④ The

$$e = \frac{W}{Q_{in}} = 0.22$$

$$W = \frac{180\,J}{\text{cylinder cycle}} \Rightarrow$$

$$P = Wf$$

$$P = \frac{180\,J}{\text{cyl cycle}} \cdot \frac{25\text{ cycles}}{\text{sec}} \cdot 4\text{ cyl}$$

$$P = 18\,\frac{kJ}{s} \Rightarrow \frac{dQ_{in}}{dt} = P \cdot e = 3960\,\frac{J}{s}$$

Ok

Gallons/se

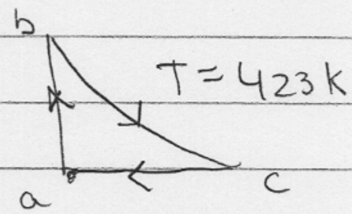
$$\frac{dQ_{in}}{dt} = 3960\,J/s = \frac{dG}{dt}\,\frac{dQ}{dG}$$

heat per gallon = 130×10^6

$$\frac{dG}{dt} = \frac{3960\,J/s}{130 \times 10^6\,J}$$

$$\frac{dt}{dG} = \frac{\text{time}}{\text{gallon}} = \frac{130 \times 10^6\,J}{3960\,J/s} = 32,828\,s \approx 9\,hrs$$

(6)



a) Clockwise

b) $\frac{W}{Q_{in}} = e$

Now:

$T_A = \text{Standard Temp} = 273°K$

$T_B = T_C = 423K$

Now

$Q_{in}^{ab} = ?$

Using

$\Delta U = Q - \cancel{W}^{0}$

$n C_V \Delta T = Q$ ← for ideal gas

for mono-atomic IG $C_V = \frac{3}{2}R$

$\frac{3}{2}R(T_C - T_A) = Q_{in}^{ab} = \frac{3}{2}nRT_c\left(1 - \frac{T_a}{T_c}\right)$

$T_f = T_b = T_c$

Now

$Q_{in}^{bc} = ?$

$\cancel{\Delta U}^{0} = Q - W$

The energy depends only on T for IG
So T is const, U = const, $\Delta U = 0$

$Q = W = nRT_c \log \frac{V_f}{V_i}$

Now notice $V_i = V_B = V_a$ = Volume of one mole of gas at STP

$V_a = \frac{nRT_A}{P_A} = 22.4L$

Now

$V_f = \frac{nRT_f}{P_f} = \frac{nRT_c}{P_A} = \left(\frac{nRT_a}{P_a}\right)\frac{T_c}{T_a} = V_a \frac{T_c}{T_a}$

$P_f = P_c = P_A$

So

$$Q^{bc} = nRT_c \log \frac{V_f}{V_i} = nRT_c \log\left(\frac{V_a T_c/T_a}{V_a}\right)$$

$$Q^{bc} = nRT_c \log\left(T_c/T_a\right) = W^{bc}$$

So the final leg one computes

Q^{ca} which is negative - heat flows out

$$W_{ca} = \int p\, dV = P_A (V_A - V_C)$$

$$= P_A V_A \left(1 - \frac{V_c}{V_A}\right) = nRT_a \left(1 - \frac{T_c}{T_a}\right)$$

$$W_{ca} = nR\,(T_a - T_c) = -nRT_c\,(1 - T_a/T_c)$$

Note

$$\Delta U = Q - W \Rightarrow Q = \overset{<0}{\Delta U} + \overset{\text{less } <0}{W}$$

