

①

(THERMO)Ex 1:

$$\Delta L = 10^{-3} \text{ m}^3$$

$$\Delta b = 10^5 \text{ Pa}$$

1) Compression isotherme $\rightarrow \Delta T = 0$
 $\rightarrow \Delta U = 0$

$$\Rightarrow Q = -W$$

$$= \int P dV$$

$$= \int P V \frac{dV}{V} = P_1 V_1 \int \frac{1}{V} dV = P_1 V_1 [\ln(V)]_1^2$$

$$= P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$Q = P_1 V_1 \ln\left(\frac{P_1}{P_2}\right) \quad \text{or } P_1 V_1 = P_2 V_2$$

$$Q = n R T_{\text{ext}} \ln\left(\frac{P_1}{P_2}\right)$$

$$2) \Delta S_{12} = \int \frac{dQ_{12}}{T} = \frac{1}{T} \int dQ_{12} = \frac{1}{T} Q_{12}$$

$$\Delta S_{12} = n R \ln\left(\frac{P_1}{P_2}\right)$$

3) air ambiant = thermostat

$$\Delta S_{\text{grade}} = \frac{Q_{12}}{T_{\text{ext}}} = n R \ln\left(\frac{P_1}{P_2}\right)$$

4) $\Delta S_{\text{grade}} = \Delta S_{12} \rightarrow$ Réversible

Ex 2:

$$1) W_{\text{gk}} = \text{aire ABCD}$$

$$= \Delta V \times \Delta P$$

$$= (V_2 - V_1)(P_2 - P_1)$$

$$W_{\text{gk}} = -V_1 P_1$$

$$\text{m}^3 \text{ Pa}$$

$$\text{A.N.: } W_{\text{gk}} = -1 \text{ kJ}$$

or $V_2 = 2V_1$ et $P_2 = 2P_1$
 négatif car sens horaire

2)

2). Etat B:

$$P_2 V_2 = n R T_2$$

$$\text{or } n R = \frac{P_1 V_1}{T_1}$$

$$P_2 V_2 = \frac{P_1 V_1}{T_1} T_2$$

$$\Rightarrow T_2 = \frac{P_2 V_2 T_1}{P_1 V_1}$$

$$\boxed{T_2 = 2 T_1}$$

$$\text{A.N.: } T_2 = 546 \text{ K}$$

. Etat C:

$$T_3 = \frac{P_3 V_3 T_1}{P_1 V_1}$$

$$\boxed{T_3 = 4 T_1}$$

$$\text{A.N.: } T_3 = 1092 \text{ K}$$

. Etat D:

Sur isotherme de B

$$\text{LD } \boxed{T_4 = 2 T_1}$$

$$3) m = n \times M \Rightarrow n = \frac{m}{M}$$

$$\boxed{m = \frac{P V}{R T_1} \times M}$$

$$\text{A.N.: } m = 12,8 \text{ g}$$

1) AB $\rightarrow$ Transformation isochore

$$Q_{AB} = m C_v (T_B - T_A)$$

$$= \frac{m C_p (T_B - T_A)}{\gamma}$$

$$\gamma = \frac{C_p}{C_v} \Rightarrow C_v = \frac{C_p}{\gamma}$$

$$\text{A.N.: } Q_{AB} = 2,44 \text{ kJ}$$

BC $\rightarrow$ Transformation isobare

$$\boxed{Q_{BC} = m C_p (T_C - T_B)}$$

$$\text{A.N.: } Q_{BC} = 6,92 \text{ kJ}$$

Il principe pour CD et DA.

$$\text{A.N.: } Q_{CD} = -4,88 \text{ kJ } Q_{DA} = -3,46 \text{ kJ}$$

Ex 3:

1). P_B ?

$$\text{Transfo adiabatique} \Rightarrow P_A V_A^\gamma = P_B V_B^\gamma$$

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$$P_B = P_A \frac{V_A^\gamma}{V_B^\gamma}$$

$$\text{or } V_B = 2V_A$$

$$\Rightarrow P_B = \frac{P_A}{2^\gamma}$$

$$\text{A.N.: } P_B = 31498 \text{ Pa}$$

$$\gamma = 5/3$$

• T_B ?

