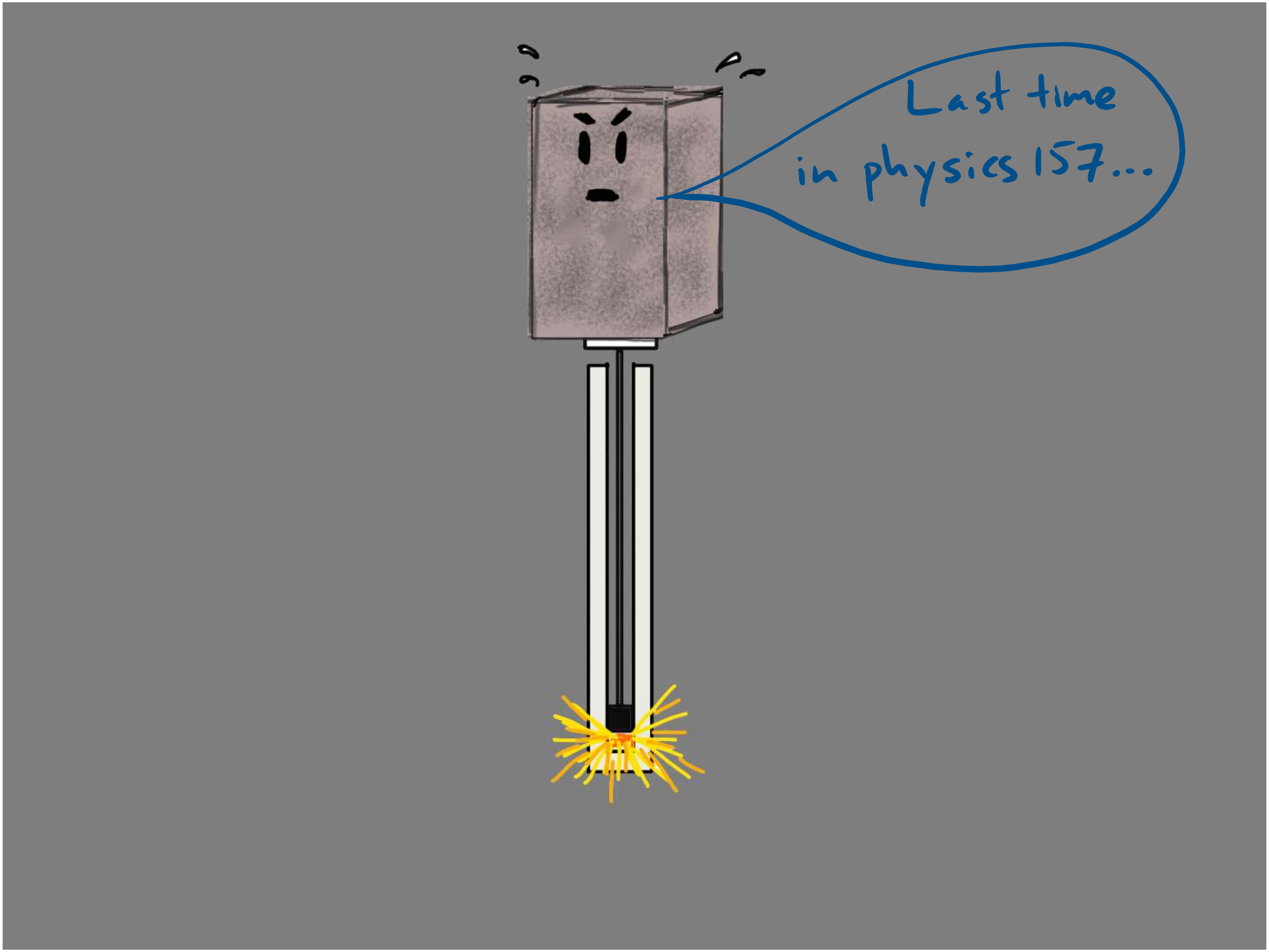

Last time
in physics 157...

What are you trying to calculate? n: use $PV = nRT$

T, V, or P: use $\frac{PV}{T} = \text{const}$

adiabatic: also have $TV^{\gamma-1} = \text{const}$

$PV^{\gamma} = \text{const}$

ΔU: have $\Delta U = nC_v \Delta T$ always

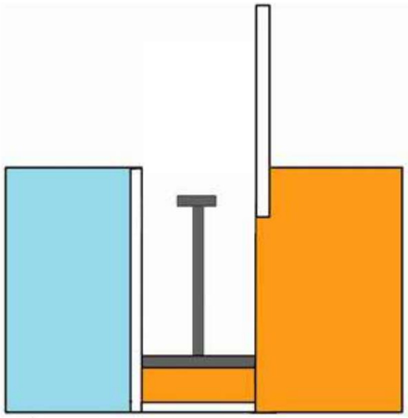
W or Q: have $W = P\Delta V$ const P

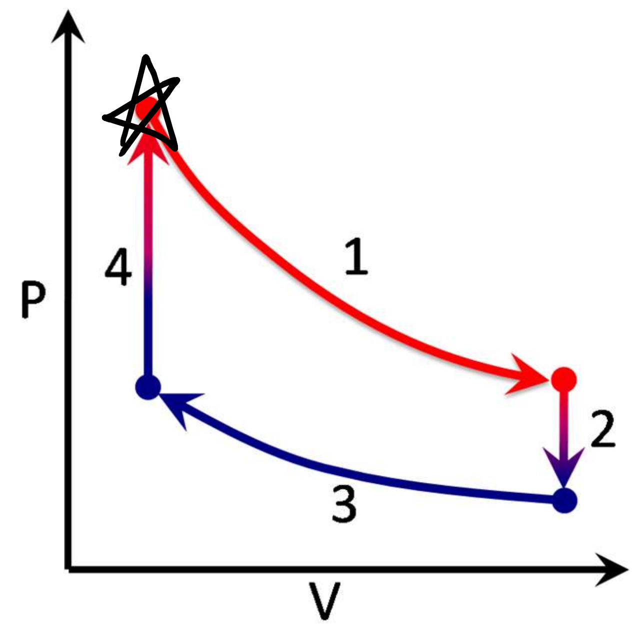
$W = nRT \ln\left(\frac{V_f}{V_i}\right)$ const T

all others: use $Q = \Delta U + W$

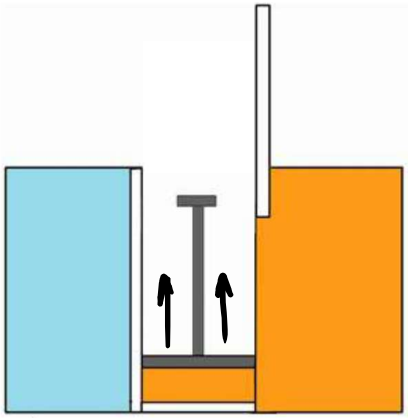
(gives $Q = nC_p \Delta T$ const P)

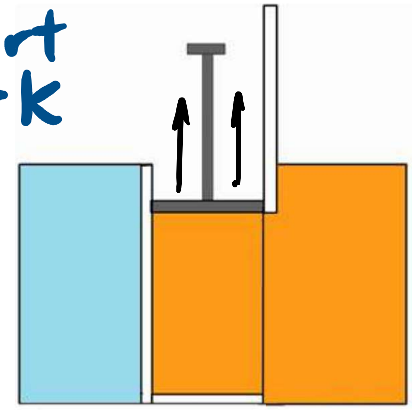
HEAT ENGINES: (partly) convert heat → work in cyclic process

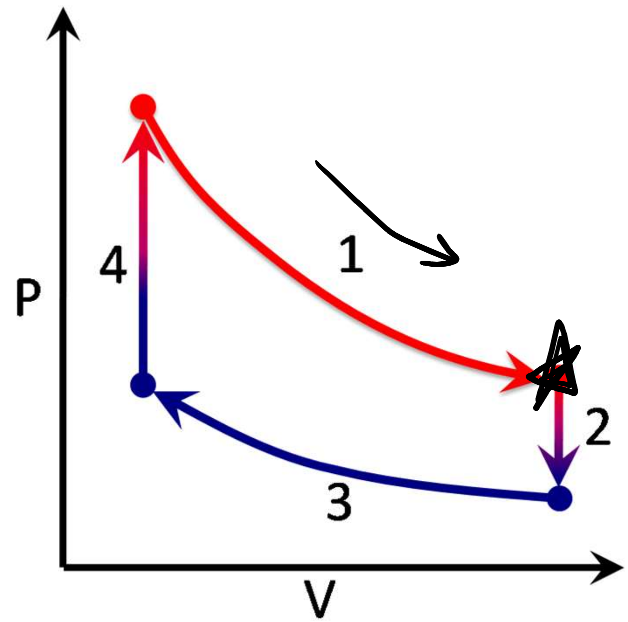




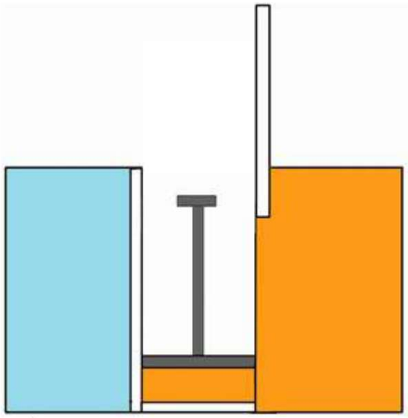
HEAT ENGINES: (partly) convert heat → work in cyclic process

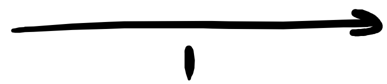


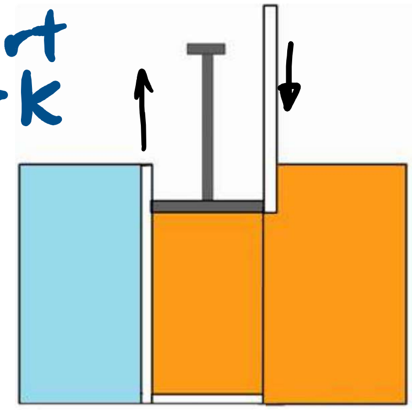


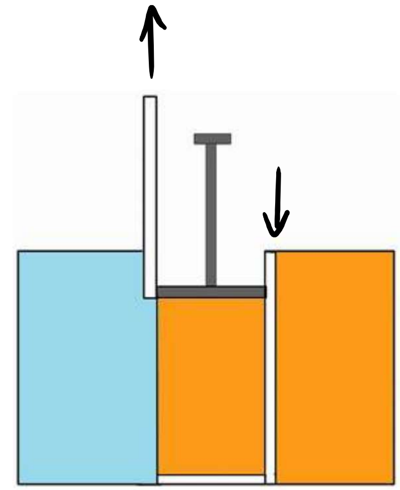


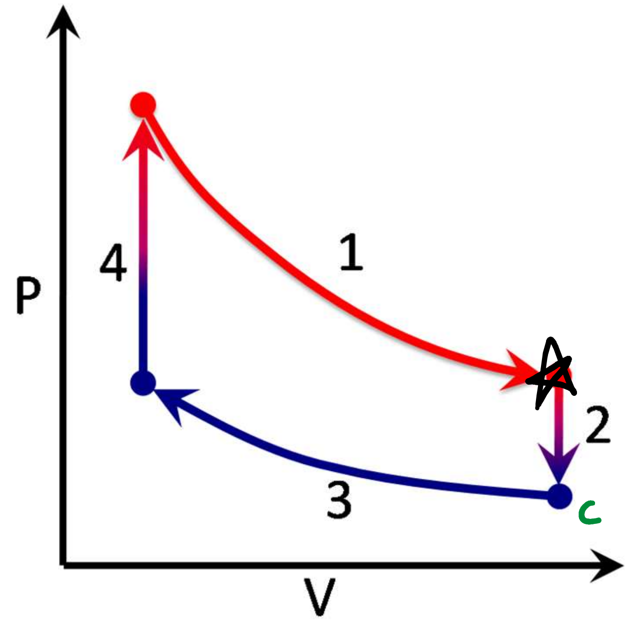
HEAT ENGINES: (partly) convert heat → work in cyclic process



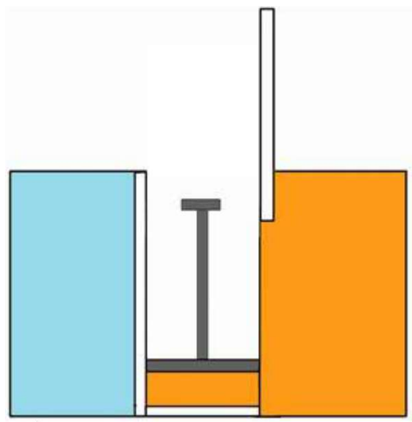


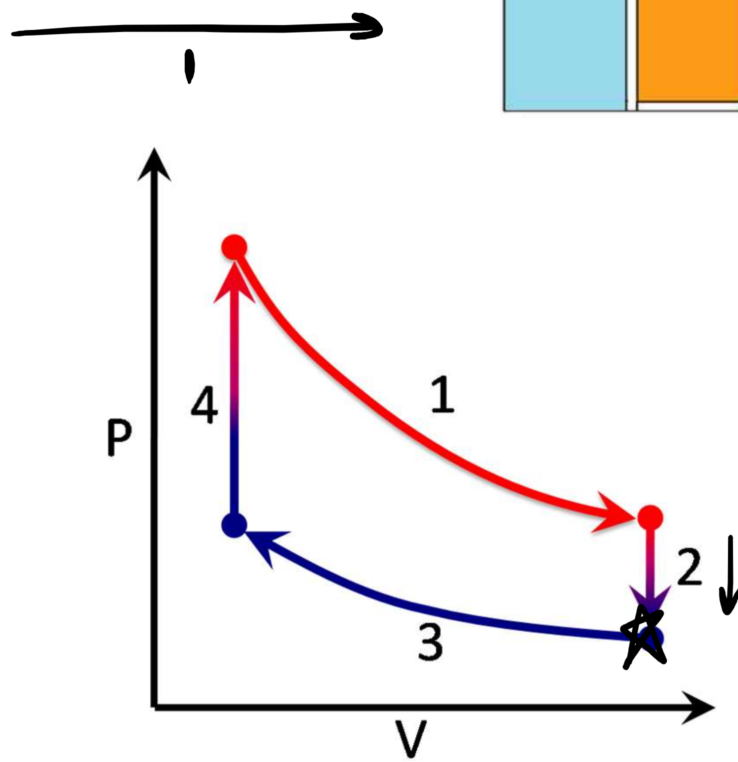


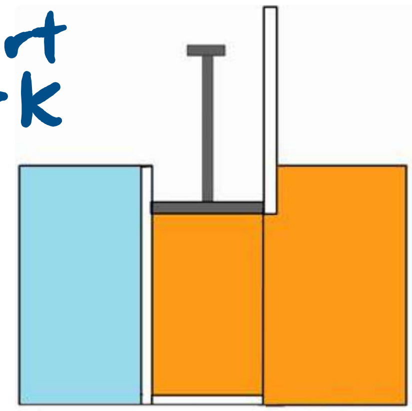


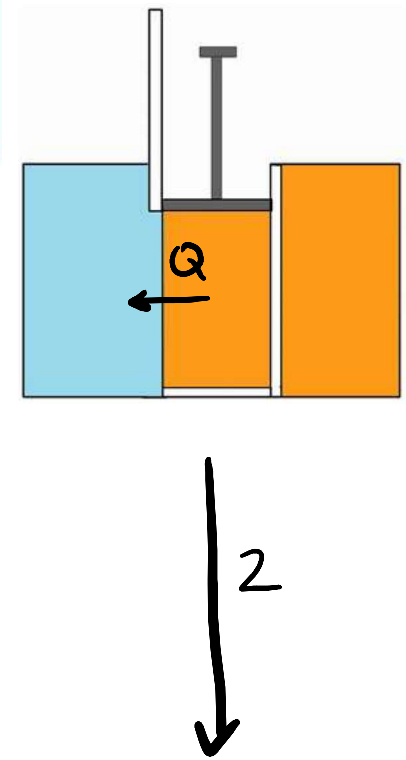


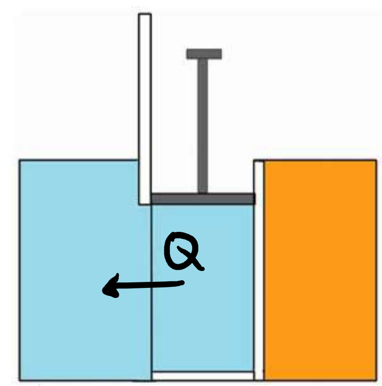
HEAT ENGINES: (partly) convert heat → work in cyclic process



