Неделя 2.

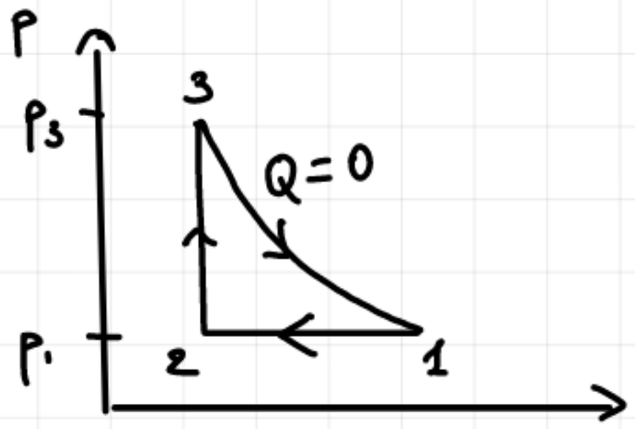
Тепловые машины.
Второе начало термодинамики.
Изменение энтропии в обратимых процессах.

4°

$\eta - ?$

$\frac{V_{max}}{V_{min}} = 2$

$i = 5$



$V_1 = V_{max} = 2V$

$V_2 = V_{min} = V$

$Q_{31} = 0$

$$\eta = \frac{A}{Q_{non}} = 1 - \frac{Q_{отд}}{Q_{non}}$$ ← подводим

$$Q_{12} = p_1(V - 2V) + \frac{5}{2}\nu R(T_2 - T_1) = -p_1 V + \frac{5}{2}(p_1 V - p_1 \cdot 2V) =$$

$$= -p_1 V - \frac{5}{2} p_1 V = -\frac{7}{2} p_1 V \quad < 0$$

$$Q_{23} = 0 + \frac{5}{2}(\nu R T_3 - \nu R T_2) = \frac{5}{2}(p_3 V - p_1 V) = \frac{5}{2}(p_3 - p_1)V \quad > 0$$

$$p_2 V^\gamma = p_1 (2V)^\gamma; \qquad p_3 = p_1 2^\gamma \qquad \text{и} \qquad \gamma = \frac{7}{5} = 1{,}4$$

$$\eta = 1 - \frac{\frac{7}{2} p_1 V}{\frac{5}{2}(2^\gamma - 1) p_1 V} = 1 - \frac{7}{5(2^{1{,}4} - 1)} = \underline{\underline{0{,}15}}$$

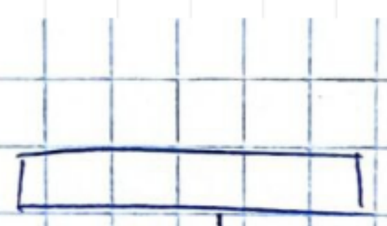
№6°

$Q_1 = 65$ Дж

$Q_2 = 80$ Дж

$T = 320$ K

$T_1 - ?$



$Q_2 = A + Q_1$

$\eta = 1 - \frac{T_1}{T}$

$\eta = 1 - \frac{Q_1}{Q_2} =$ $\qquad \frac{T_1}{T} = \frac{Q_1}{Q_2}$

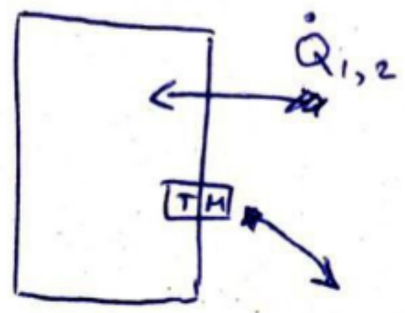
$$T_1 = \frac{Q_1}{Q_2} T = \frac{65}{80} \cdot 320\,\text{K} = 260\,\text{K}$$