temperature drops

So assemble

$$e = \frac{W}{Q_{in}} = \frac{W^{bc} + W^{ca}}{Q^{ab} + Q^{bc}}$$

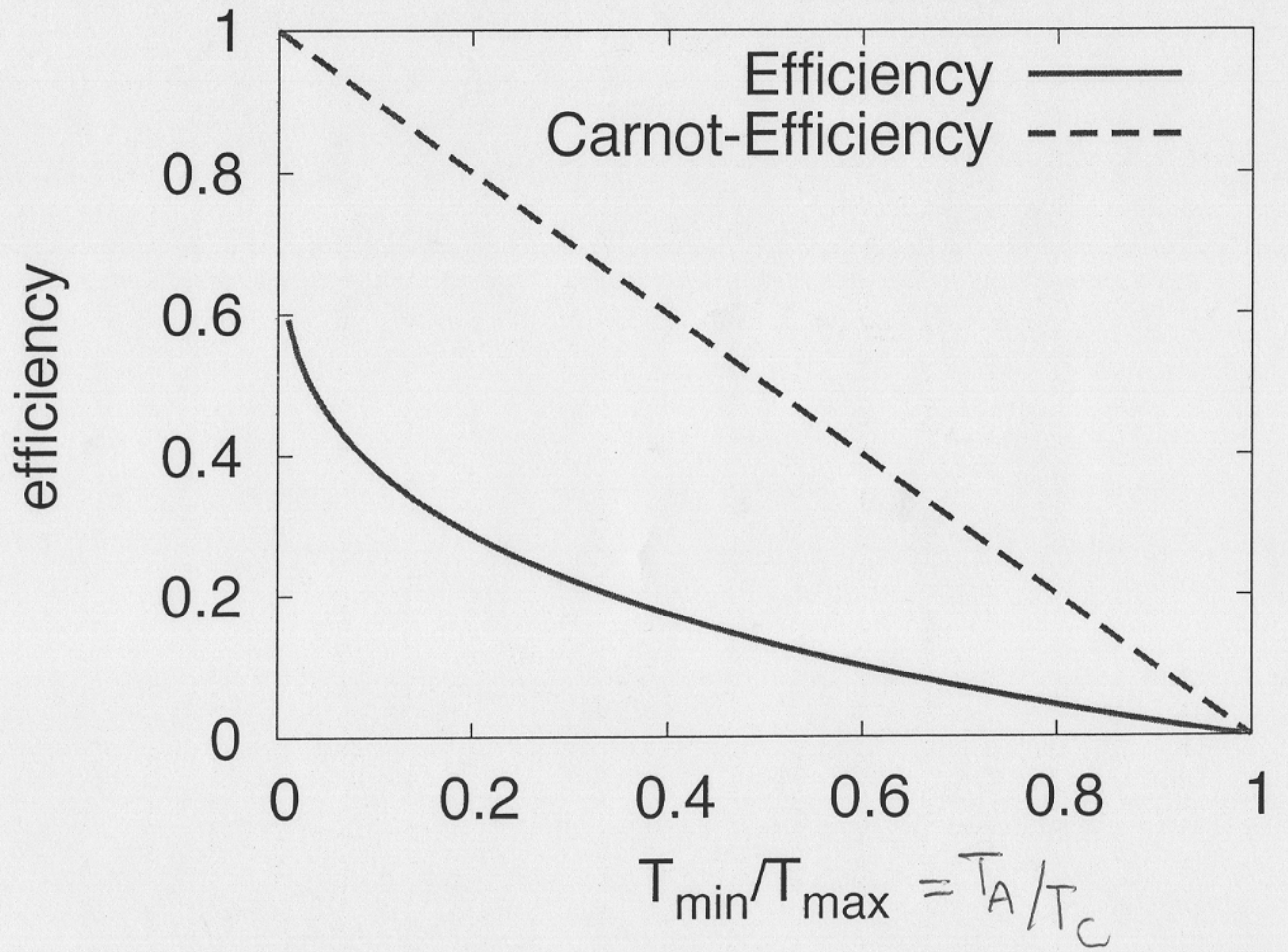
$$e = \frac{nRT_c \log(T_c/T_a) - nRT_c(1 - T_a/T_c)}{\frac{3}{2} nRT_c (1 - T_a/T_c) + nRT_c \log T_c/T_a}$$

$$e = \frac{\log(T_c/T_a) - (1 - T_a/T_c)}{\frac{3}{2}(1 - T_a/T_c) + \log \frac{T_c}{T_A}}$$

$$\boxed{e = 1 - \frac{5/2\,(1 - T_A/T_c)}{3/2\,(1 - T_A/T_c) + \log(T_c/T_A)}}$$

$e = 0.086$

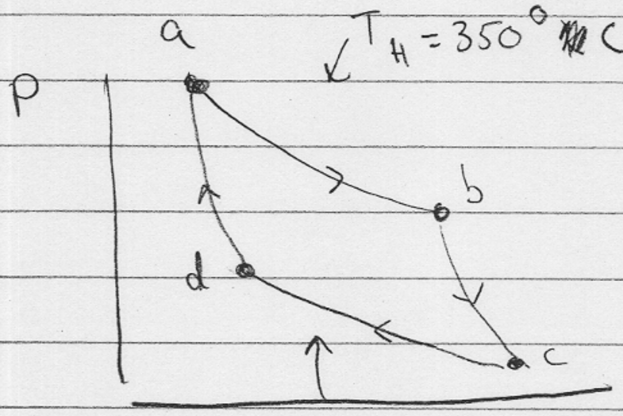
$$\frac{T_A}{T_C} = \frac{273^\circ K}{423^\circ K} = 0.64$$



efficiency
Efficiency
Carnot-Efficiency
0
0.2
0.4
0.6
0.8
1
Tmin/Tmax = TA/TC

20)