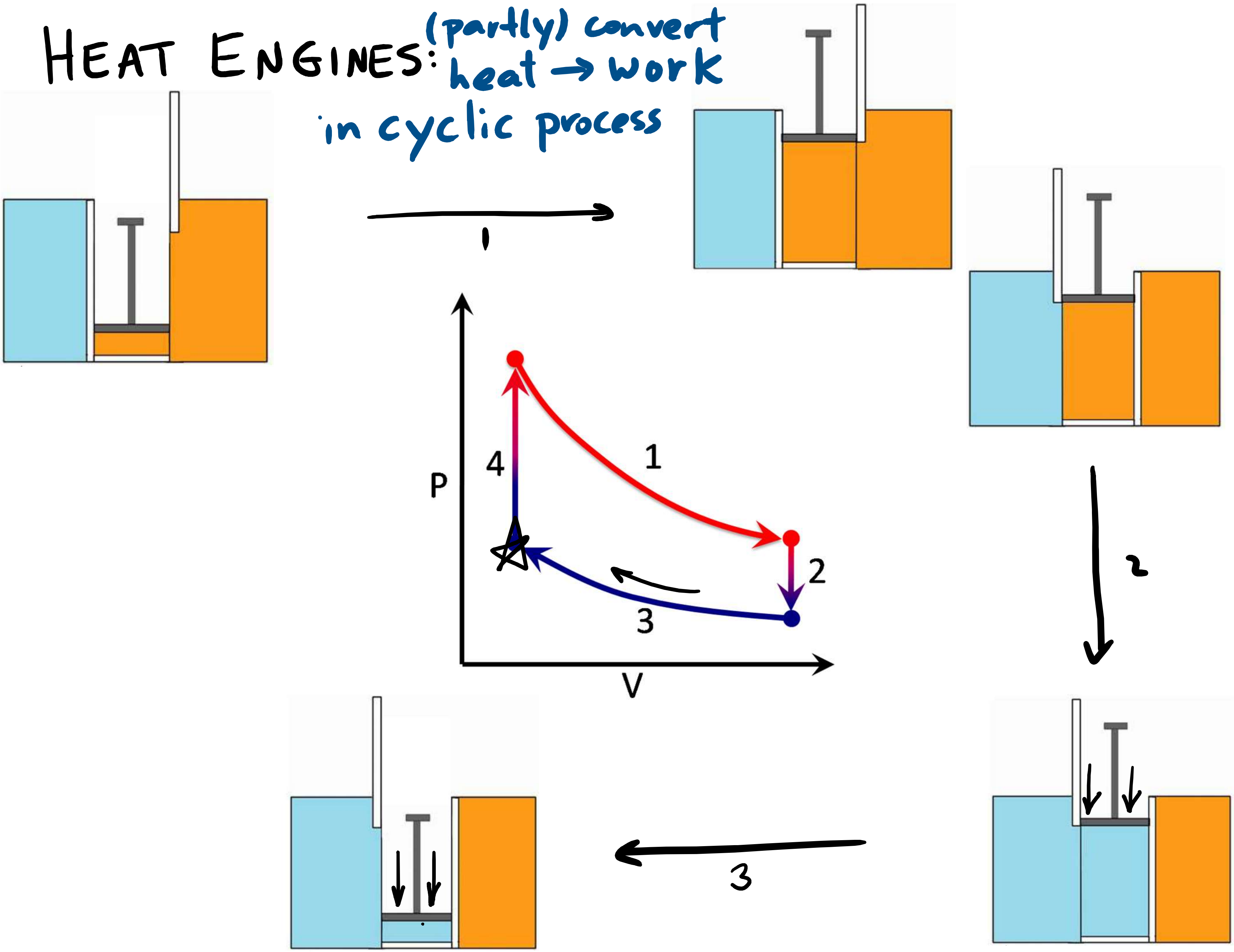




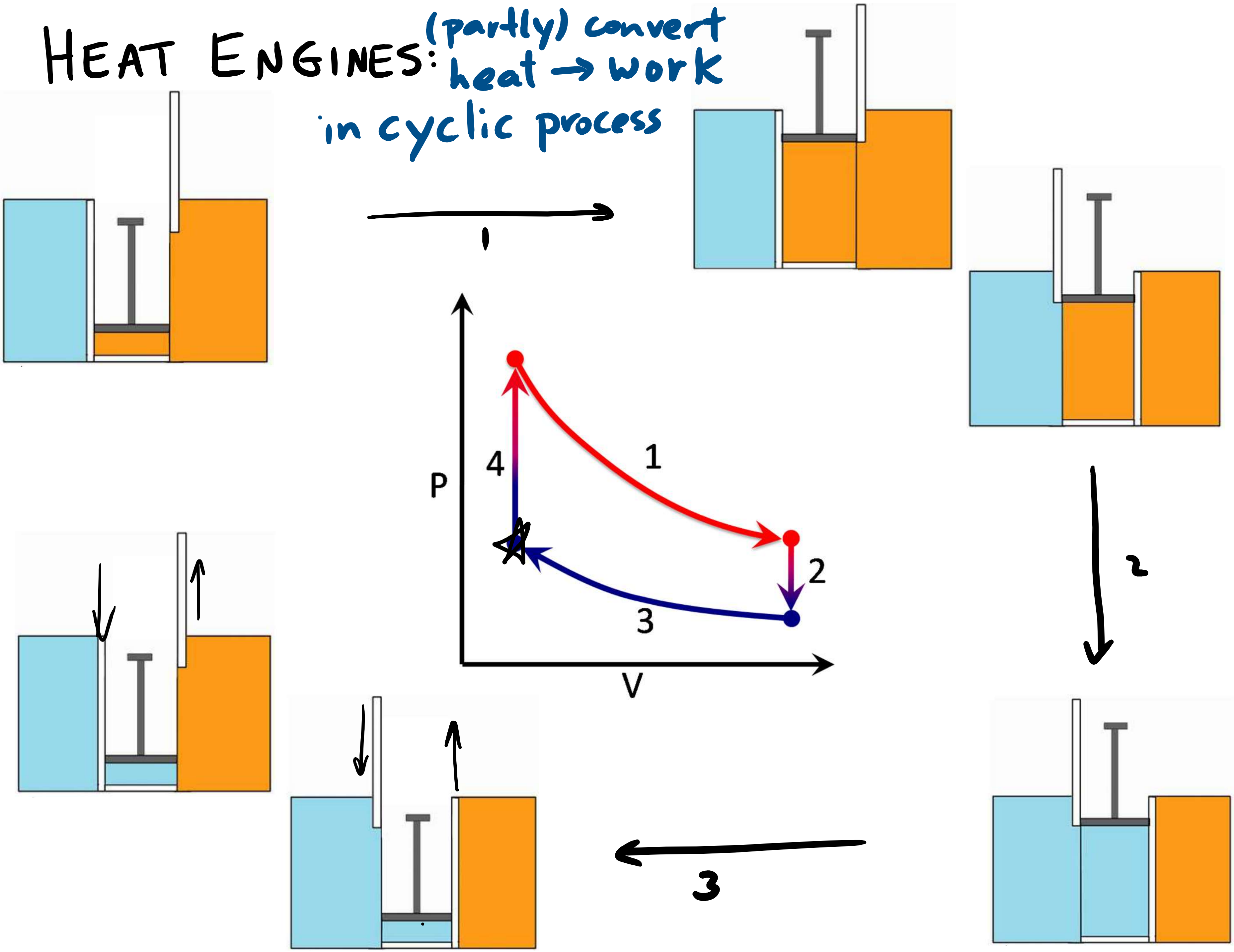




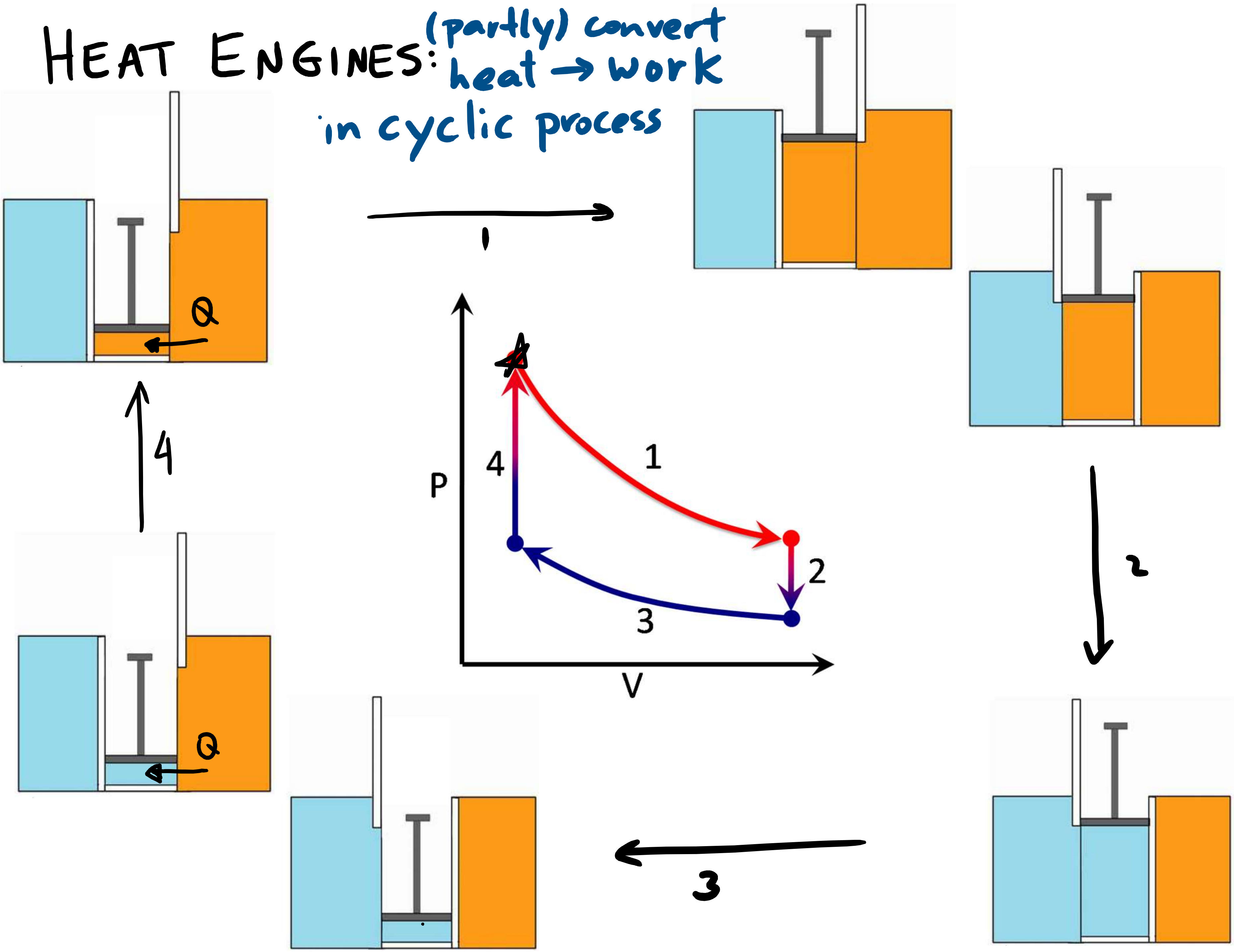
HEAT ENGINES: (partly) convert heat → work in cyclic process



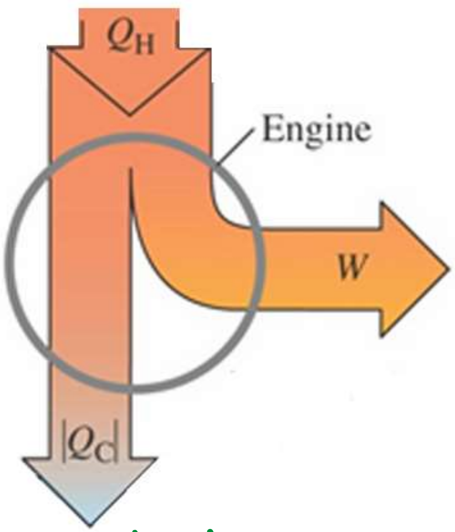
HEAT ENGINES: (partly) convert heat → work in cyclic process



HEAT ENGINES: (partly) convert heat → work in cyclic process



Efficiency of an Engine



$Q_H = |Q_C| + W$

Q_H : Heat absorbed by gas each cycle

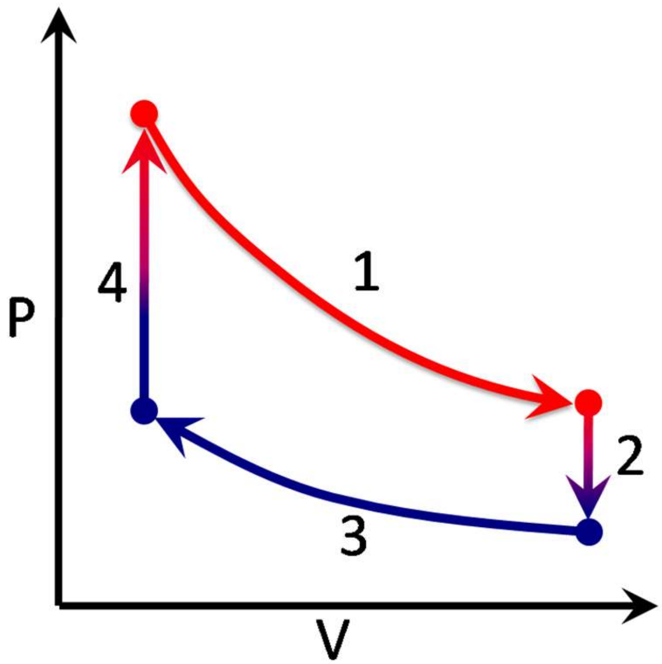
Q_C : Heat expelled by gas

W : Net work done each cycle

Efficiency is: $e = \frac{W}{Q_H}$

← work we get out (W)

← heat we need to supply (Q_H)



In the picture, process 1 and 3 are isothermal. During how many of the four processes does (positive) heat flow in to the gas?