3.47

$T_1 = 26°C = 299\ K$

$T_2 = 26° + 5° = 31°C = 304\ K$

$T_0 = 21°C = 294\ K$



$\eta_1 = 1 - \frac{T_0}{T_1} \qquad \eta_2 = 1 - \frac{T_0}{T_2}$

$\dot{Q}_1 = \alpha(T_1 - T_0) \qquad \dot{Q}_2 = \alpha(T_2 - T_0)$

$\dot{Q} = \eta \dot{A} \; ; \quad \dot{A} = \frac{\dot{Q}}{\eta}$

$$\frac{\dot{A}_2}{\dot{A}_1} = \frac{\eta_1}{\eta_2}\frac{\dot{Q}_2}{\dot{Q}_1} = \frac{(T_2 - T_0)T_1}{(T_1 - T_0)T_2} \cdot \frac{\alpha(T_2 - T_0)}{\alpha(T_1 - T_0)} = \frac{T_1}{T_2}\frac{(T_2 - T_0)^2}{(T_1 - T_0)^2} =$$

$$= \frac{299}{304} \cdot \left(\frac{304 - 294}{299 - 294}\right)^2 = \frac{299}{304} \cdot \left(\frac{10}{5}\right)^2 = \text{около } \underline{\underline{3{,}93 \approx 4}}$$

4.73

$\delta Q = TdS = C(T)\,dT$

$C_1 = \alpha T$

$C_2 = \beta\sqrt{T}$

$C(T) = \frac{TdS}{dT}$

$T_{min} = T_1$

(1) $\alpha T = \frac{TdS}{dT}$

$dS = \alpha dT$

$S_2 - S_1 = \alpha(T_2 - T_1)$

(2) $\beta\sqrt{T} = \frac{TdS}{dT}$

$dS = \frac{\beta dT}{\sqrt{T}}$

$S_2 - S_1 = 2\beta(\sqrt{T_2} - \sqrt{T_1}) =$

$= 3\alpha\sqrt{T_1}(\sqrt{T_2} - \sqrt{T_1})$

$\eta - ?$

$2\beta = 3\alpha\sqrt{T_1}$

$\alpha, \beta > 0$

$\alpha(\sqrt{T_2} + \sqrt{T_1}) = 3\alpha\sqrt{T_1}$

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

$T_2 = 4T_1$

$\eta = \frac{Q_1 + Q_2}{Q_1}$

$$Q_1 = \int_{T_1}^{T_2} C_1\,dT = \alpha\int_{T_1}^{T_2} T\,dT = \frac{\alpha}{2}(T_2^2 - T_1^2) = \frac{15}{2}\alpha T_1^2$$

$$Q_2 = \int_{T_1}^{T_2} C_2\,dT = \alpha\sqrt{T_1}\left(T_1^{\frac{3}{2}} - T_2^{\frac{3}{2}}\right) = \alpha\sqrt{T_1}\cdot 4\left(T_1^{3/2} - 8\right)$$

$$= -7\alpha T_1^{1/2 + 3/2} = -7\alpha T_1^2$$

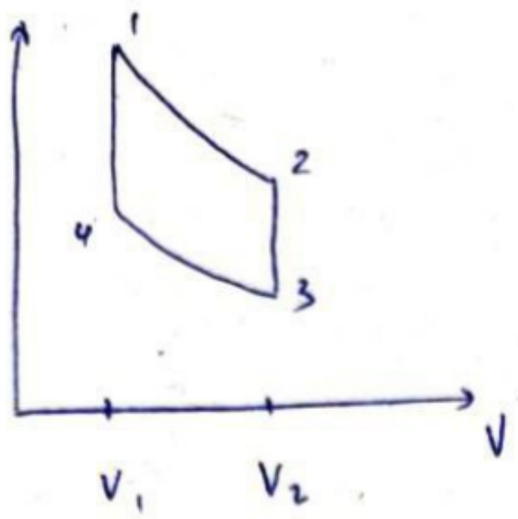
$$\underline{\eta} = 1 + \frac{Q_2}{Q_1} = 1 - \frac{+7\alpha T_1^2}{\frac{15}{2}\alpha T_1^2} = 1 - \frac{14}{15} = \underline{\frac{1}{15}}$$

