CH365 Chemical Engineering Thermodynamics

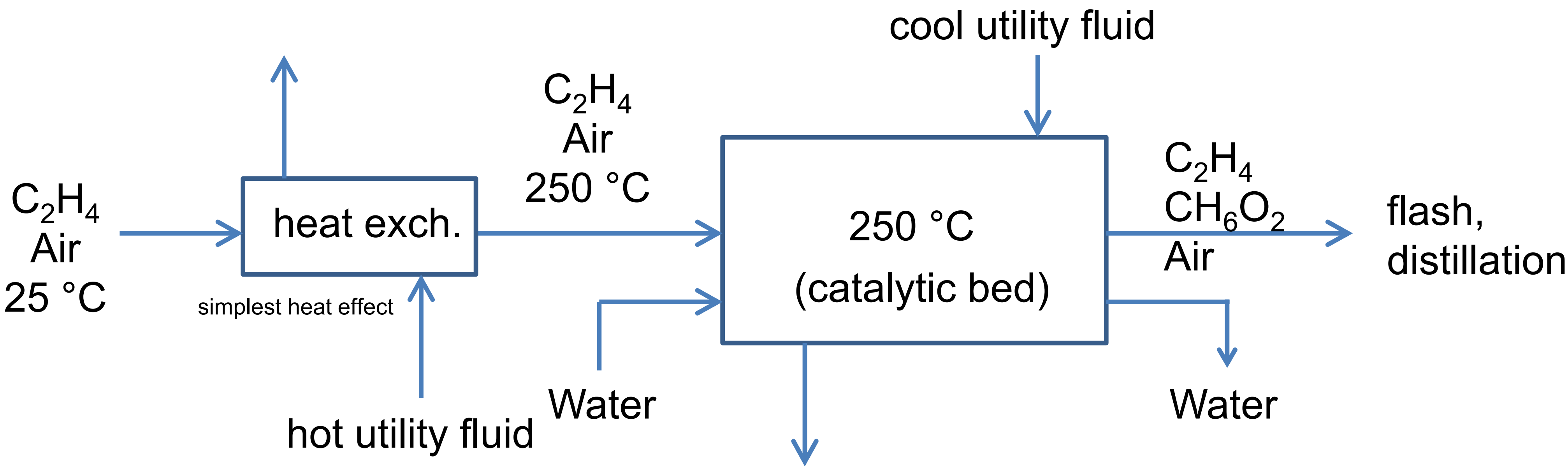
Lesson 16

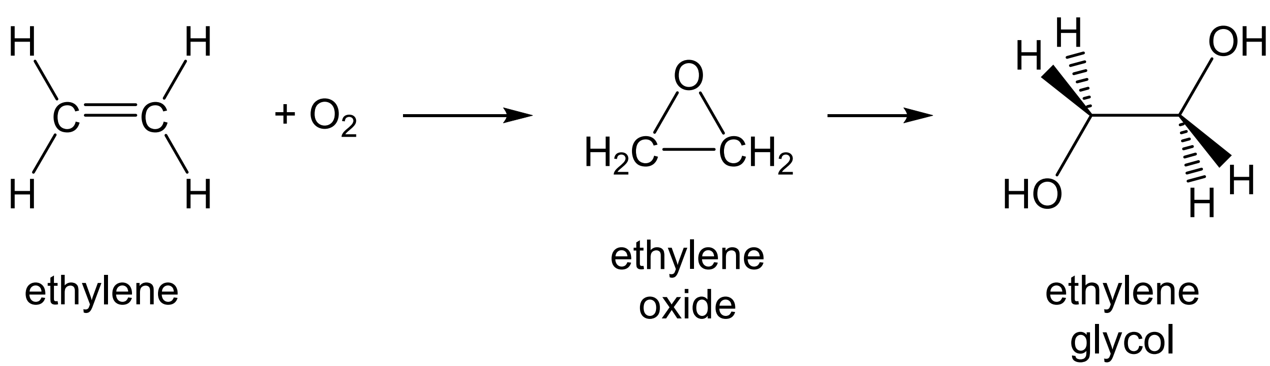
Sensible Heat Effects

Ethylene Glycol Process

- Sensible heat effects are associated with temperature change
- Latent heat (phase changes) – no temperature change
- Heat of Reaction
- Heat of Mixing