$T_H = 350^\circ C = 623^\circ K$



V

$T_L = 210^\circ C = 483^\circ K$

$P_a = 8.8 \text{ atm}$

$n = 1$

$\frac{V_b}{V_A} = 2$ $\qquad$ $\frac{V_c}{V_d} = 2$

a) $P_a = 8.8 \text{ atm}$ $\qquad$ $V_a = \frac{nRT_a}{P_a} = 0.00587 m^3 = 5.9 L = P_a$

b) Now V doubles $\rightarrow$ $V_b = 11.8 L = \boxed{2V_a = V_b}$

$P_b = \frac{nRT_b}{V_b} \Rightarrow P \propto \frac{1}{V}$ so $\boxed{P_b = \frac{P_a}{2}} = 4.4 \text{atm}$

(c) Now in an adiab expansion

$$PV^{\gamma} = C$$

So

$$P_b V_b^{\gamma} = P_c V_c^{\gamma}$$

Also

$$T_b V_b^{\gamma-1} = T_c V_c^{\gamma-1}$$

$$\left(\frac{T_b}{T_c}\right) = \left(\frac{V_c}{V_b}\right)^{\gamma-1}$$

$$\left(\frac{T_b}{T_c}\right)^{\frac{1}{\gamma-1}} = \frac{V_c}{V_b} \qquad \gamma = \frac{5}{3} \qquad \frac{1}{\gamma-1} = \frac{1}{\frac{5}{3}-1} = \frac{3}{2}$$

$$\left(\frac{T_b}{T_c}\right)^{3/2} = \frac{V_c}{V_b}$$

$T_b = 623°K$

$T_c = 483°K$

So $\frac{V_c}{V_b} = 1.46$ $\qquad \boxed{V_c = 17.2\ L}$ $\qquad \boxed{V_c = 2V_a \left(\frac{T_b}{T_c}\right)^{3/2}}$

$$= \left(T_b / T_c\right)^{3/2}$$

$$P_c = \frac{nRT_c}{V_c}$$

$$P_c = \frac{nRT_b}{V_b}\left(\frac{V_b}{V_c}\right)\frac{T_c}{T_b}$$

$$= P_b\left(\frac{T_c}{T_b}\right)^{3/2}\frac{T_c}{T_b}$$

$$P_c = P_b\left(\frac{T_c}{T_b}\right)^{5/2} = \boxed{\frac{P_a}{2}\left(\frac{T_c}{T_b}\right)^{5/2} = P_c}$$

d) Now

$$V_d = \frac{V_c}{2} = \boxed{V_a\left(\frac{T_b}{T_c}\right)^{3/2} = V_d}$$

$P_d \propto \frac{1}{V_d}$ along CD, $P_d = 2P_c$ since $V_D = \frac{V_c}{2}$

$$\boxed{P_D = P_a\left(\frac{T_c}{T_b}\right)^{5/2}}$$

So

AB

$$W = nRT_b \log \frac{V_b}{V_a} = nRT_b\left[\log 2\right]$$

BC

$$\Delta U = \cancel{Q}^{0} - W$$

$$W = -\Delta U = -nC_v \Delta T = -n\frac{3}{2}R\,(T_c - T_b)$$

$$W = nRT_b\left[\left(1 - \frac{T_c}{T_b}\right)\cdot\frac{3}{2}\right]$$

CD

$$W = nRT_c \log \frac{V_d}{V_c} = +nRT_c \log\left(\frac{1}{2}\right)$$

$$W = -nRT_b\left[\frac{T_c}{T_b}\log 2\right]$$

DA

$$W = -\Delta U = -nC_v \Delta T = -n\frac{3}{2}R\,(T_b - T_c)$$

$$W = -nRT_b \cdot \left[\frac{3}{2}\left(1 - T_c/T_b\right)\right]$$

Now Q, ΔU

AB

$\Delta U = 0 \qquad Q = W = nRT_b \log 2 = Q_{in}$

BC

$Q = 0 \qquad \Delta U = -W = -\frac{3}{2} nRT_b \left(1 - \frac{T_c}{T_b}\right)$

CD

$\Delta U = 0 \qquad Q = W = -nRT_b \left[\frac{T_c}{T_b} \log 2\right] = -Q_{out}$

DA

$Q = 0 \qquad \Delta U = -W = \frac{3}{2} nRT_b \left[1 - \frac{T_c}{T_b}\right]$