3.52 $\nu = 1$ моль, $i = 3$, ИГ

$T_{max} = T_1$

$T_{min} = T_3$

$A_{max} - ?$



$$A = Q_{12} + Q_{23} + Q_{34} + Q_{41} \overset{0}{=} Q_{23} + Q_{41} \quad (=)$$

$$Q_{23} = C_V (T_3 - T_2) = \frac{3}{2} R (T_3 - T_2)$$

$$Q_{41} = C_V (T_1 - T_4) = \frac{3}{2} R (T_1 - T_4)$$

$$(=) \frac{3}{2} R (T_3 - T_2 + T_1 - T_4) = \frac{3}{2} R (T_1 + T_3 - T_2 - T_4) \quad (\equiv)$$

$pV^\gamma = const$ 1-2, 3-4 $\gamma = \frac{5}{3}$

$$\left.\begin{aligned} p_1 V_1^\gamma &= p_2 V_2^\gamma \\ p_4 V_1^\gamma &= p_3 V_2^\gamma \end{aligned}\right| \longrightarrow \frac{p_1}{p_4} = \frac{p_2}{p_3}$$

$$\left.\begin{aligned} T_1 V_1^{\gamma-1} &= T_2 V_2^{\gamma-1} \\ T_4 V_1^{\gamma-1} &= T_3 V_2^{\gamma-1} \end{aligned}\right| \longrightarrow \frac{T_1}{T_4} = \frac{T_2}{T_3}, \quad \frac{T_1}{T_2} = \frac{T_4}{T_3} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

$$T_4 = T_3 \left(\frac{V_2}{V_1}\right)^{\gamma-1} \qquad T_2 = T_1 \left(\frac{V_2}{V_1}\right)^{1-\gamma}$$

$$(\equiv) \frac{3}{2} R \left(T_1 + T_3 - T_1 \left(\frac{V_2}{V_1}\right)^{1-\gamma} - T_3 \left(\frac{V_2}{V_1}\right)^{\gamma-1}\right)$$

$A - max$, $dA = 0$, $\frac{V_2}{V_1} = \varepsilon$

$$\frac{dA}{d\varepsilon} = \frac{3}{2} R \left(T_1 \left(-(1-\gamma)\left(\frac{V_2}{V_1}\right)^{-\gamma}\right) + T_3 \left(-(\gamma-1)\left(\frac{V_2}{V_1}\right)^{\gamma-2}\right)\right) =$$

$$= \frac{3}{2} R \left(T_1 ((\gamma-1)\varepsilon^{-\gamma}) + T_3 ((1-\gamma)\varepsilon^{\gamma-2}\right) = 0$$

