixture.

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    Compute $\alpha_{B/T} = 2.453$ at $T = 370\ K$.
  - Guess ξ_T and solve for ξ_B, ϕ and T from:

$$\begin{aligned}
\xi_B &= \frac{\alpha_{B/T}\xi_T}{1 + (\alpha_{B/T} - 1)\xi_T} \\
\phi &= \frac{50(\xi_B + \xi_T)}{100} \\
P_T^0(T) &= \frac{P}{\bar{\alpha}}
\end{aligned}$$

- With this information, calculate:

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0.585	0.776	369.5	0.680	12.993

- With this information, calculate:

$$\Delta H(T) = \phi \Delta H_V(T) + (1-\phi)\Delta H_L(T)$$

  and compare with $\Delta H_{spec} = 12.862$.

- Adjust ξ_T till the computed ΔH converges to the specified value.

ξ_T	ξ_B	T	ϕ	$\Delta H(T)$
0.700	0.851	370.1	0.776	68.439
0.600	0.786	369.5	0.693	20.876
0.570	0.765	369.4	0.667	4.895
0.585	0.776	369.5	0.680	12.993

Thus, the stream is 68% vaporized at a temperature of $369.5\ K$.