Example: Manufacture of Ethylene Glycol – Chapter 4 Intro





"Sensible" Heat Effects

Sensible = No phase transitions, no chemical reactions, and no change in composition.

$$U = U(T, V)$$

Total differential introduced in L10, Slide 9, page 138

0 for constant volume process, ideal gases, or incompressible fluids

$$dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \cancel{\left(\frac{\partial U}{\partial V}\right)_T} dV$$

$$\frac{C_V^{ig}}{R} = \frac{C_P^{ig}}{R} - 1$$

Eq. 4.6

dimensionless

L11, Slide 3

$$dU = C_V dT$$

Eq. 4.1

$$Q = \Delta U = \int_{T_1}^{T_2} C_V dT$$

$Q=\Delta U$ for mechanically reversible, constant volume process (why? $\Delta U=Q+W$)

$$H = H(T, P)$$

0 for constant pressure process, ideal gases or approximately for real gases at high T and low P

$$C^{ig}_{P,mixture} = y_A C^{ig}_{P_A} + y_B C^{ig}_{P_B} + \ldots$$

Eq. 4.7

$$dH = \left(\frac{\partial H}{\partial T}\right)_P dT + \cancel{\left(\frac{\partial H}{\partial P}\right)_T} dP$$

Need $C_P(T)$

(constitutive – CH485)

$$\frac{C_P^{ig}}{R} = A + BT + CT^2 + DT^{-2}$$

Eq. 4.5

(dimensionless)

Eq. 4.3

L11, Slide 3

$$dH = C_P dT$$

Eq. 4.2

$$Q = \Delta H = \int_{T_1}^{T_2} C_P dT$$

steady-flow heat transfer

$Q=\Delta H$ for mechanically reversible, constant pressure closed-system processes or when ΔE_K, ΔE_P, and W_s=0 in H-form of 1st Law eq 2.31

$$\Delta H + \cancelto{0}{\frac{\Delta(u^2)}{2}} + \cancelto{0}{g\Delta z} = Q + \cancelto{0}{W_{shaft}}$$

Mean Heat Capacity

Integral evaluated forms – “user-defined functions” – simplifies working with mixtures

These forms are used in later derivations in the textbook.

ICPH: $$\int_{T_0}^{T} \frac{C_P}{R} dT = A\left(T - T_0\right) + \frac{B}{2}\left(T^2 - T_0^2\right) + \frac{C}{3}\left(T^3 - T_0^3\right) + D\left(\frac{T - T_0}{T \cdot T_0}\right)$$ Eq. 4.8

$$\Delta H = ICPH \cdot R$$

$$\int_{T_0}^{T} \frac{C_P}{R} dT = \left[A + \frac{B}{2}\left(T + T_0\right) + \frac{C}{3}\left(T^2 + T_0^2 + T \cdot T_0\right) + \frac{D}{T \cdot T_0}\right]\left(T - T_0\right)$$

MCPH: $$\frac{\left\langle C_P \right\rangle_H}{R} = \left[A + \frac{B}{2}\left(T + T_0\right) + \frac{C}{3}\left(T^2 + T_0^2 + T \cdot T_0\right) + \frac{D}{T \cdot T_0}\right]$$ Eq. 4.9