$$T_1 \varepsilon^{-\gamma} = T_3 \varepsilon^{\gamma-2}$$

3.43

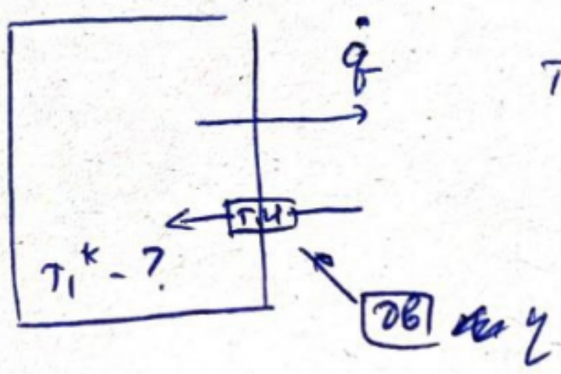
$t_1 = -3°C$ 270K

$t_2 = -23°C$ 250K

бензиновая горелка

двигнок $\eta = 9\eta$ тепловой насос

$T_1^* - ?$



$$\dot{q} = \alpha (T_1 - T_2)$$

Мосуд. т.и $\rightarrow \dot{Q}_и = \dot{Q}_{уд} = \alpha (T_1^* - T_2)$

$$\frac{\dot{Q}_и}{T_1^*} = \frac{\dot{Q}_{уд}}{T_2}, \quad \dot{A} = \dot{Q}_{нас} - \dot{Q}_{уд} = \dot{Q}_и \left(1 - \frac{\dot{Q}_{уд}}{\dot{Q}_и}\right) = \dot{Q}_и \left(1 - \frac{T_2}{T_1^*}\right)$$

$$\dot{A} = \eta \dot{q}$$

$$\dot{A} = \eta \dot{q} = \dot{Q}_н \left(1 - \frac{T_2}{T_1^*}\right)$$

$$\eta \cancel{\alpha}(T_1 - T_2) = \cancel{\eta} \cancel{\alpha}(T_1^* - T_2)\left(1 - \frac{T_2}{T_1^*}\right)$$

$$\eta (T_1 - T_2) = \frac{1}{T_1^*}(T_1^* - T_2)^2$$

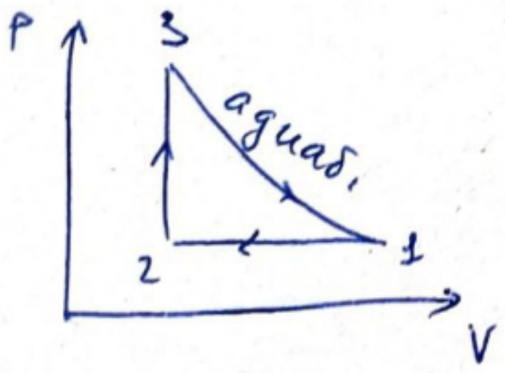
$$T_1^* (\eta (T_1 - T_2)) = T_1^{*2} + T_2^2 - 2 T_2 T_1^*$$

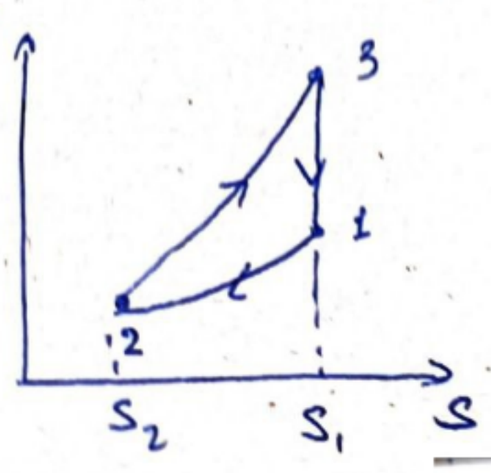
$$T_1^{*2} + T_1^* (-2T_2 - \eta T_1 + \eta T_2) + T_2^2 = 0$$

$$T_1^{*2} - 508\, T_1^* + 250^2 = 0$$

$$T_1^* = 254 \pm \sqrt{254^2 - 250^2} = \underline{\underline{299\ K}} \Rightarrow \underline{\underline{t_1^* = 26^\circ C}}$$

4.15





$$b = \frac{\cancel{(}Q_{12}\cancel{)}}{c_V} = 0{,}2 \qquad \gamma = \frac{c_p}{c_V} = \frac{4}{3}$$

