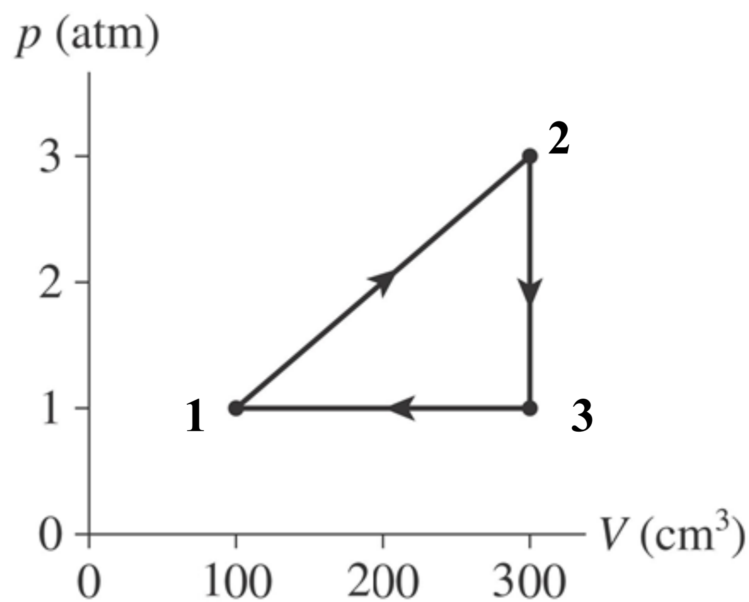
Quantitative example. 0.005 mol of a diatomic ideal gas is brought from state (1) V_1= 100 cm^3 and P_1=1.0 atm to state (2) V_2=300 cm^3 and P_2=3.0 atm.

a) Draw a PV diagram for this process (assume it follows a straight line). Find Q for this process 1-2.

Use 1 atm = 1×10^5 Pa to simplify calculation.

States	P	V	T
1	1 atm	100 cm^3	T_1
2	3 atm	300 cm^3	T_2

Processes	Q	W	ΔU
1→2			
	$\Delta U = Q + W$	$W = -\int_1^2 P dV$	$\Delta U = nC_V \Delta T$



Work = −area under the curve

$\mathrm{R} = 8.31\,\mathrm{J/mol \cdot K}$ $\qquad$ $\mathrm{R} = 0.082\,\dfrac{\mathrm{L \cdot atm}}{\mathrm{mol \cdot K}}$

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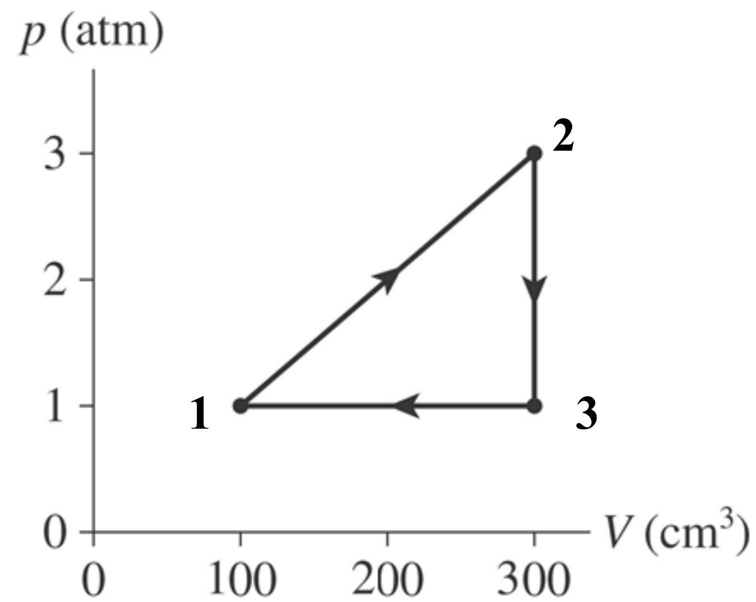

$$R = 8.31\ \mathrm{J/mol\cdot K} \qquad R = 0.082\ \frac{\mathrm{L\cdot atm}}{\mathrm{mol\cdot K}}$$

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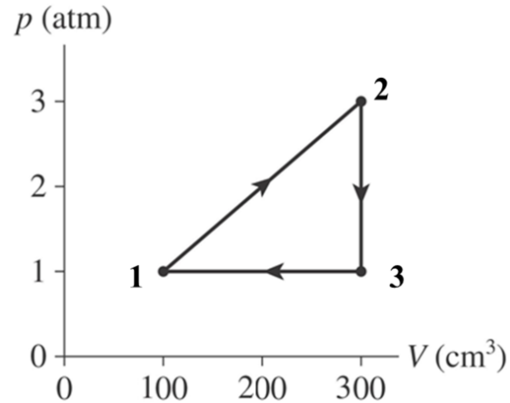
The gas is then brought to state (3) V_3= 300 cm^3 and P_3=1.0 atm and then back to state (1).

b) Complete the PV diagram for this whole cycle.

c) Find W, Q and ΔU for processes 2-3 and 3-1, and for the whole cycle.