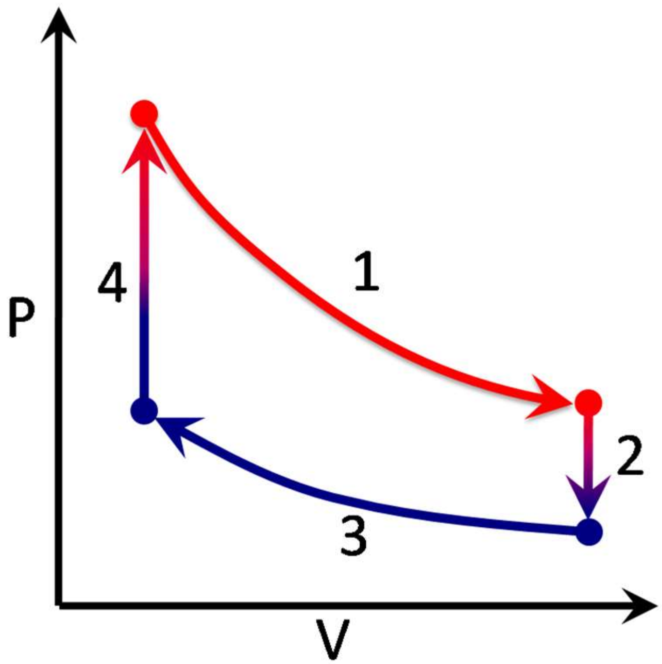
A) 0

B) 1

C) 2

D) 3

E) 4



In the picture, process 1 and 3 are isothermal. During how many of the four processes does (positive) heat flow in to the gas?

A) 0

B) 1

C) 2

D) 3

E) 4

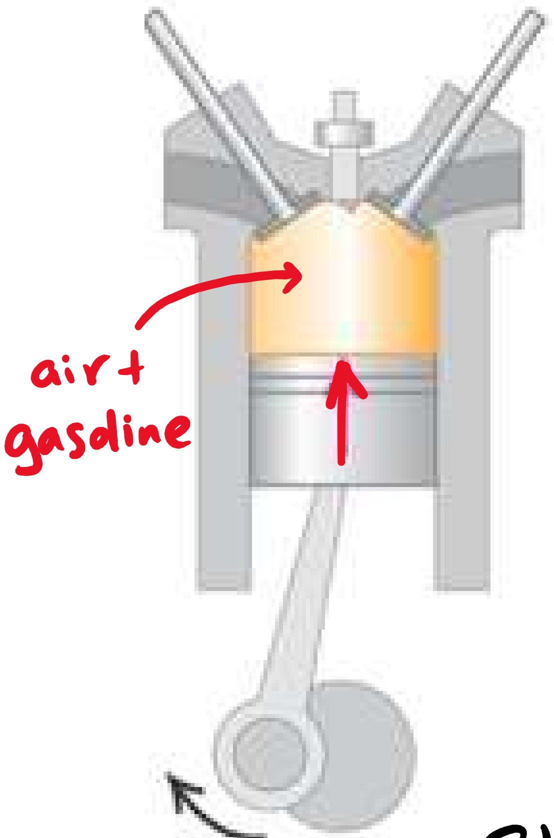
4: $W=0$ so $Q=\Delta U=nC_v\Delta T$ positive since $P\uparrow$ implies $T\uparrow$ at const. volume

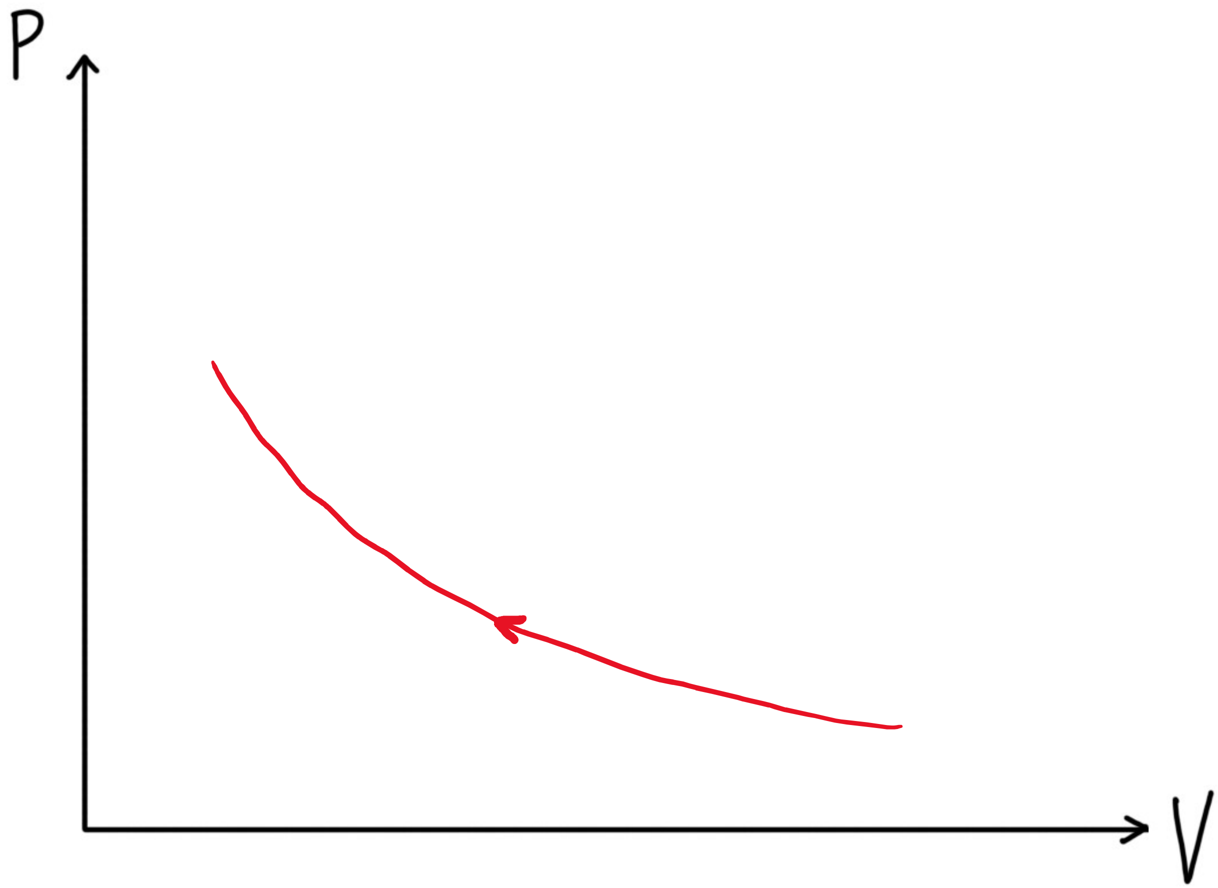
1: $\Delta U=0$ so $Q=W>0$ since expanding

other two are like the reverse of these two, so $Q<0$

Internal combustion engine movie:

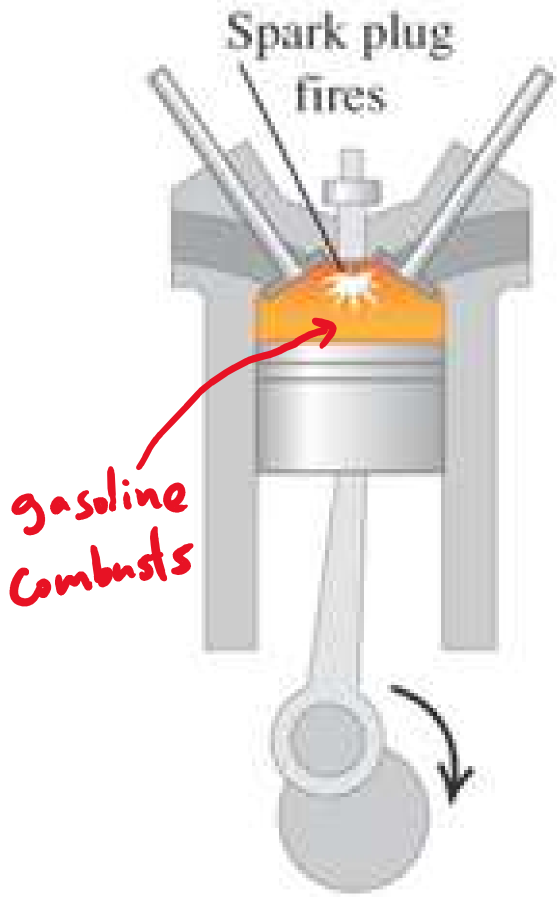
https://youtu.be/5tN6eynMMNw?t=26

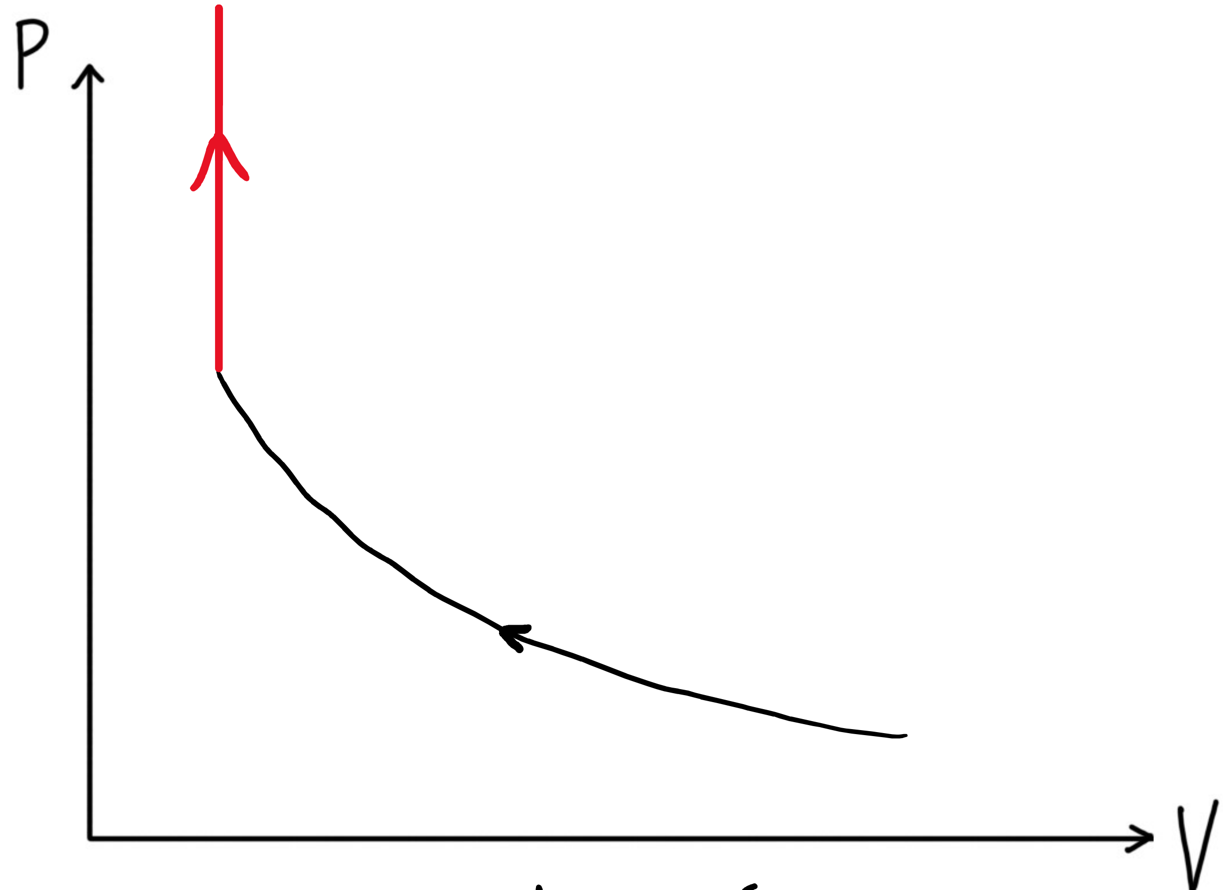




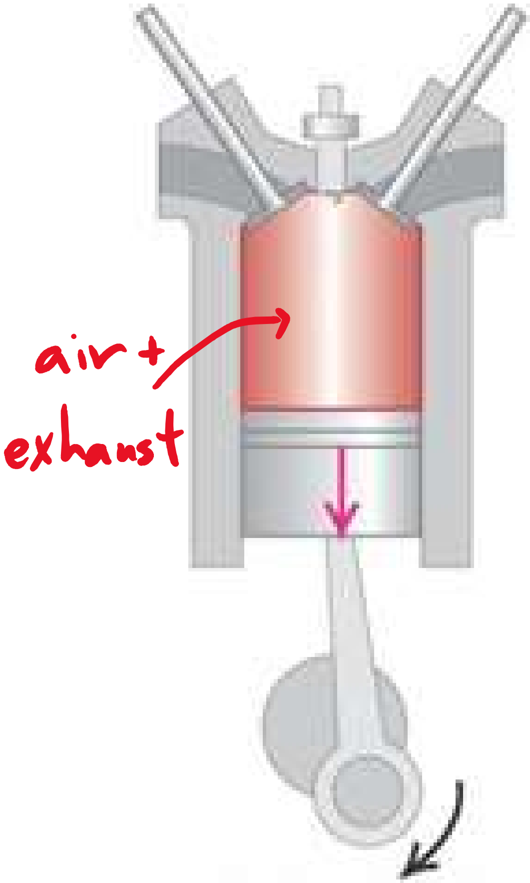
Step 1: adiabatic compression

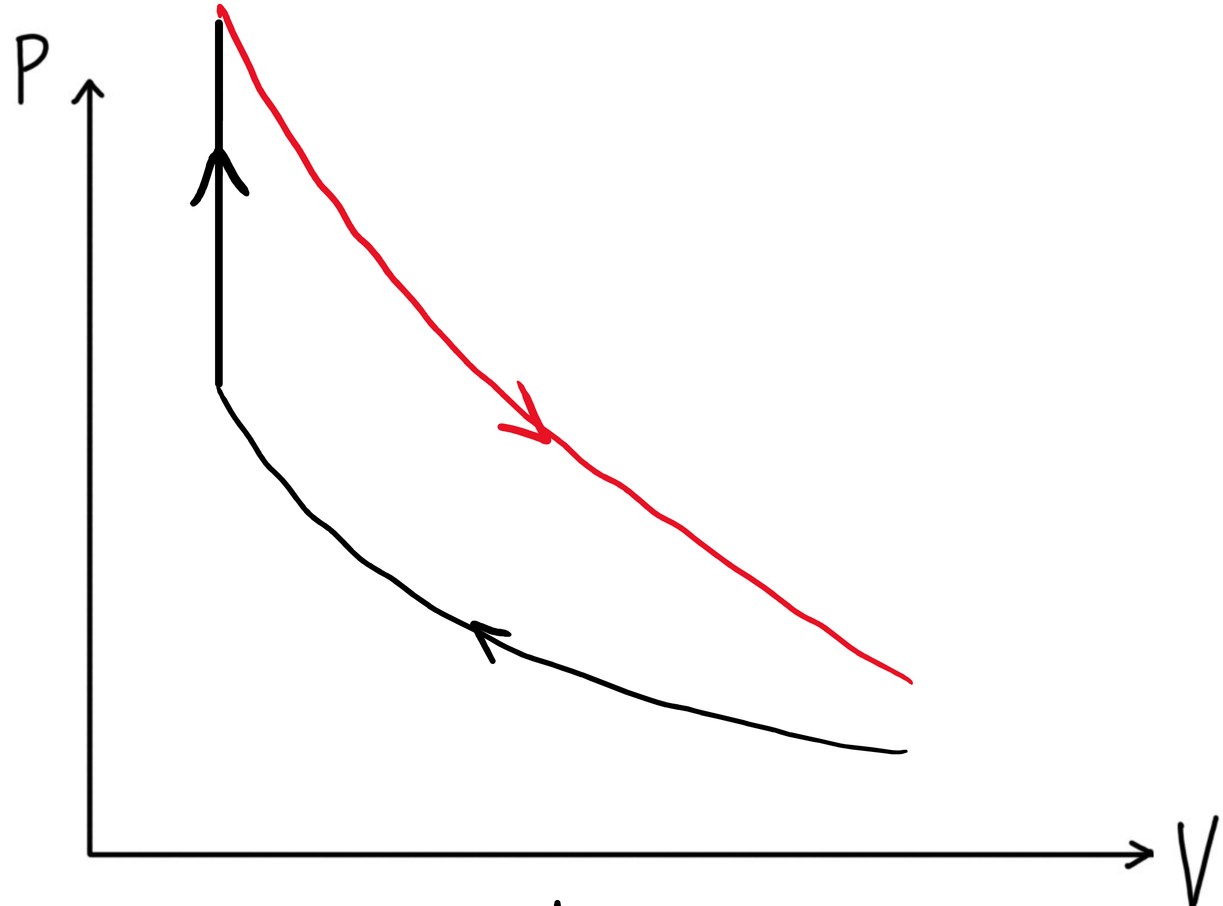
"compression stroke"





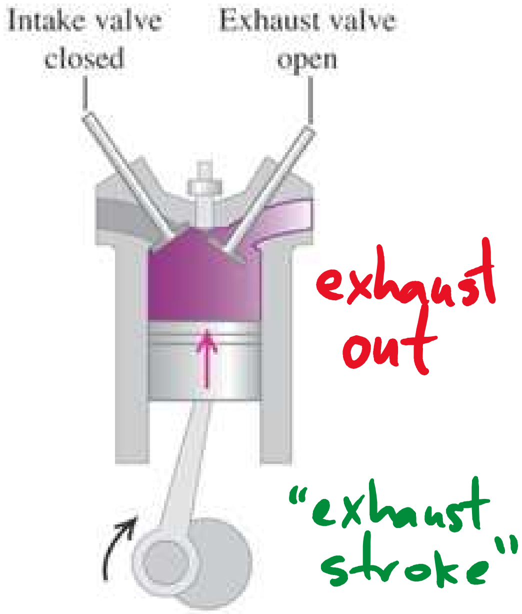
Step 2: combustion of gasoline
≈ heating at constant volume

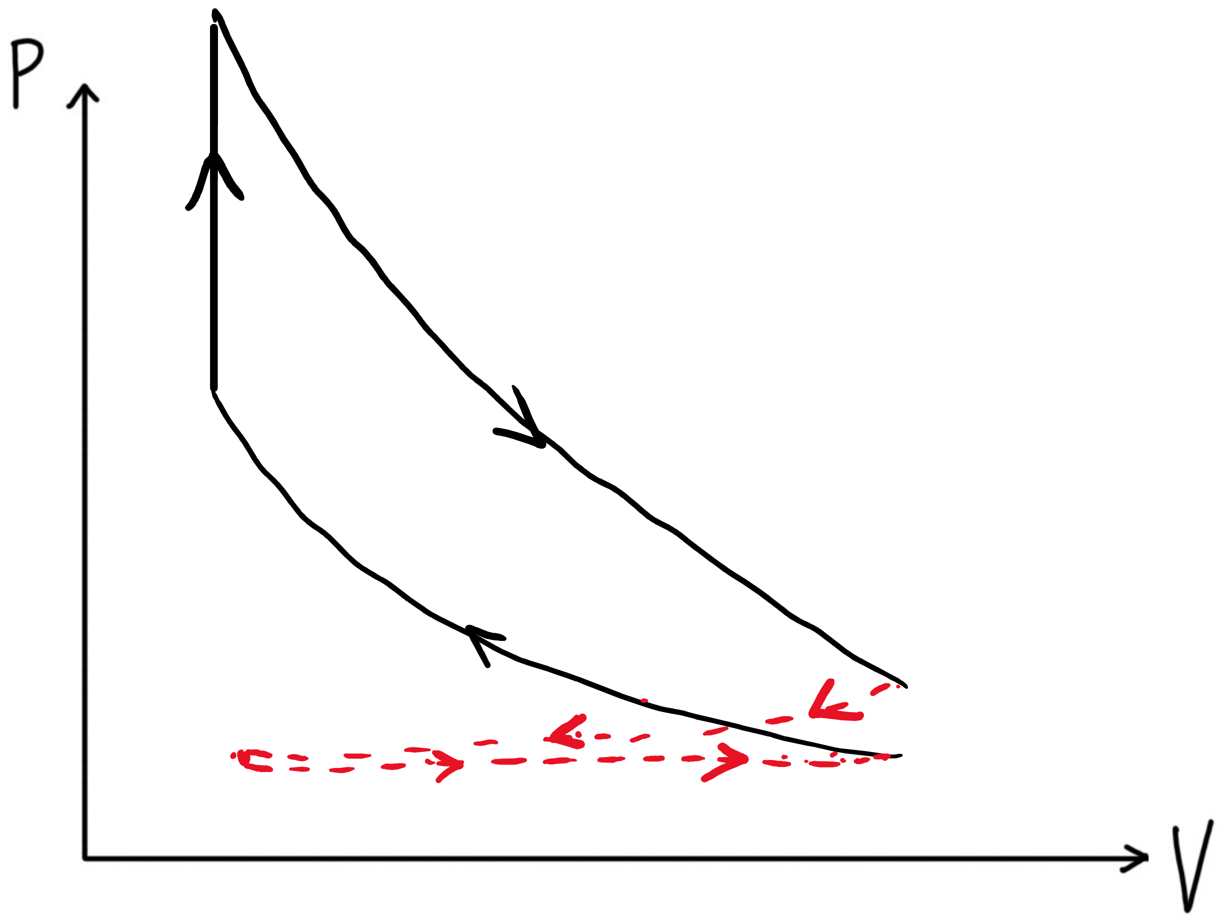


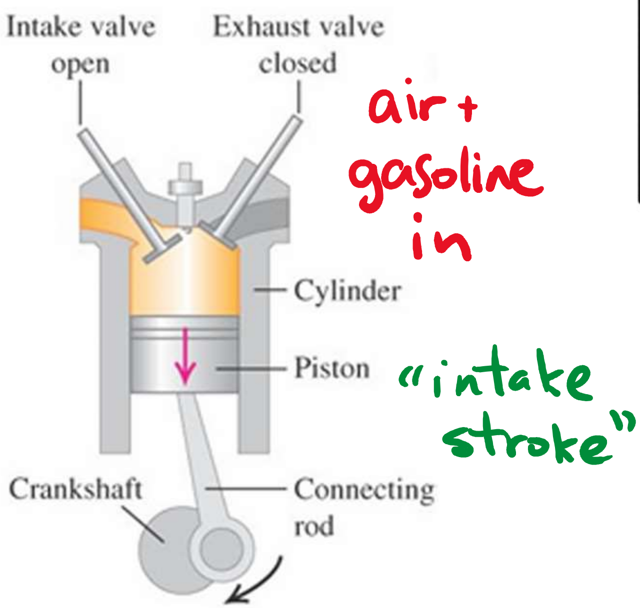


Step 3: Adiabatic expansion

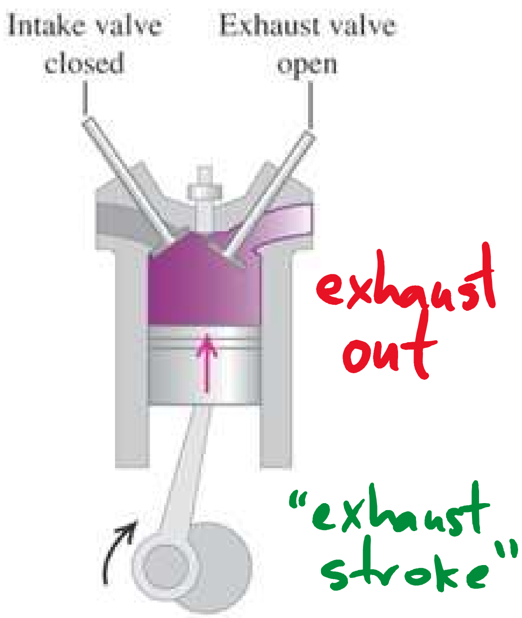
"power stroke"


Intake valve closed
Exhaust valve open
exhaust out
"exhaust stroke"

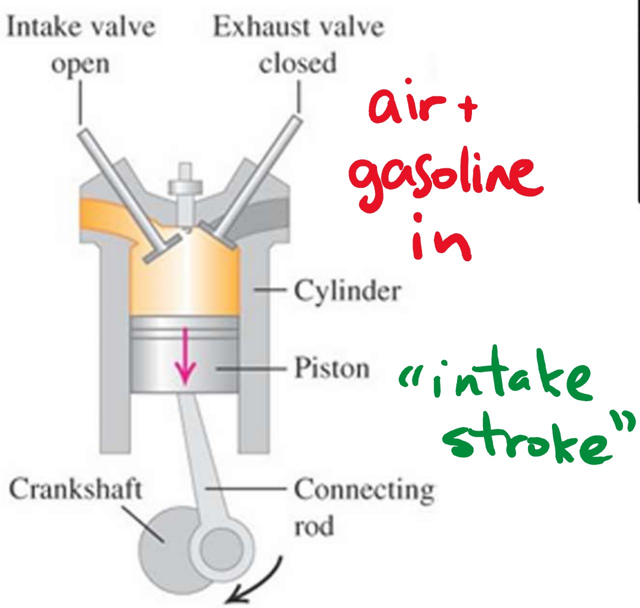

P
V


Intake valve open
Exhaust valve closed
air + gasoline in
Cylinder
Piston
"intake stroke"
Crankshaft
Connecting rod