$\left\langle C_P \right\rangle_H$ is the **mean heat capacity.**

$$\Delta H = \left\langle C_P \right\rangle_H \left(T - T_0\right)$$ Eq. 4.9

$$\Delta H = MCPH \cdot R \cdot \left(T - T_0\right)$$

Ideal Gas Heat Capacity in Simulators

Improved function – used in professional simulators such as CC and Aspen+

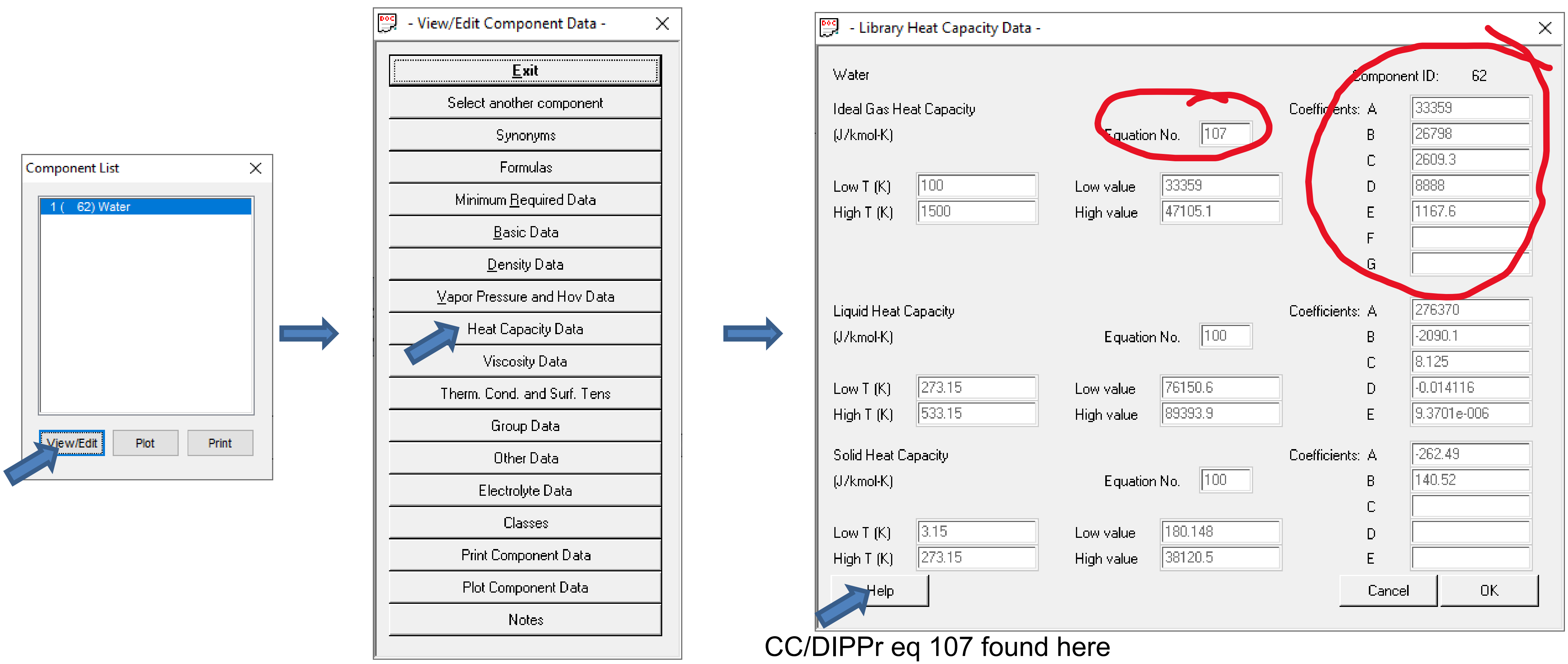
F. A. Aly and L. L. Lee, “Self-Consistent Equations for calculating the Ideal Gas Heat Capacity, Enthalpy, and Entropy,” *Fluid Phase Equilibria*, 1981, Vol. 6, Issues 3-4, pp. 169-179.

a, b, c, d & e are constants published and maintained by DIPPr (link on course web site).

$$C_P = C_P(T) = a + b\cdot\left(\frac{c/T}{\mathrm{Sinh}[c/T]}\right)^2 + d\cdot\left(\frac{e/T}{\mathrm{Cosh}[e/T]}\right)^2 \qquad \text{DIPPr Eq 107}$$

hyperbolic sine

hyperbolic cosine



CC/DIPPr eq 107 found here

Ideal Gas Heat Capacity in Simulators

Improved function – used in professional simulators such as CC and Aspen+

F. A. Aly and L. L. Lee, "Self-Consistent Equations for calculating the Ideal Gas Heat Capacity, Enthalpy, and Entropy," *Fluid Phase Equilibria*, 1981, Vol. 6, Issues 3-4, pp. 169-179.