States	P	V	T
1	1 atm	100 cm^3	243.90K
2	3 atm	300 cm^3	2195.12K
3	1 atm	300 cm^3	



Processes	Q	W	ΔU
1→2	242.7 J	-40 J	202.7 J
2→3		0	
3→1			
Cycle			

$$R = 8.31\ \mathrm{J/mol \cdot K}$$

$$R = 0.082\ \frac{\mathrm{L \cdot atm}}{\mathrm{mol \cdot K}}$$

$\Delta U = Q + W$ $\quad W = -\int_1^2 PdV$ $\quad \Delta U = nC_V \Delta T$

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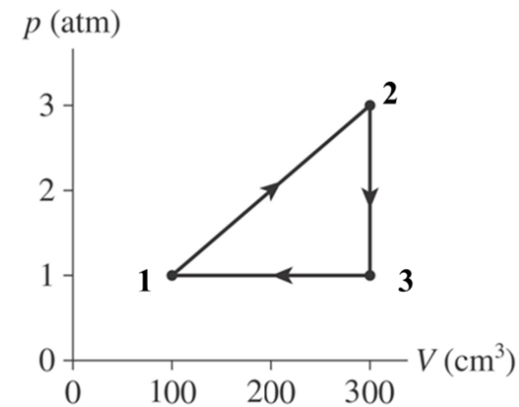
States	P	V	T
1	1 atm	100 cm^3	243.90K
2	3 atm	300 cm^3	2195.12K
3	1 atm	300 cm^3	731.70 K



Processes	Q	W	ΔU
1→2	242.7 J	-40 J	202.7 J
2→3	-152.1 J	0	-152.1 J
3→1	-70.6 J	20 J	-50.6 J
Cycle	20 J	-20 J	0

$$R = 8.31\ \text{J/mol}\cdot\text{K}$$

$$R = 0.082\ \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}$$

$\Delta U = Q + W$ $\quad W = -\int_1^2 PdV$ $\quad \Delta U = nC_V\Delta T$

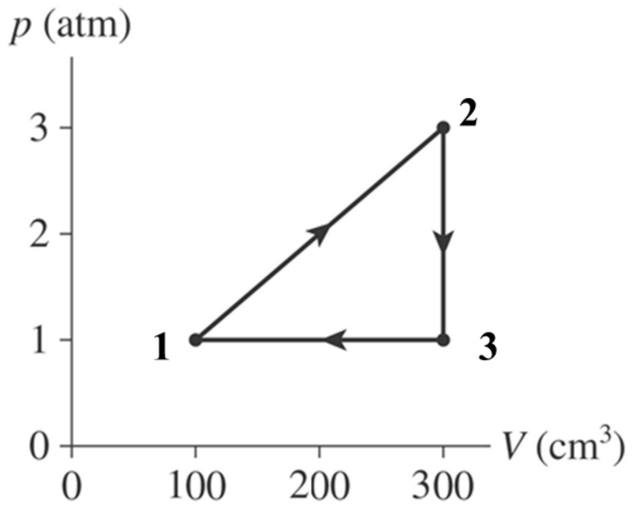
$$\Delta U = nC_V\Delta T \qquad \Delta U = Q + W$$

Consider this complete cycle (1 → 2 → 3 → 1), the work done on the gas from the exerted force is negative. The heat transfer to the gas is positive.

From the external view point, the work done to the external world is Positive!

That is, the external world can give heat to the gas and make it run in cycles. The gas can then do work to the external world – so this is a "heat engine".

Processes	Q	W	ΔU
1→2	242.7 J	-40 J	202.7 J
2→3	-152.1 J	0	-152.1 J
3→1	-70.6 J	20 J	-50.6 J
Cycle	20 J	-20 J	0



Work done by the gas to the external world is 20 J.

Heat engine: A cycle of thermal processes that produces work in exchange for heat.