$$P_B V_B = n R T_B$$

$$\text{avec } nR = \frac{P_A V_A}{T_A}$$

$$T_B = \frac{P_B V_B}{P_A V_A} T_A$$

$$= \frac{2 P_B T_A}{P_A} = \frac{2 T_A}{2^\gamma} = \frac{T_A}{2^{\gamma-1}}$$

$$\text{A.N.: } T_B = 287 \text{ K}$$

• V_C ?

$$\text{Transfo isochore BC} \Rightarrow \Delta V = 0 \Rightarrow V_C = V_B = 2V_A = 20 \text{ L}$$

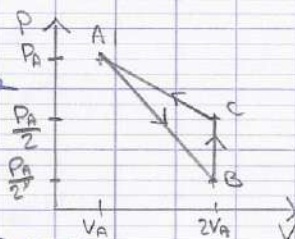
• T_C ?

$$\text{CA Transfo isotherme} \Rightarrow \Delta T = 0 \Rightarrow T_C = T_A = 300 \text{ K}$$

• P_C ?

$$P_C = n R T_C = \frac{P_A V_A T_C}{V_C T_A} = \frac{P_A}{2}$$

$$\text{A.N.: } P_C = 5.10^4 \text{ Pa}$$



$$2) Q_{AB} = 0 \quad W_{AB} = \frac{P_B V_B - P_A V_A}{\gamma - 1}$$

$$\text{A.N.: } W_{AB} = -555,6 \text{ J}$$

$$Q_{BC} = \frac{V(P_C - P_B)}{\gamma - 1} \quad W_{BC} = 0 \quad \gamma - 1$$

$$\text{A.N.: } Q_{BC} = 555,6 \text{ J}$$

$$Q_{CA} = -W_{CA} \quad W_{CA} = -P_C (V_C - V_A)$$

$$\text{A.N.: } Q_{CA} = -693,1 \text{ J} \quad W_{CA} = 693,1 \text{ J}$$

$$3) Q_{\text{tot}} = -137,5 \text{ J} \quad W_{\text{tot}} = 137,5 \text{ J}$$

$$\Delta U_{\text{cycle}} = Q_{\text{tot}} + W_{\text{tot}} = 0 \Rightarrow \text{Consistent}$$

Ex 4:

1) Compression adiabatique

$$P_1 V_1^\gamma = P_2 V_2^\gamma \Leftrightarrow \frac{P_1}{P_2} = \left(\frac{V_2}{V_1} \right)^\gamma$$

$$\gamma = \frac{5}{3} \text{ car gaz parfait monoatomique}$$

$$V_2 = \left(\frac{P_1}{P_2} \right)^{\frac{1}{\gamma}} \times V_1$$

$$2) W_g = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1}$$

3) Compression adiabatique $\rightarrow Q = 0$

$$\Delta U = W_g$$

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$$4) \Delta U = n C_v \Delta T = W$$

$$\Rightarrow \Delta T = \frac{W(k)}{nR}$$

$$C_v = \frac{R}{\gamma - 1}$$

Ex 5:

1 → 2 : Transfo. isobare
 2 → 3 : — isochore
 3 → 4 : — isobare
 4 → 1 : — isochore

$$W_{12} = - \int P dV = - P_1 \Delta V = - P_1 (V_2 - V_1)$$

$$W_{23} = - \int P dV \text{ or } dV = 0 \Rightarrow W_{23} = 0$$

$$W_{34} = - \int P dV = - P_2 \Delta V = - P_2 (V_1 - V_2)$$

$$W_{41} = 0$$

$$W_{\text{tot}} = W_{12} + W_{34}$$

$$= (P_2 - P_1)(V_2 - V_1)$$

$$Q_{12} = n C_p \Delta T$$

$$= n C_p (T_2 - T_1)$$

$$= C_p \frac{P_1 V_2 - P_1 V_1}{\gamma - 1}$$

$$= \frac{\gamma P_1 (V_2 - V_1)}{\gamma - 1}$$

$$T_2 = \frac{P_1 V_2}{nR}; T_1 = \frac{P_1 V_1}{nR} \text{ avec } h = \frac{1 \text{ mol}}{m = 1 \text{ kg}}$$