So

$$e = \frac{W}{Q_{in}} = \frac{nRT_b \log 2 - nRT_b \log 2 \cdot T_c/T_b}{nRT_b \log 2}$$

$$e = 1 - T_c/T_b = 1 - \frac{483^\circ K}{623^\circ K} = 22\%$$

Numerical Summary

	P(atm)	V (L)
a)	8.8	5.9
b)	4.4	11.8
c)	2.3	17.3
d)	4.65	8.65

Process	Q	W (kJ)	ΔU
AB	= W	3.6	0
BC	0	1.75	= −W
CD	= W	−2.8	0
DA	0	−1.75	= −W

Adiabatic Process

$$W = \frac{P_1 V_1}{\gamma - 1}\left[1 - \left(\frac{V_1}{V_2}\right)^{\gamma-1}\right]$$

see class lecture

Now

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma} = C$$

So

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

Or

$$W = \frac{P_1 V_1}{\gamma - 1} - \frac{P_2 V_2}{\gamma - 1}$$

b) For const vol

$$dU = dQ - \cancel{dW}^{\,0}$$

$$dU = nC_v\,dT \quad \leftarrow \text{any subst at } V = \text{const}$$

Now for an ideal gas U is a function of temperature only, not of V

So

$$dU = nC_v\,dT \quad \text{is true in general}$$

c) For adiab $dQ = 0$

$$dU = \cancel{dQ} - p\,dV$$

$$\Delta U = -W$$

Then:

$$\Delta U = nC_v(T_f - T_i) = -W$$

now for ideal gas

$$C_p = C_v + R \Rightarrow \frac{C_p}{C_v} \equiv \gamma = 1 + \frac{R}{C_v}$$

So

$$C_v = R/(\gamma - 1)$$

$$\Delta U = \frac{nR}{\gamma-1} T_f - \frac{nRT_i}{\gamma-1}$$

$$\Delta U = \frac{P_2 V_2}{\gamma-1} - \frac{P_1 V_1}{\gamma-1} = -W$$

<u>Sound 1</u>

$$I_{1m} = I_0 \, 10^{\beta_0/10} \qquad \beta_0 = 100\,dB$$

Now

power

$$I = \frac{P_0}{4\pi r^2}$$

$$\frac{I_{1km}}{I_{1m}} = \left(\frac{1m}{1000m}\right)^2 = 10^{-6}$$

So

$$I_{1km} = 10^{-6} I_{1m} = 10^{-60/10} I_0 10^{\beta_0/10}$$

So $$I_{1km} = I_0 \, 10^{(\beta_0 - 60)/10}$$

So $$\beta_0 = 100\,dB - 60\,dB = 40\,dB$$

(b) Still pretty loud

(c) $I = \frac{(\Delta P)^2}{2V_s \rho}$

$$\Delta P = \sqrt{2v_s \rho I}$$

$$\frac{\Delta P}{P_0} = \sqrt{\frac{2v_s \rho}{P_0^2} \times I_0 \times 10^{\beta/10}}$$

$$\frac{\Delta P}{P_0} = \sqrt{\frac{2v_s \rho I_0}{P_0^2}} \times 10^{\beta/20}$$

$V_s = 343\,m/s$

$P_0 = 1atm = 1bar$
$= 10^5 N/m^2$

$I_0 = 1 \times 10^{-12} \frac{W}{m^2}$

$\rho = 1.29 \frac{kg}{m^3}$

$$\frac{\Delta P}{P_0} = 0.29 \times 10^{-9} \times 10^{\beta/20}$$

$$\frac{\Delta P}{P_0} = 0.29 \times 10^{(\beta - 180)/20}$$

$$\frac{\Delta P}{P_0} = 0.29 \times 10^{-80/20} = 0.26 \times 10^{-4}$$

$\beta = 100\,dB$

Sound 2

(b) Lets do B first

$$y = A\sin(2\pi f_1 t) + A\sin(2\pi f_2 t)$$

$$y = A\sin(2\pi(\bar{f} + \frac{\Delta f}{2})t) + A\sin(2\pi(\bar{f} - \frac{\Delta f}{2})t)$$

Now

$$\sin(A \pm B) = \sin A\cos B \pm \cos A\sin B$$

$$y = 2A\sin(2\pi\bar{f}t)\cos(2\pi\frac{\Delta f}{2}t)$$

So Looking at fig 1

a) The period is of the rapid oscillations are

$$T \sim \frac{4\,\text{cycles}}{2 \times 10^{-3}\,s} \simeq \frac{2}{10^{-3}\,s}$$

(I count four cycles between two and fou

$$\bar{f} = \frac{1}{T} \simeq 500\,Hz$$

The period of the slow oscillations if

$$T = 6 \times 10^{-3}\,s \qquad \frac{\Delta f}{2} = \frac{1}{T} = 0.166 \times 10^{3}\,Hz$$

I count one cycle between 2 and 8

So

$$\Delta f \simeq 0.3 \times 10^{3}\ Hz$$

So

$$f_1 = \bar{f} + \frac{\Delta f}{2} = 666\ Hz$$

$$f_2 = \bar{f} - \frac{\Delta f}{2} = 340\ Hz$$