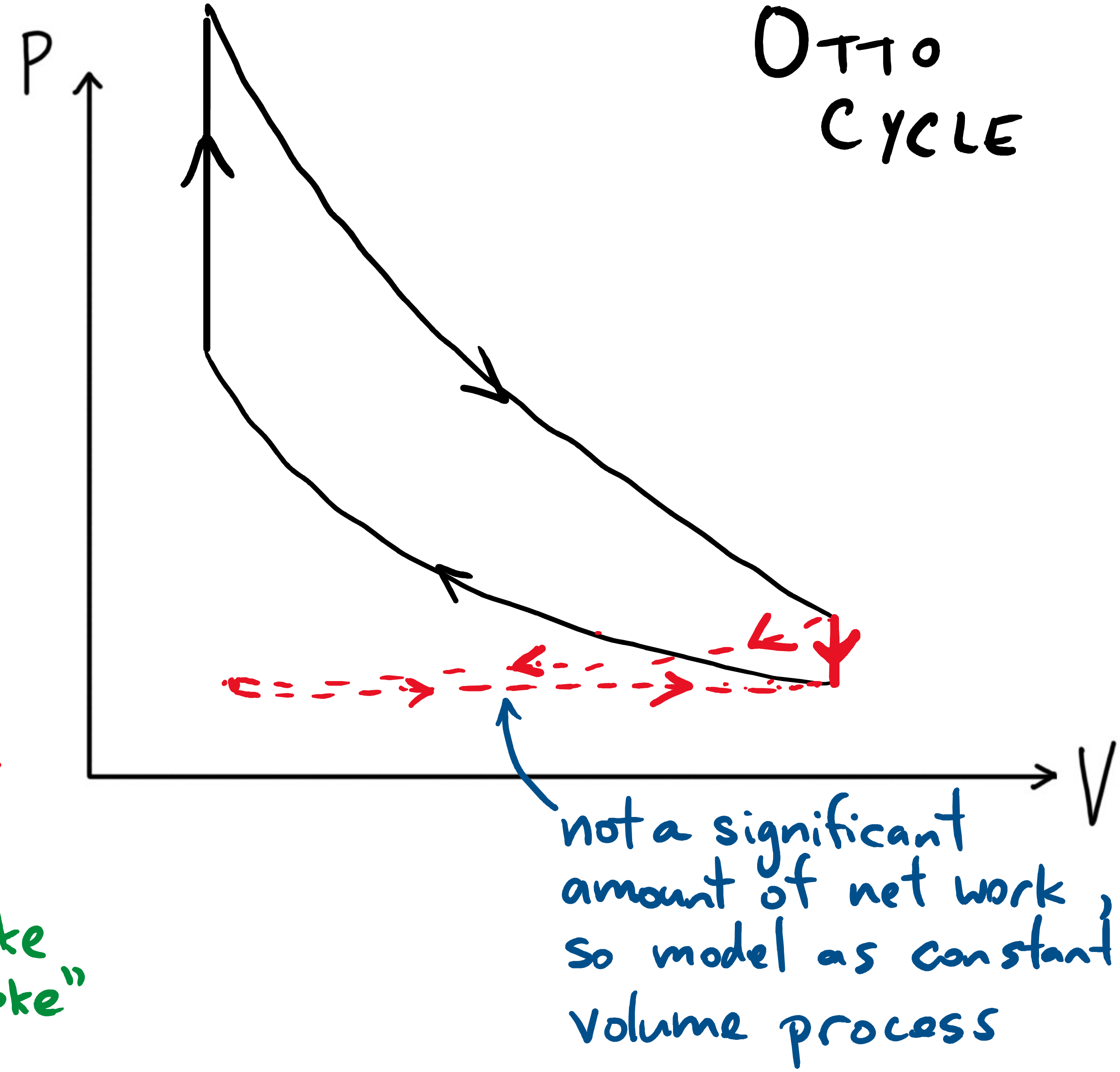
Otto Cycle



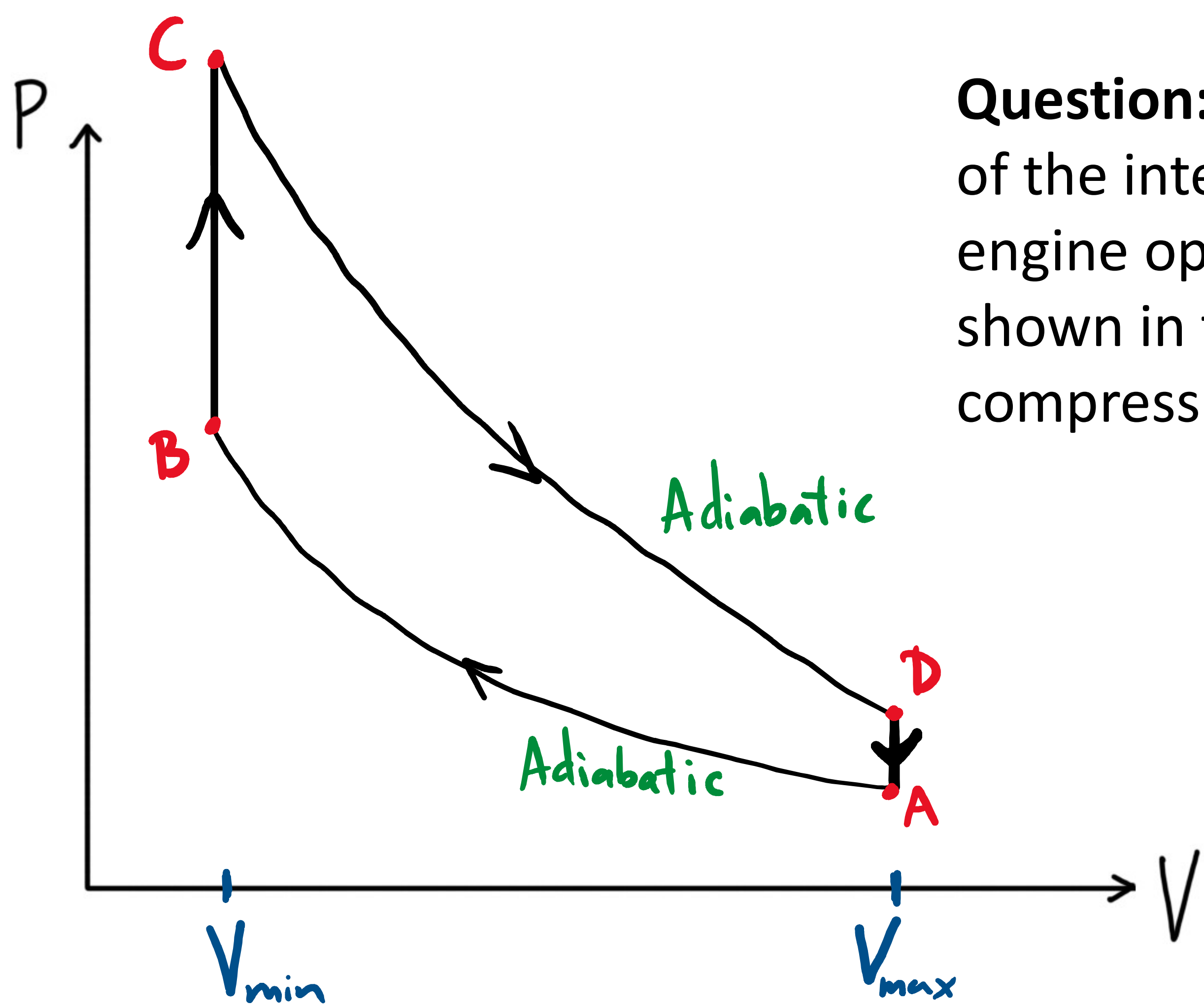
Intake valve closed
Exhaust valve open
exhaust out
"exhaust stroke"



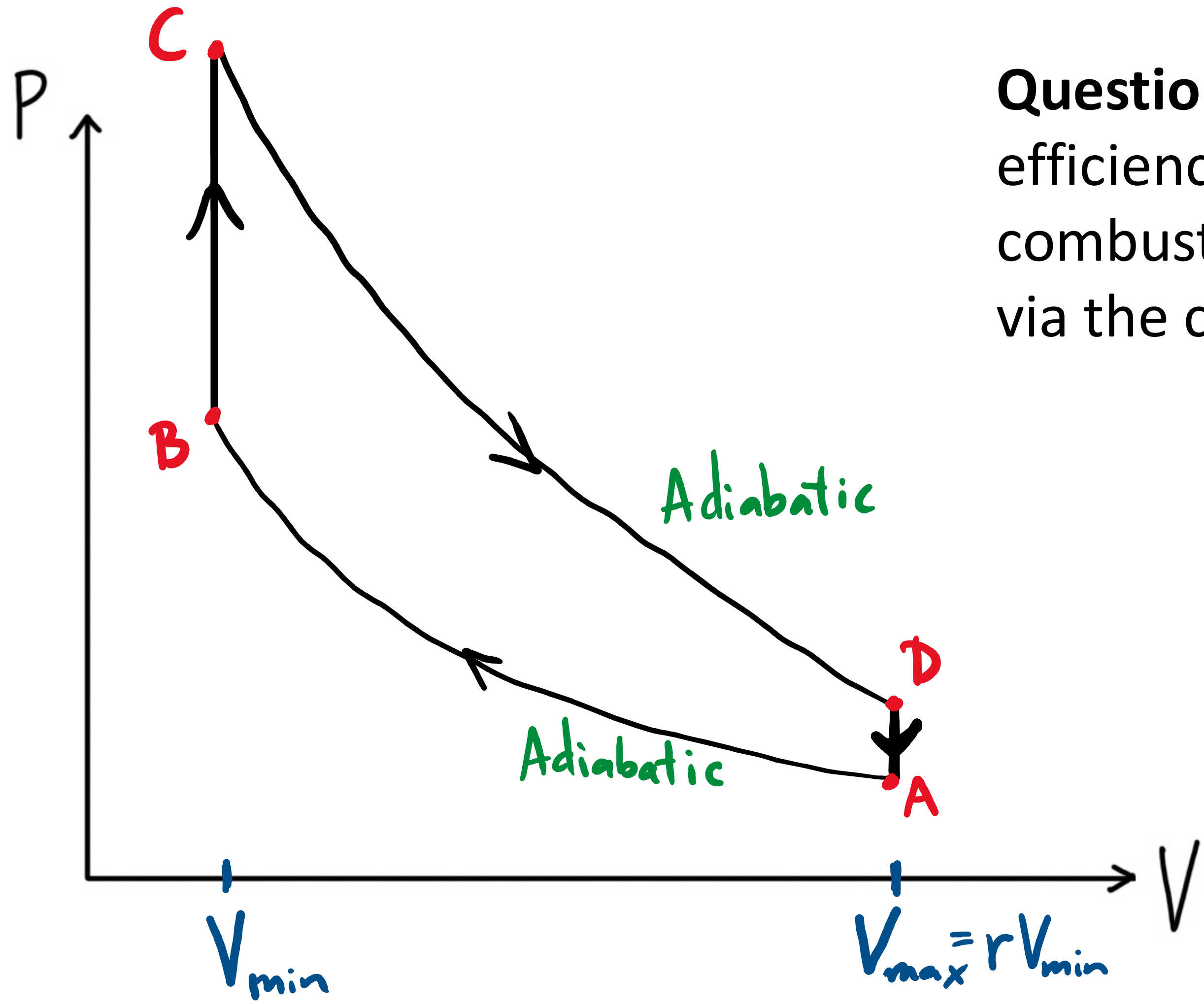
Intake valve open
Exhaust valve closed
air + gasoline in
Cylinder
Piston
"intake stroke"
Crankshaft
Connecting rod



P
V
not a significant amount of net work, so model as constant volume process

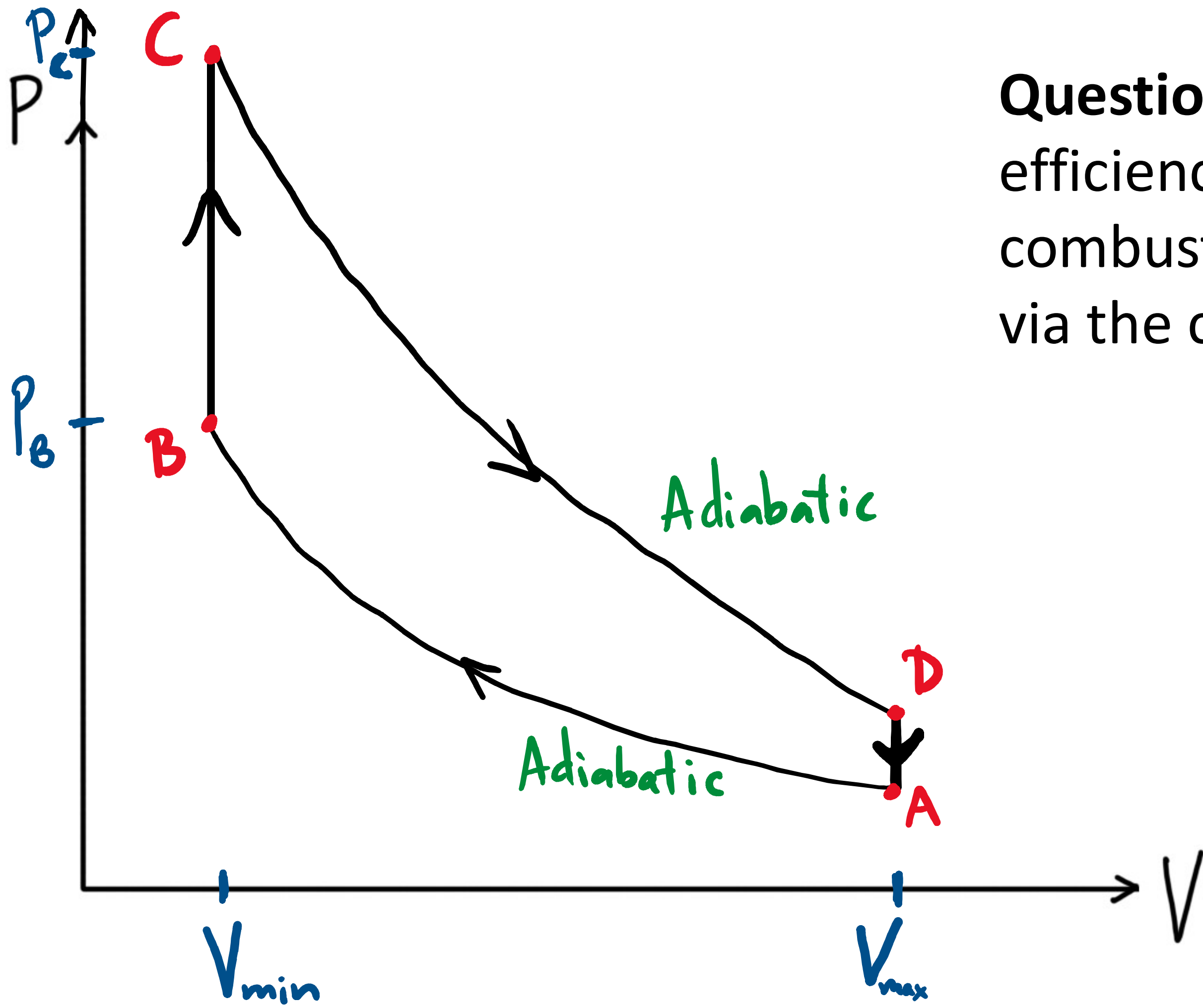


Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown in terms of the compression ratio $\mathbf{r = V_{max} / V_{min}}$



Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 1: find P, V, T for the various points if not given.