$$\text{gaz parfait: } C_p = \frac{\gamma R}{\gamma - 1}$$

$$Q_{23} = n C_v \Delta T$$

$$= \frac{R}{\gamma - 1} (T_3 - T_2)$$

$$= \frac{V_2}{\gamma - 1} (P_2 - P_1)$$

$$C_v = \frac{R}{\gamma - 1}; T_3 = \frac{P_2 V_2}{nR}; T_2 = \frac{P_1 V_2}{nR}$$

$$Q_{34} = \frac{\gamma P_2 (V_1 - V_2)}{\gamma - 1}$$

$$Q_{41} = \frac{V_1}{\gamma - 1} (P_1 - P_2)$$

$$Q_{\text{tot}} = - (P_2 - P_1)(V_2 - V_1)$$

$$\Delta U_{\text{cycle}} = W_{\text{tot}} + Q_{\text{tot}} = 0$$

↳ Cohérent

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Thermodynamics

Ex 6:

1 → 2, 3 → 4 : Transf isochore

2 → 3, 4 → 1 : Transf isotherme

$$W_{12} = - \int P dV \text{ or } dV = 0 \Rightarrow W_{12} = 0$$

$$W_{23} = - \int P dV = - PV \int \frac{1}{V} dV = - PV \ln\left(\frac{V_2}{V_1}\right) \\ = - RT_2 \ln\left(\frac{V_2}{V_1}\right)$$

$$PV = nRT_2 \quad \text{area } n = 1$$

$$W_{34} = 0$$

$$W_{41} = - \int P dV = - PV \ln\left(\frac{V_1}{V_2}\right) \\ = - RT_1 \ln\left(\frac{V_1}{V_2}\right)$$

$$PV = nRT_1$$

$$W_{TOT} = W_{12} + W_{23} + W_{34} + W_{41} \\ = - R \left(\ln\left(\frac{V_1}{V_2}\right) T_1 + \ln\left(\frac{V_2}{V_1}\right) T_2 \right) \\ = - R (T_2 - T_1) \ln\left(\frac{V_2}{V_1}\right)$$

$$Q_{12} = nC_V(T_2 - T_1) \\ = \frac{R}{\gamma - 1} (T_2 - T_1)$$

$$C_V = \frac{R}{\gamma - 1}; \quad n = 1$$

$$Q_{23} = - W_{23}$$

$$\text{car } \Delta T = 0 \Rightarrow \Delta U = 0$$

$$Q_{34} = nC_V(T_1 - T_2) \\ = \frac{R}{\gamma - 1} (T_1 - T_2)$$

$$Q_{41} = - W_{41}$$

$$Q_{TOT} = Q_{12} + Q_{23} + Q_{34} + Q_{41}$$

$$= - W_{23} - W_{41} \\ = R (T_2 - T_1) \ln\left(\frac{V_2}{V_1}\right)$$

$$\Delta U_{\text{cycle}} = W_{TOT} + Q_{TOT} = 0 \Rightarrow \text{Coherent}$$

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Ex 7:

1 → 2, 3 → 4: Transfo isobare

2 → 3, 4 → 1: — isotherme

$$W_{12} = - \int P dV = - P \Delta V = - P (V_2 - V_1)$$

$$= - R (T_2 - T_1)$$

$$PV = nRT$$

avec $n = 1$

$$W_{23} = - \int P dV = - P_1 V_1 \int \frac{1}{V} dV = - P_1 V_1 \ln \left(\frac{V_2}{V_1} \right)$$

$$= - R T_2 \ln \left(\frac{P_1}{P_2} \right)$$

$$P_1 V_1 = n R T_2$$

$$W_{34} = - \int P dV = - P \Delta V = - P_2 (V_1 - V_2)$$

$$= - R (T_1 - T_2)$$

$$W_{41} = - \int P dV = - P_2 V_2 \int \frac{1}{V} dV = - P_2 V_2 \ln \left(\frac{V_1}{V_2} \right)$$

$$= - R T_1 \ln \left(\frac{P_2}{P_1} \right)$$

$$W_{\text{tot}} = - R \left(T_2 \ln \left(\frac{P_1}{P_2} \right) + T_1 \ln \left(\frac{P_2}{P_1} \right) \right) = - R \ln \left(\frac{P_1}{P_2} \right) (T_2 - T_1)$$