! не обязательно И.Г.!
обратимый процесс
$\eta - ?$

$$Q_{12} = c_p (T_2 - T_1) < 0$$

$$Q_{23} = c_V (T_3 - T_2) > 0$$

$$Q_{31} = 0$$

$$\eta = \frac{Q_{12} + Q_{23}}{Q_{23}}$$

$$S_2 - S_1 = c_p \ln \frac{T_2}{T_1} = -b c_V$$

$$\frac{T_2}{T_1} = \exp\left(-\frac{b c_V}{c_p}\right) = e^{-\frac{b}{\gamma}}$$

$$S_3 - S_2 = c_V \ln \frac{T_3}{T_2}$$

$$S_3 - S_1 = 0 = c_p \ln \frac{T_2}{T_1} + c_V \ln \frac{T_3}{T_2}$$

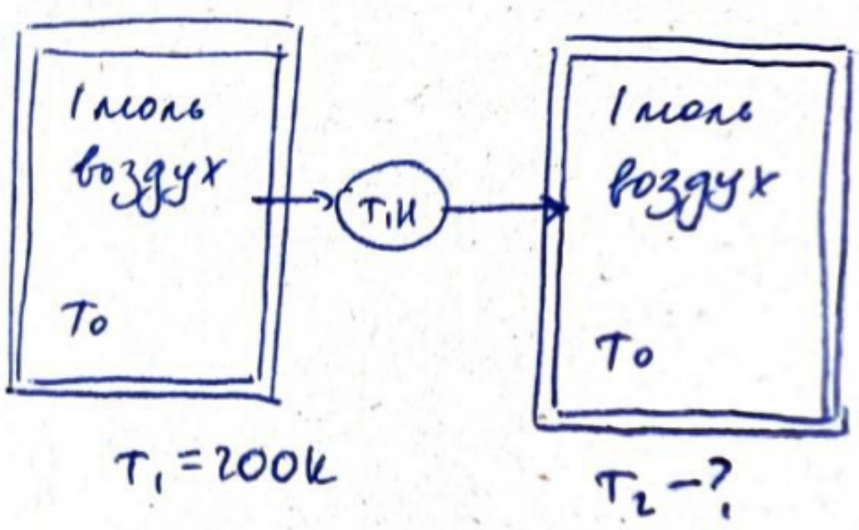
$$\ln \frac{T_3}{T_2} = \frac{c_p}{c_V} \ln \frac{T_1}{T_2} = \ln\left(\frac{T_1}{T_2}\right)^\gamma$$

$$\frac{T_3}{T_2} = \left(\frac{T_1}{T_2}\right)^\gamma = e^{\frac{b}{\gamma}\gamma} = e^b$$

$$\eta = \frac{Q_{12} + Q_{23}}{Q_{23}} = 1 + \frac{Q_{12}}{Q_{23}} = 1 + \gamma \frac{T_2 - T_1}{T_3 - T_2} = 1 - \gamma \frac{\frac{T_1}{T_2} - 1}{\frac{T_3}{T_2} - 1} =$$

$$= 1 - \gamma \frac{e^{\frac{b}{\gamma}} - 1}{e^b - 1} = 1 - \frac{4}{3} \frac{e^{0{,}2 \cdot \frac{3}{4}} - 1}{e^{0{,}2} - 1} = \underline{\underline{0{,}25}}$$

Т-2 $T_0 = 300K$, $T_2 - ?$, $A_{min} - ?$



Теплоемкостью стенок сосуда пренебречь

сосуд изолирован

$$\oint \frac{\delta Q}{T} = 0$$

$$\oint_{T_1} \frac{C_v dT}{T} + \int_{T_0}^{T_2} \frac{C_v dT}{T} = 0$$

$$\ln \frac{T_1}{T_0} + \ln \frac{T_2}{T_0} = 0$$

$$\ln\left(\frac{T_1 T_2}{T_0^2}\right) = 0$$

$$\underline{\underline{T_2 = \frac{T_0^2}{T_1} = \frac{300^2}{200} = 450\,K}}$$

$$T_1 \xi^{-\gamma} = T_3 \xi^{\gamma-2} \qquad 2\gamma - 2 = \frac{10}{3} - \frac{6}{3} = \frac{4}{3}$$

$$\alpha = \frac{T_1}{T_3} = \xi^{2\gamma-2}, \quad \xi = \left(\frac{T_1}{T_3}\right)^{\frac{1}{2\gamma-2}} = \left(\frac{T_1}{T_3}\right)^{\frac{3}{4}} = \alpha^{\frac{3}{4}}$$