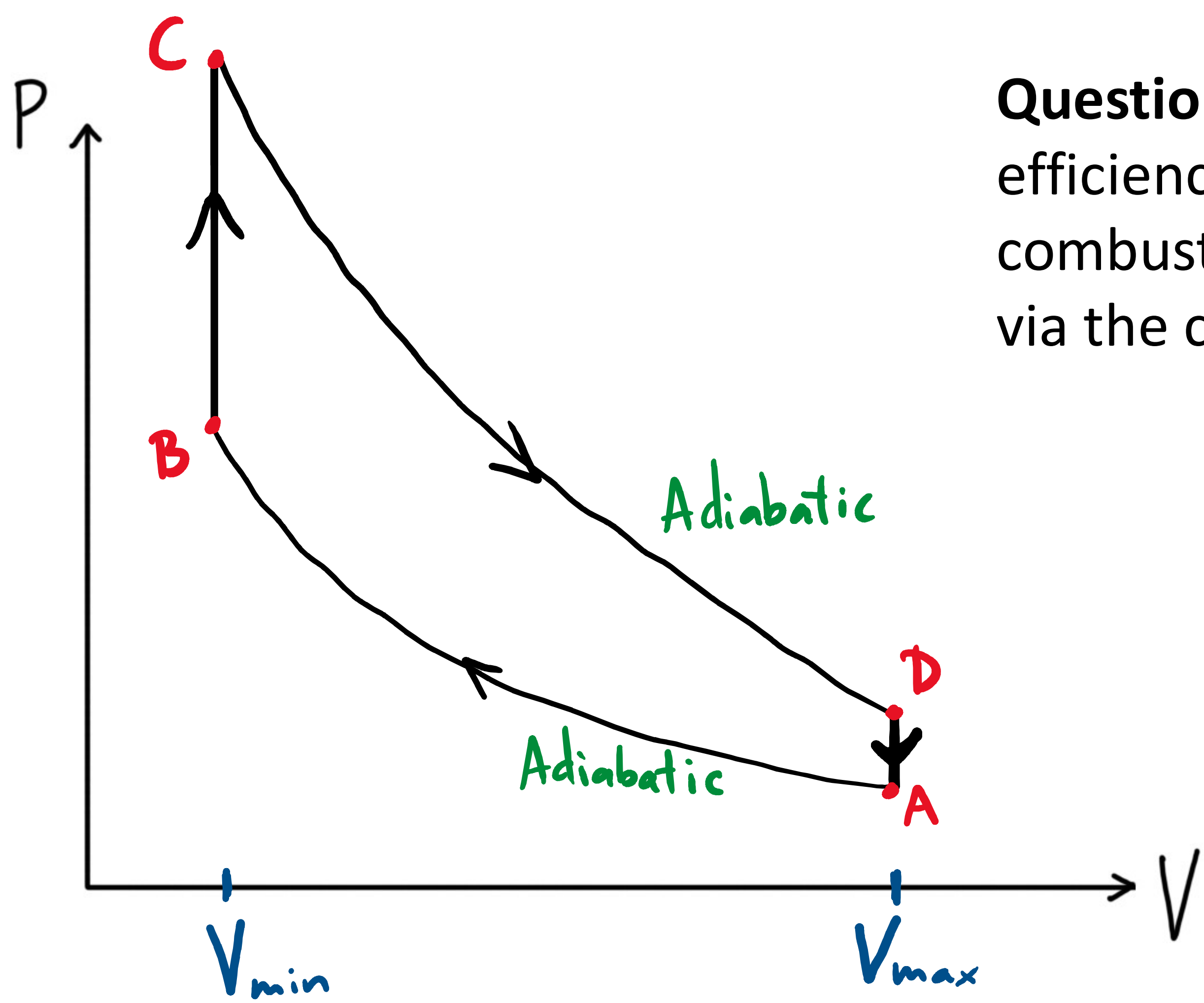
Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 1 : find P, V, T for the various points if not given.

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

What are the temperatures T_B, T_C, and T_D in term of T_A, $r = V_{max} / V_{min}$, and $x = P_C/P_B$

Click A if you are finished. Click B if you are stuck.



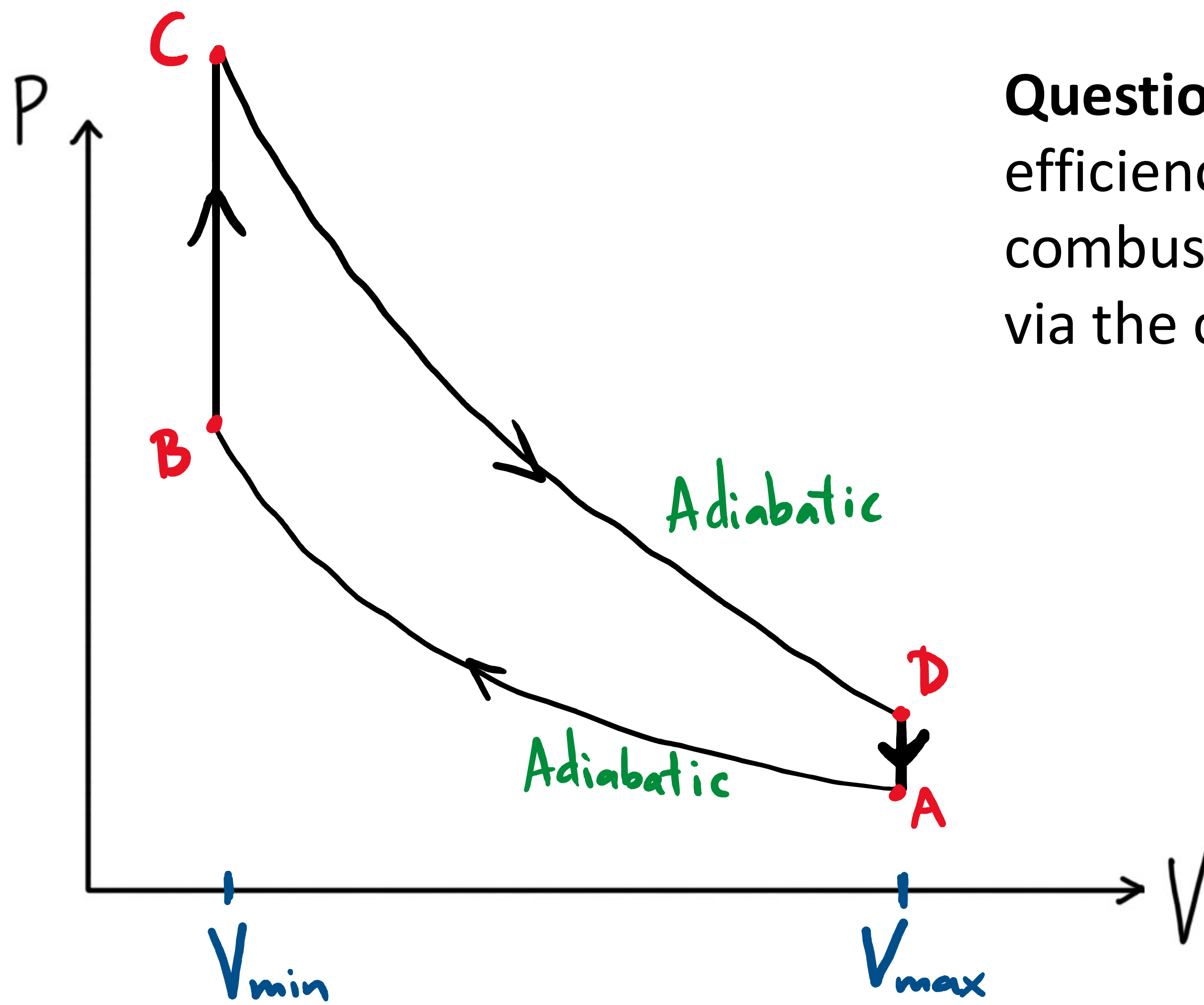
Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 1: find P, V, T for the various points if not given.

$$T_B V_B^{\gamma-1} = T_A V_A^{\gamma-1} \Rightarrow T_B = T_A \left(\frac{V_A}{V_B}\right)^{\gamma-1} = T_A \cdot r^{\gamma-1}$$

$$\frac{T_C}{P_C} = \frac{T_B}{P_B} \Rightarrow T_C = \frac{P_C}{P_B} \cdot T_B$$

$$T_D V_D^{\gamma-1} = T_C V_C^{\gamma-1}$$

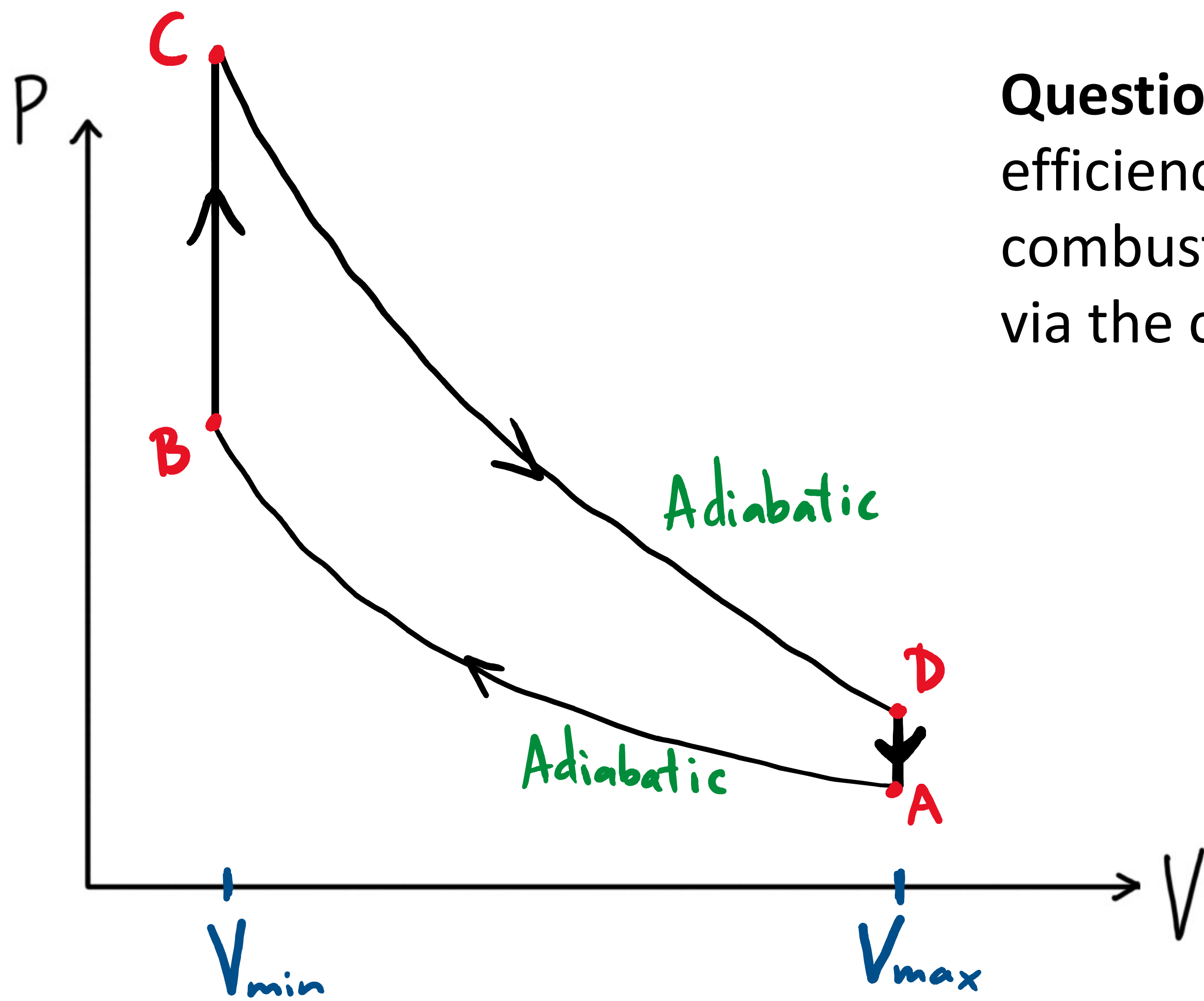


Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 2: find the work for each part and add them up.

The work for the process B -> C is

A) Positive B) Negative C) Zero

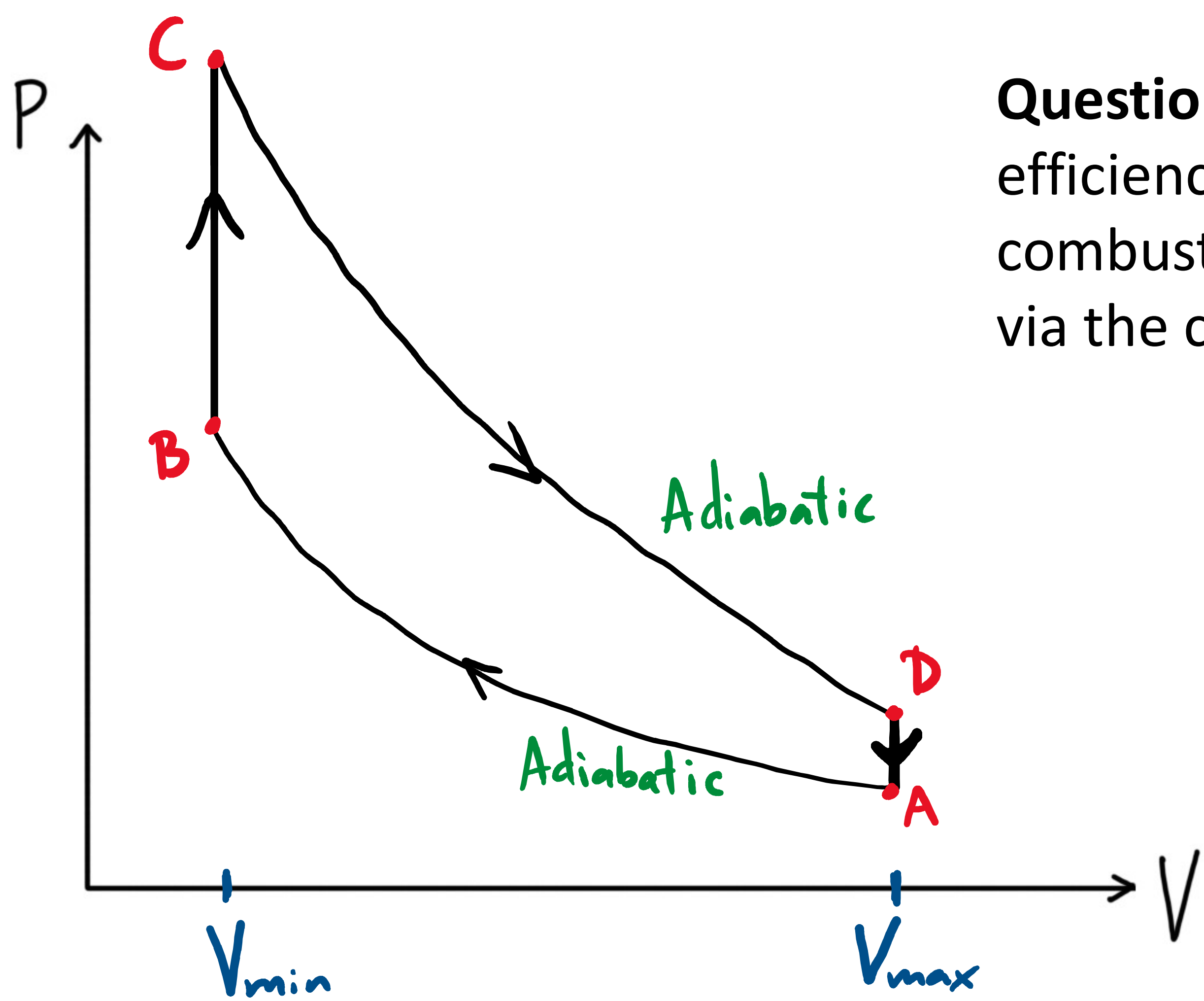


Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 2: find the work for each part and add them up.