$$Q_{12} = n C_p (T_2 - T_1)$$

$$= \frac{\gamma R}{\gamma - 1} (T_2 - T_1)$$

$$C_p = \frac{\gamma R}{\gamma - 1}$$

$$Q_{23} = - W_{23} = R T_2 \ln \left(\frac{P_1}{P_2} \right)$$

$$Q_{34} = n C_p (T_1 - T_2)$$

$$= \frac{\gamma R}{\gamma - 1} (T_1 - T_2)$$

$$Q_{41} = - W_{41} = R T_1 \ln \left(\frac{P_2}{P_1} \right)$$

$$Q_{\text{tot}} = R \ln \left(\frac{P_1}{P_2} \right) (T_2 - T_1)$$

$$\Delta U_{\text{cycle}} = Q_{\text{tot}} + W_{\text{tot}} = 0 \Rightarrow \text{Coherent}$$

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Ex 8:

$$\begin{aligned}
 1) \Delta S &= \Delta S_1 + \Delta S_2 \\
 &= \int \frac{+Q_1}{T} + \int \frac{+Q_2}{T} \\
 &= m_1 c_1 \int \frac{1}{T} dT + m_2 c_2 \int \frac{1}{T} dT \\
 &= m_1 c_1 \ln\left(\frac{T_e}{T_1}\right) + m_2 c_2 \ln\left(\frac{T_e}{T_2}\right)
 \end{aligned}$$

 $T_e ?$

$$T_e = \frac{m_1 T_1 + m_2 T_2}{m_1 + m_2}$$

$$\text{A.N.: } T_e = 302 \text{ K}$$

$$\Delta S = 15,4 \text{ J}$$

$$\begin{aligned}
 2) \Delta S &= \Delta S_e + \Delta S_g \\
 &= M_1 c_1 \ln\left(\frac{T_e}{T_1}\right) + \int_{T_2}^{T_e} \frac{+Q_g}{T} \\
 &= M_1 c_1 \ln\left(\frac{T_e}{T_1}\right) + \int_{T_2}^{T_0} \frac{+Q_g}{T} + \int_{T_0}^{T_e} \frac{+Q_g}{T} + \frac{+Q}{T} \\
 &= M_1 c_1 \ln\left(\frac{T_e}{T_1}\right) + M_2 c_2 \ln\left(\frac{T_0}{T_2}\right) + M_2 c_2 \ln\left(\frac{T_e}{T_0}\right) + \frac{M_2 L}{T_0}
 \end{aligned}$$

 $T_e ?$

$$T_e = \frac{M_1 c_1 T_1 + M_2 [(c_1 - c_2) T_0 + c_2 T_2 - L]}{(M_1 + M_2) c_1}$$

$$\text{A.N.: } T_e = 289,8 \text{ K} \approx 17^\circ \text{C}$$

$$\Delta S = 141 \text{ J.K}^{-1}$$

Ex 9:

1). Chaleur nécessaire pour faire fondre la glace

$$Q_g = m_g \times L_g$$

$$\text{A.N.: } Q_g = 168 \text{ kJ}$$

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Chaleur fournie par l'eau

$$Q_e = Mc\Delta T \quad \text{A.N.: } Q_e = 84 \text{ kJ}$$

$$Q_g > Q_e \rightarrow \text{Eau + glace à } T_e = 0^\circ \text{C}$$

$$a) \Delta S_{\text{eau}} = \int \frac{+Q_e}{T} = M_e c_e \ln\left(\frac{T_e}{T}\right) \quad \text{A.N.: } \Delta S_{\text{eau}} = -296,9 \text{ J}$$

b) Masse de glace fondue ?

$$m = Q_e / L_g \quad \text{A.N.: } m = 0,25 \text{ kg}$$

$\Rightarrow$ La moitié de la glace a fondue

$$\Delta S_g = \int \frac{+Q}{T} = \int_{\text{fondue}} \frac{+Q}{T} + \int_{\text{reste}} \frac{+Q}{T} = \underbrace{m c \ln \frac{T_e}{T_0}}_0 + \frac{m L_g}{T_0}$$

$$\text{A.N.: } \Delta S_g = 307,7 \text{ J}$$

3) $\Delta S_g \neq \Delta S_{\text{eau}} \Rightarrow$ Transformation irréversible