~~$A_{adiab} = \frac{3}{2}R$~~ $\qquad 1-\gamma = 1-\frac{5}{3} = -\frac{2}{3}, \quad \gamma - 1 = \frac{2}{3}$

$$\underline{\underline{A_{min}^{min} = \frac{3}{2}R\left(T_1(1-\xi^{1-\gamma}) + T_3(1-\xi^{\gamma-1})\right) = \frac{3}{2}RT_3\left(\frac{T_1}{T_3} - \frac{T_1}{T_3}\xi^{1-\gamma} + 1 - \xi^{\gamma-1}\right)}} \ominus$$

$$\frac{T_1}{T_3}\xi^{1-\gamma} = \frac{T_1}{T_3}\alpha^{-\frac{2}{3}\cdot\frac{3}{4}\cdot\frac{1}{2}} = \frac{T_1}{T_3}\alpha^{-\frac{1}{2}} = \alpha^{\frac{1}{2}}, \quad \xi^{\gamma-1} = \alpha^{\frac{3}{4}\cdot\frac{2}{3}\cdot\frac{1}{2}} = \alpha^{\frac{1}{2}}$$

$$\ominus \frac{3}{2}RT_3\left(\alpha - \alpha^{\frac{1}{2}} + 1 - \alpha^{\frac{1}{2}}\right) = \frac{3}{2}RT_3\left(\frac{T_1}{T_3} - 2\left(\frac{T_1}{T_3}\right)^{\frac{1}{2}} + 1\right) = \underline{\underline{\frac{3}{2}RT_3\left(\sqrt{\frac{T_1}{T_3}} - 1\right)^2}}$$

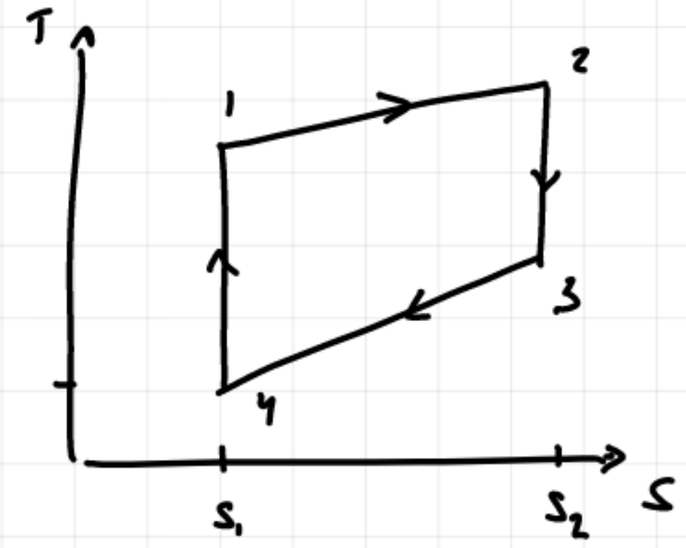
05

$T_2 = \frac{3}{2}T_1$

$T_3 = \frac{3}{4}T_1$

$T_4 = \frac{1}{20}T_1$

$\eta - ?$



$$Q_{12} = \int_1^2 T dS = \frac{1}{2}(T_1 + T_2)(S_2 - S_1)$$

$$A = \oint T dS = \frac{(T_1 - T_4) + (T_2 - T_3)}{2}(S_2 - S_1)$$

$$\underline{\underline{\eta = \frac{A}{Q_{12}} = \frac{T_1 + T_2 - T_3 - T_4}{T_1 + T_2} = 1 - \frac{T_3 + T_4}{T_1 + T_2}}} =$$

$$= 1 - \frac{3/4 + 1/20}{1 + 3/2} = \underline{\underline{\frac{17}{25}}}$$