What is the work for the processes C -> D in terms of n, C_V, and the various temperatures, volumes or pressures?

Click A when you have an answer *(and then try to calculate the net work)*



Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 2: find the work for each part and add them up.

const. volume

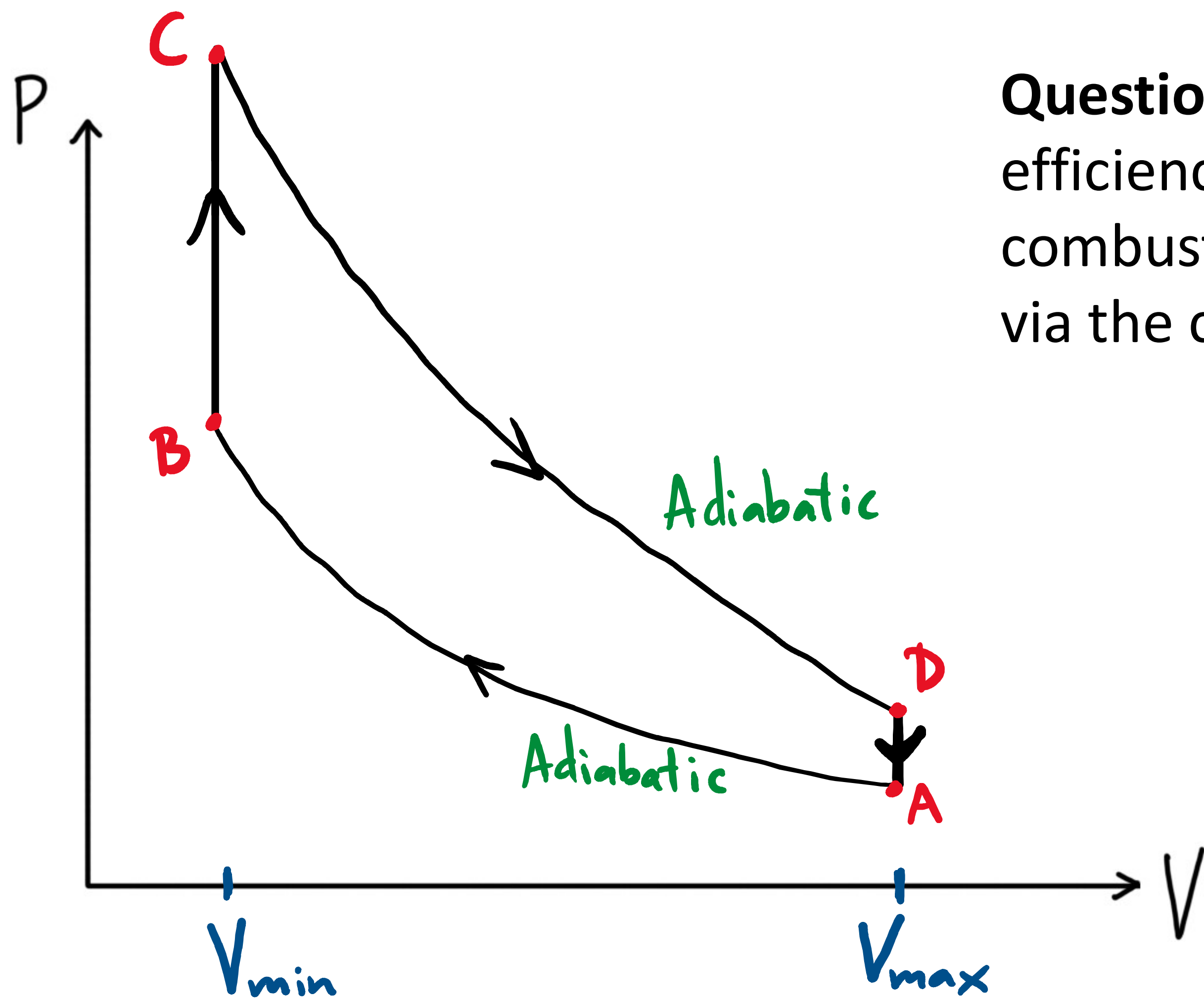
$C \to D$: $Q = 0$ so $W = -\Delta U = -nC_v(T_D - T_C)$

$W_{B\to C} = 0$

$A \to B$: $Q = 0$ so $W = -\Delta U = -nC_v(T_B - T_A)$

$W_{D\to A} = 0$

$$W_{net} = nC_v(T_C - T_D + T_A - T_B)$$

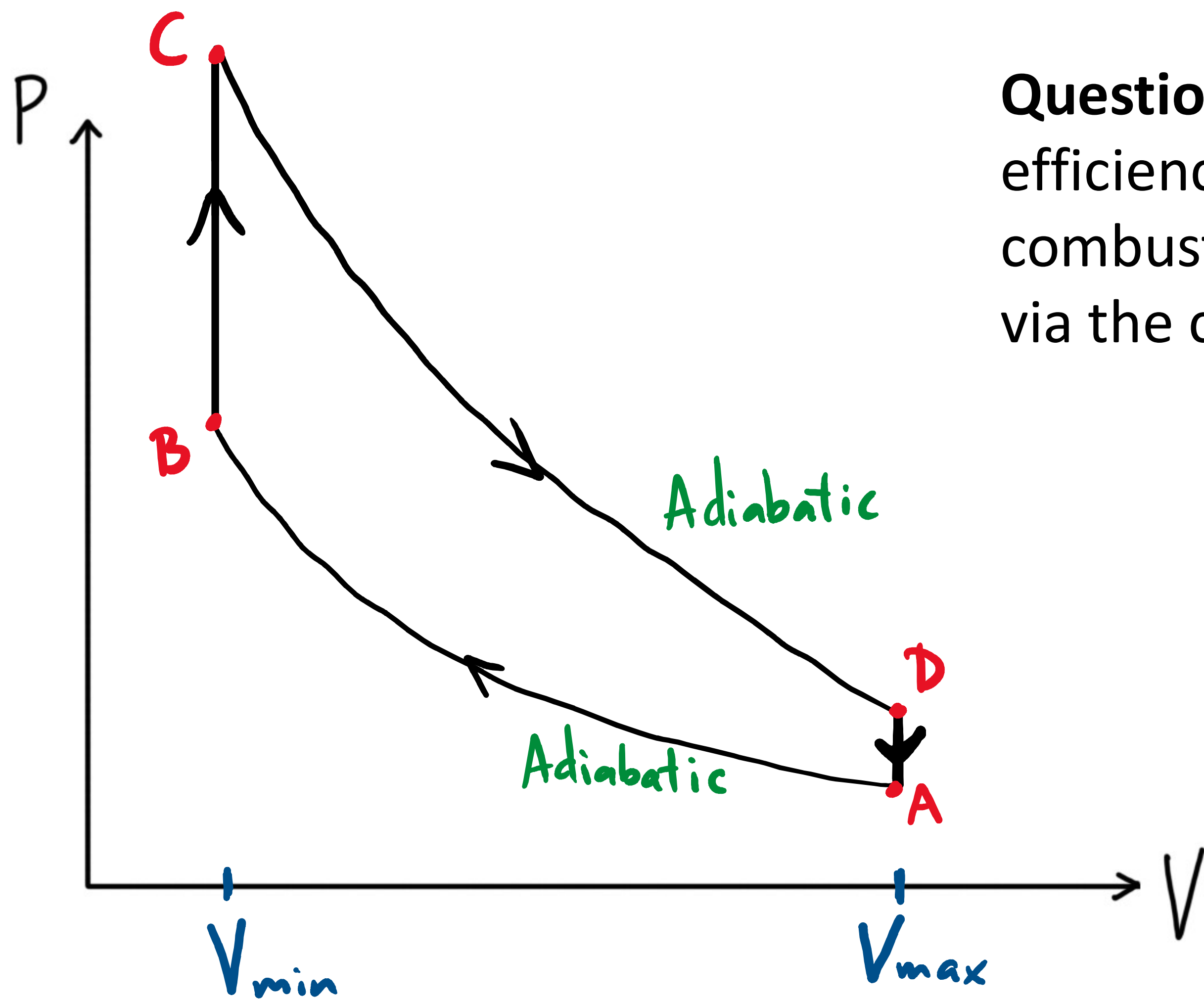


Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 3: find the heat for the steps with Q > 0.

How many of the steps have Q > 0?

A) 0 B) 1 C) 2 D) 3 E) 4

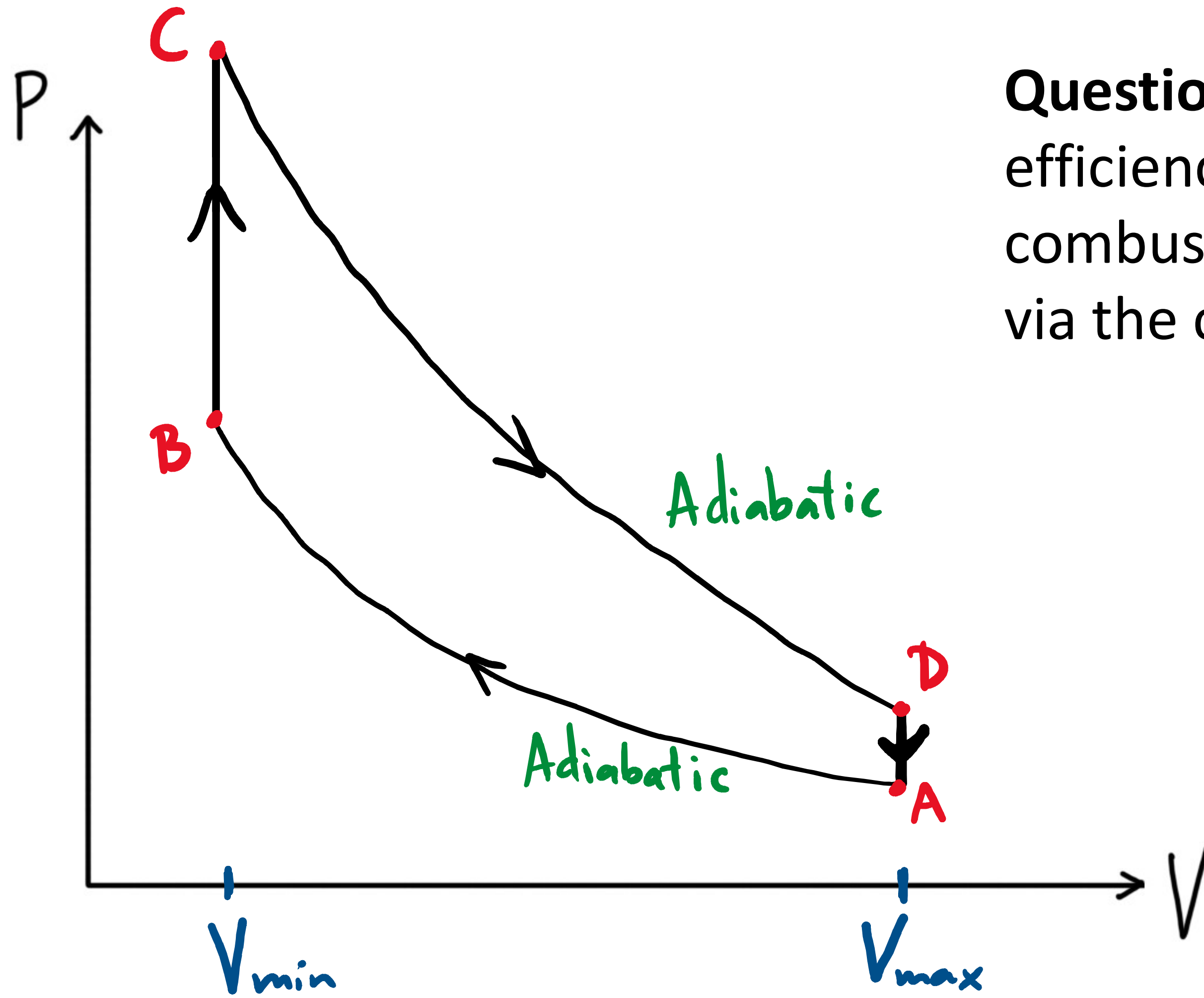


Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 3: find the heat for the steps with Q > 0.

Calculate Q for the process B -> C, in terms of n, C_V and the various temperatures, pressures, and volumes.

Click A when you have an answer, or B if you are stuck.