---

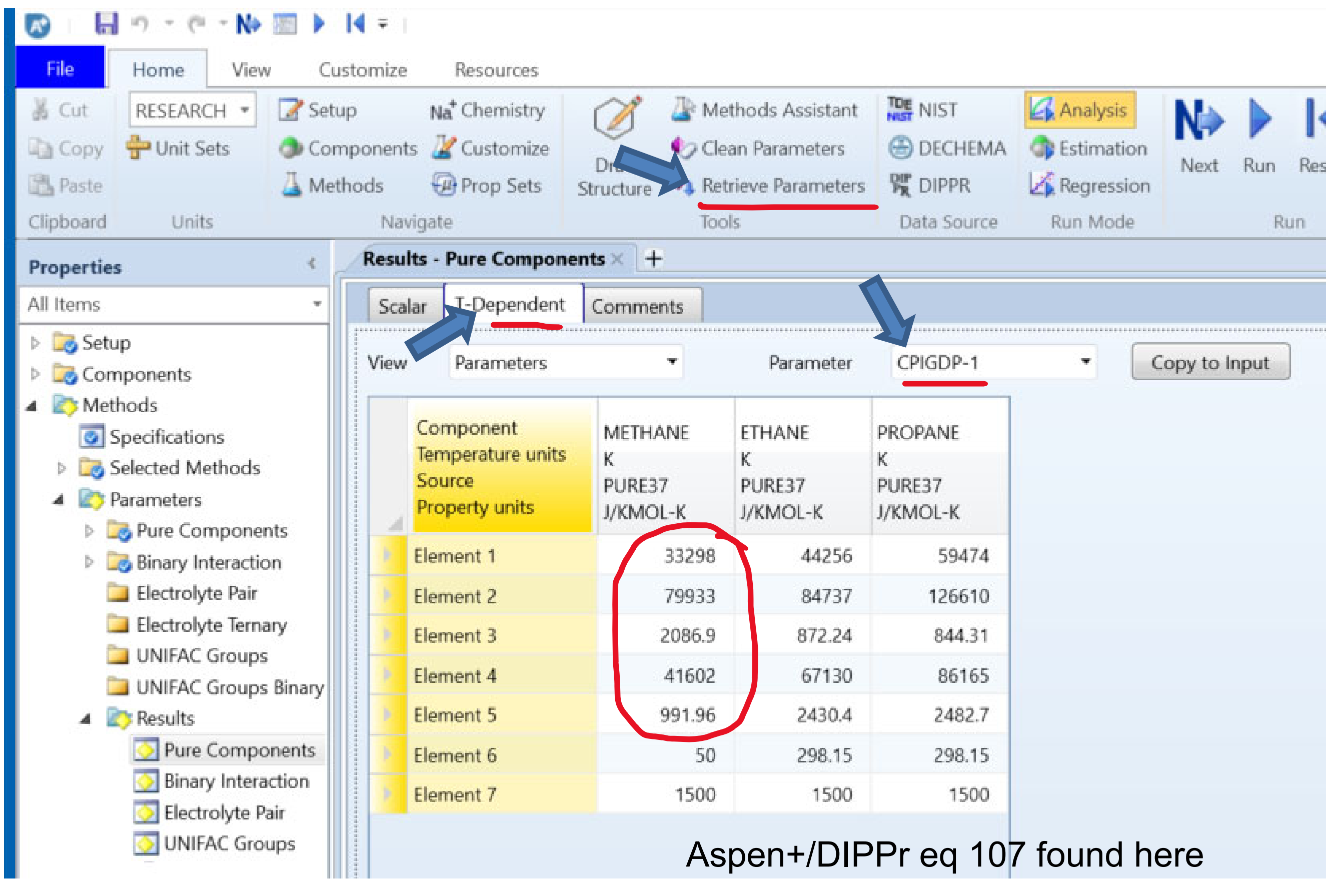
a, b, c, d & e are constants published and maintained by DIPPr (link on course web site).

$$C_P = C_P(T) = a + b\cdot\left(\frac{c/T}{\mathrm{Sinh}[c/T]}\right)^2 + d\cdot\left(\frac{e/T}{\mathrm{Cosh}[e/T]}\right)^2$$

DIPPr Eq 107

hyperbolic sine

hyperbolic cosine



Component	METHANE	ETHANE	PROPANE
Temperature units	K	K	K
Source	PURE37	PURE37	PURE37
Property units	J/KMOL-K	J/KMOL-K	J/KMOL-K
Element 1	33298	44256	59474
Element 2	79933	84737	126610
Element 3	2086.9	872.24	844.31
Element 4	41602	67130	86165
Element 5	991.96	2430.4	2482.7
Element 6	50	298.15	298.15
Element 7	1500	1500	1500

Aspen+/DIPPr eq 107 found here

Homework

Problem 4.5

How much heat is required when 10,000 kg of $CaCO_3$ is heated at atmospheric pressure from 50 deg C to 880 deg C?

Solve by three methods: (a) direct integration of C_P polynomial, (b) ICPH, and (c) MCPH

Express all answers in MJ.

Submission in Mathematica required.
All problems and cover sheet bundled into single pdf.