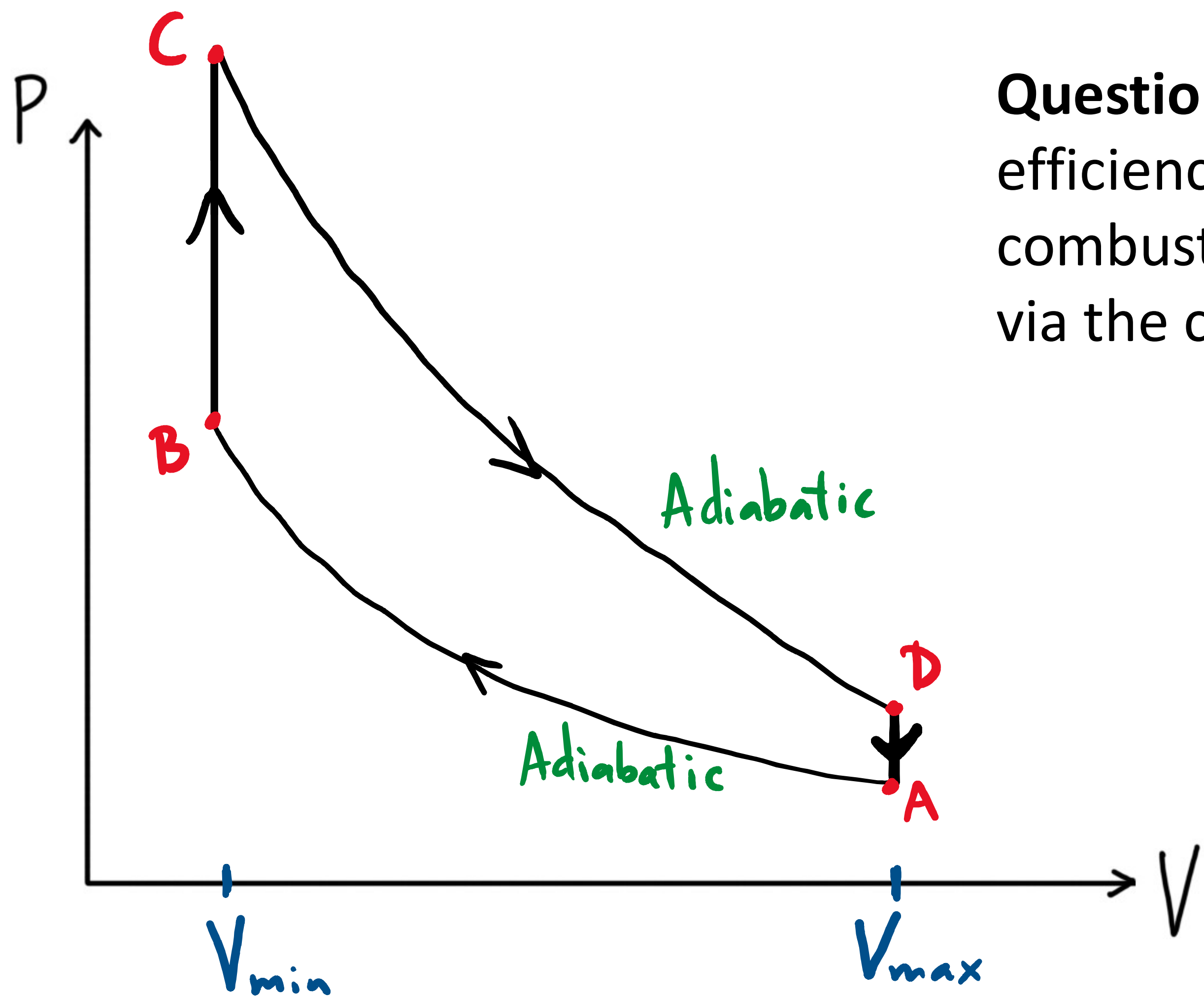


Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 3: find the heat for the steps with $Q > 0$.

Calculate Q for the process B -> C: const. volume $\therefore W = 0$

$$Q = \Delta U = n C_v (T_C - T_B)$$

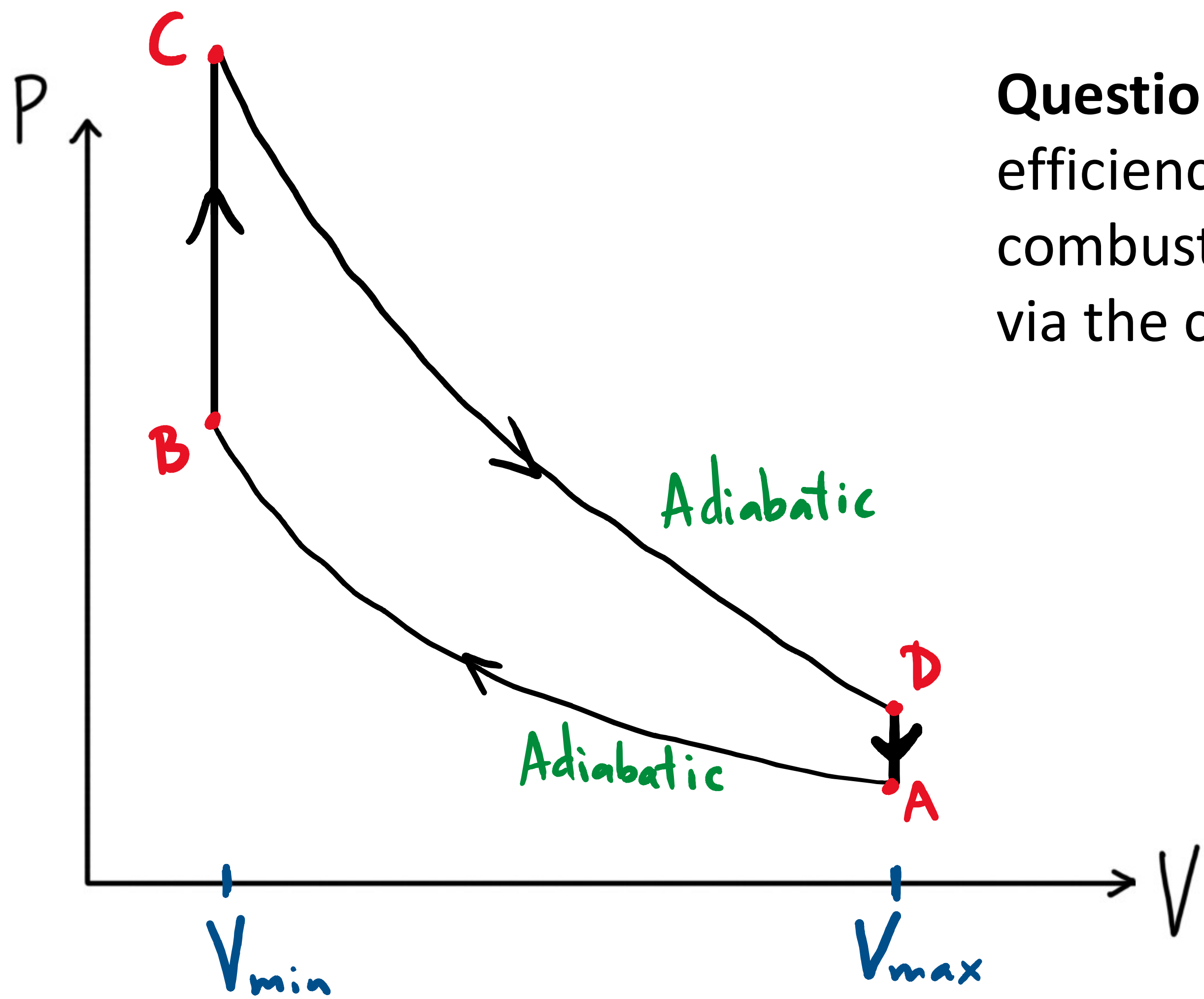


Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 4: calculate efficiency $e = \frac{W}{Q_{in}}$

$$W = nC_v(T_C - T_D + T_A - T_B)$$

$$Q = nC_v(T_C - T_B)$$



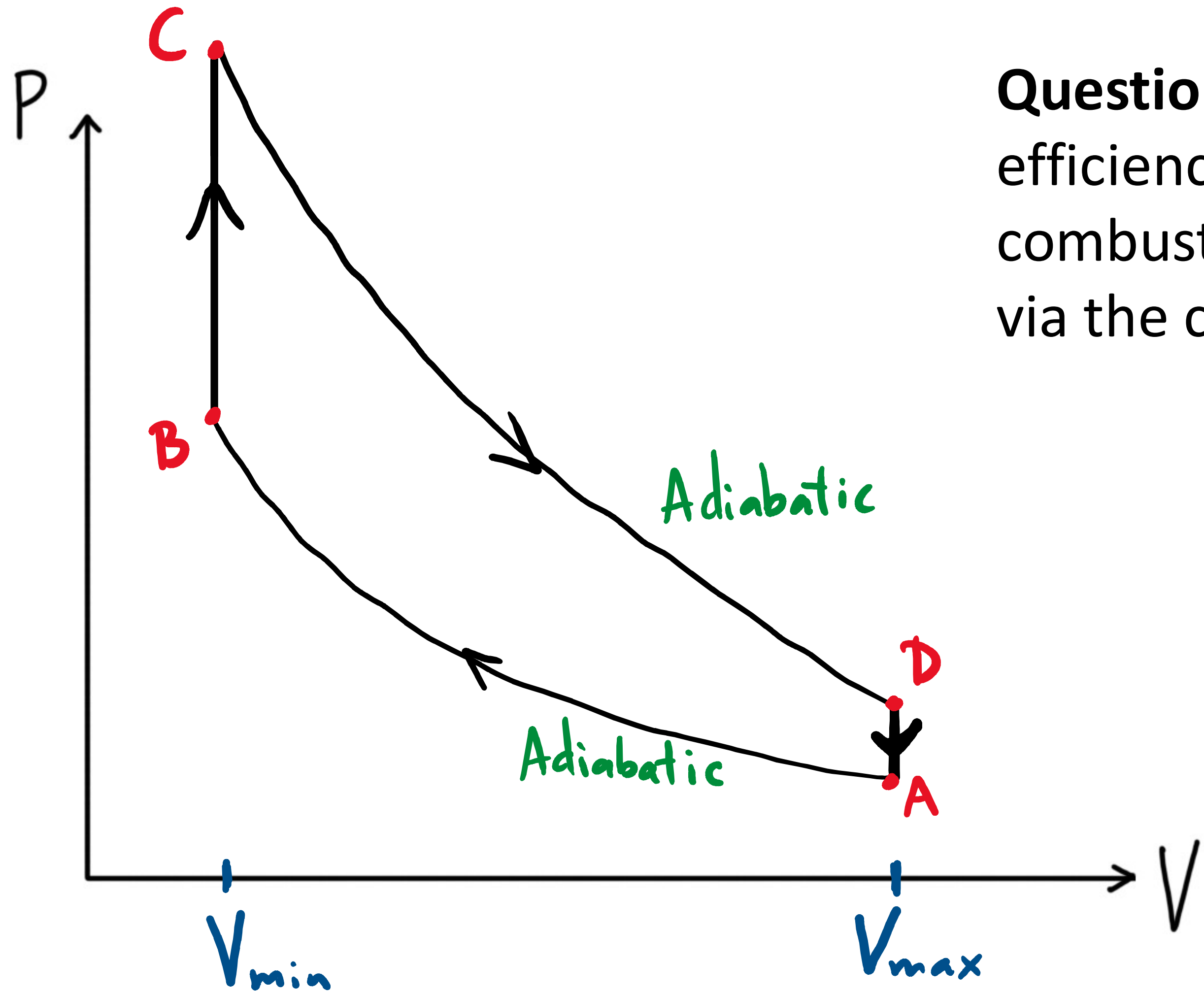
Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

Step 4: calculate efficiency $e = \frac{W}{Q_{in}}$

$W = nC_v(T_C - T_D + T_A - T_B)$

$Q = nC_v(T_C - T_B)$

$$\frac{W}{Q} = \frac{T_C - T_D + T_A - T_B}{T_C - T_B}$$



Question: Calculate the efficiency of the internal combustion engine operating via the cycle shown.

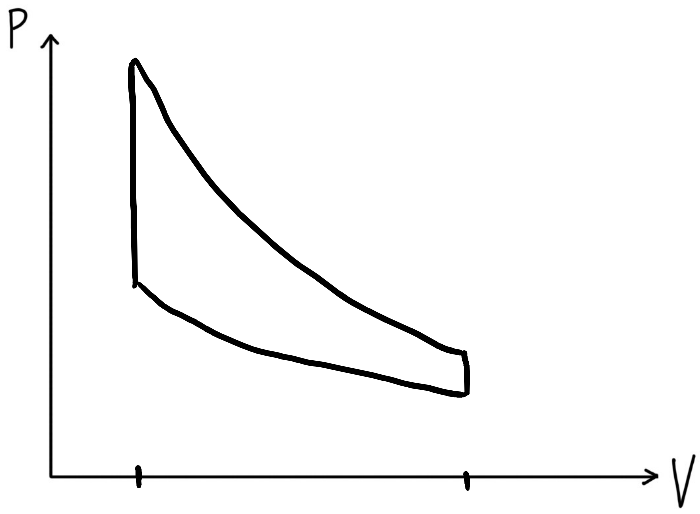
Step 4: calculate efficiency $e = \frac{W}{Q_{in}}$

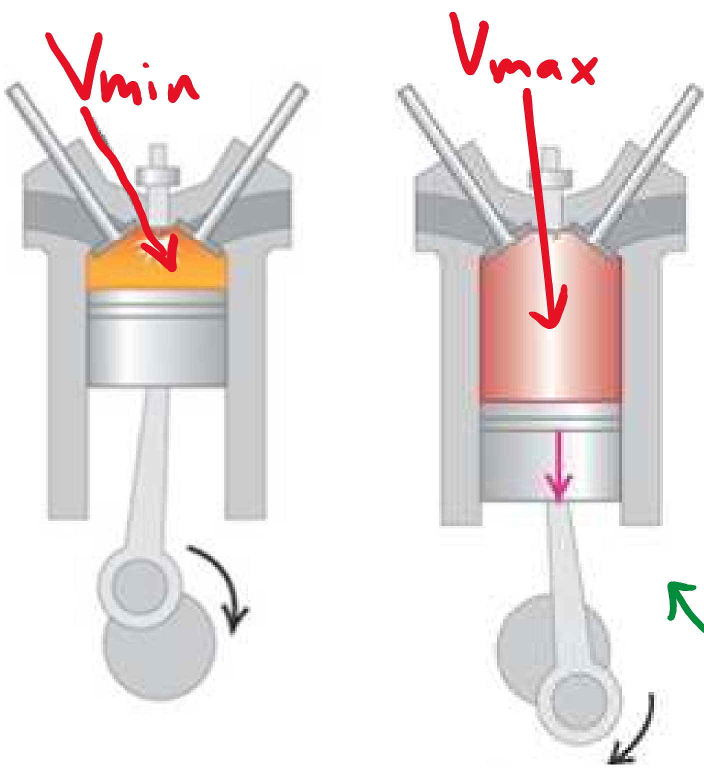
$W = nC_v(T_C - T_D + T_A - T_B)$

$Q = nC_v(T_C - T_B)$

$$\frac{W}{Q} = \frac{T_C - T_D + T_A - T_B}{T_C - T_B} \xrightarrow[\text{for temperatures}]{\text{plug in results}} e = 1 - \frac{1}{r^{\gamma - 1}}$$

OTTO CYCLE: efficiency is $e = 1 - \frac{1}{r^{\gamma-1}}$





Higher efficiency for larger compression ratio.

BUT: gasoline will spontaneously ignite if r too large

"engine knocking"

High octane fuel: higher ignition temp., so less knocking

real engines: $r = 8 - 10$