Problem 4.9

A process stream is heated as a gas from 25 deg C to 250 deg C at constant P. A quick estimate of the energy requirement is obtained from Eq. 4.3, with C_p taken as constant and equal to its value of 25 deg C. Is the estimate of Q likely to be low or high? Why?

Submission in Mathematica required.
All problems and cover sheet bundled into single pdf.

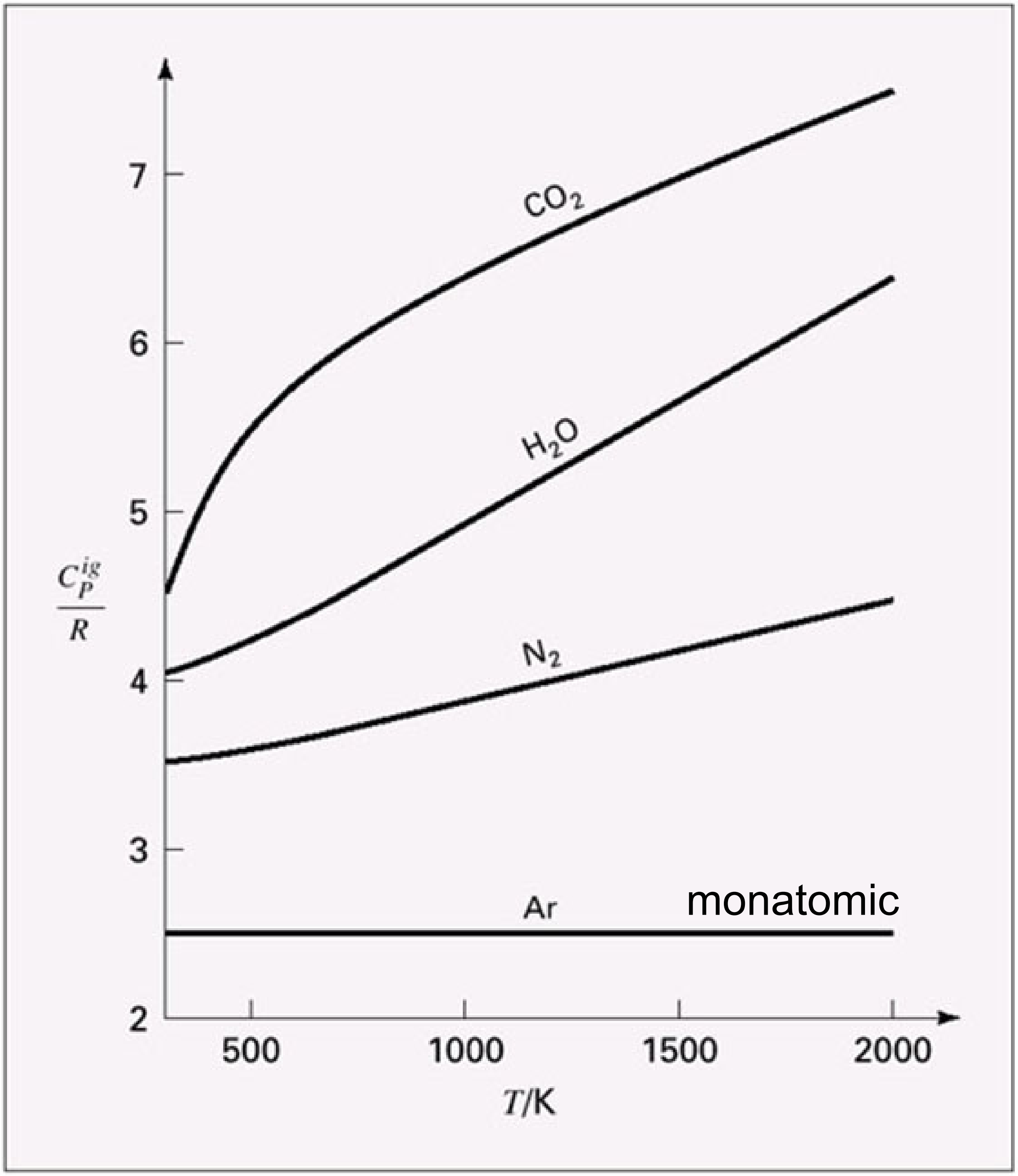


Figure 4.1. Ideal-gas heat capacities of argon, nitrogen, water, and carbon dioxide.