Another way to write 1st Law of Thermodynamics Heat Engine

$$\Delta U = W_{\text{onGas}} + Q$$

$$\boxed{Q = W_{\text{by gas}} + \Delta U}$$

Any energy transferred into a system as ***heat*** is either used to ***do work*** or ***stored within the system as an increased internal energy***.

Heat Engine

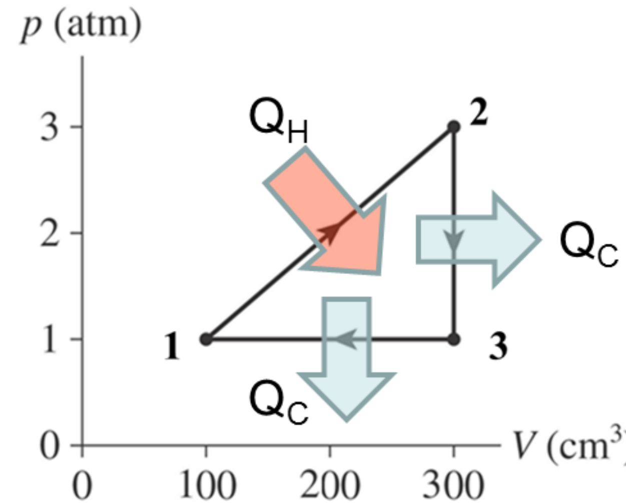
- PV diagram
  - Clockwise cycle: heat engine
  - Counterclockwise cycle: refrigerator
- Schematic representation

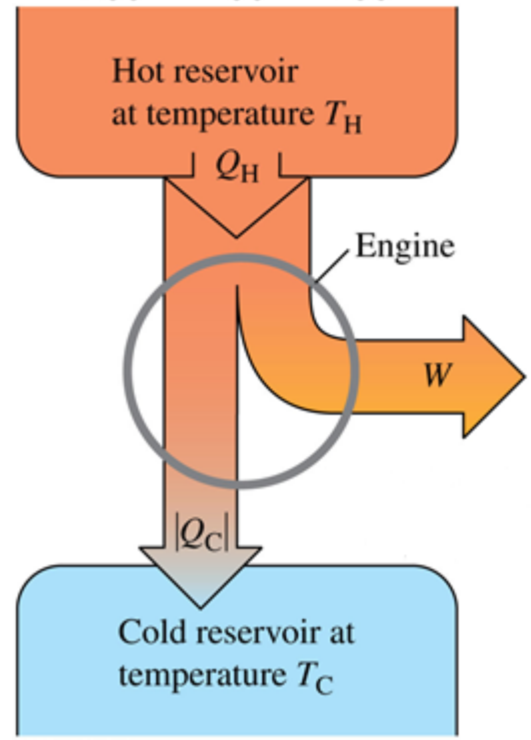
  Energy-flow diagram

$$W_{out} = Q_H - Q_C$$

- Efficiency: Fraction of heat you put in that's converted to work

$$e = \frac{W_{out}}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

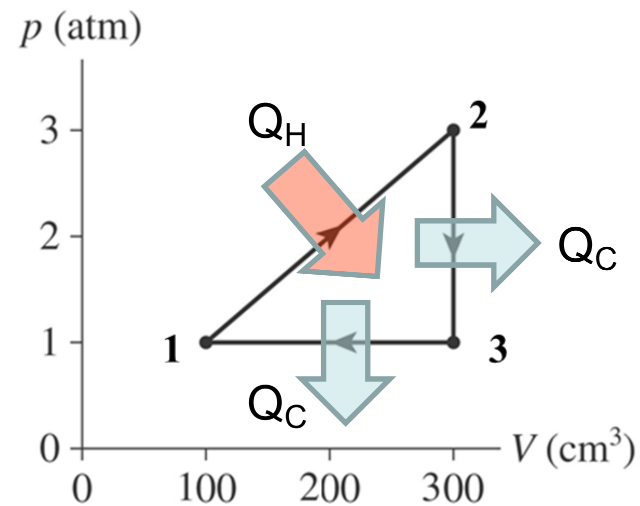




Thermal Efficiency

$$e = \frac{W_{out}}{Q_H} = \frac{\text{Work output}}{\text{Heat supplied}} = \frac{\text{What you get}}{\text{What you had to pay}}$$

Processes	Q	W	ΔU
1→2	242.7 J	-40 J	202.7 J
2→3	-152.1 J	0	-152.1 J
3→1	-70.6 J	20 J	-50.6 J
Cycle	20 J	-20 J	0

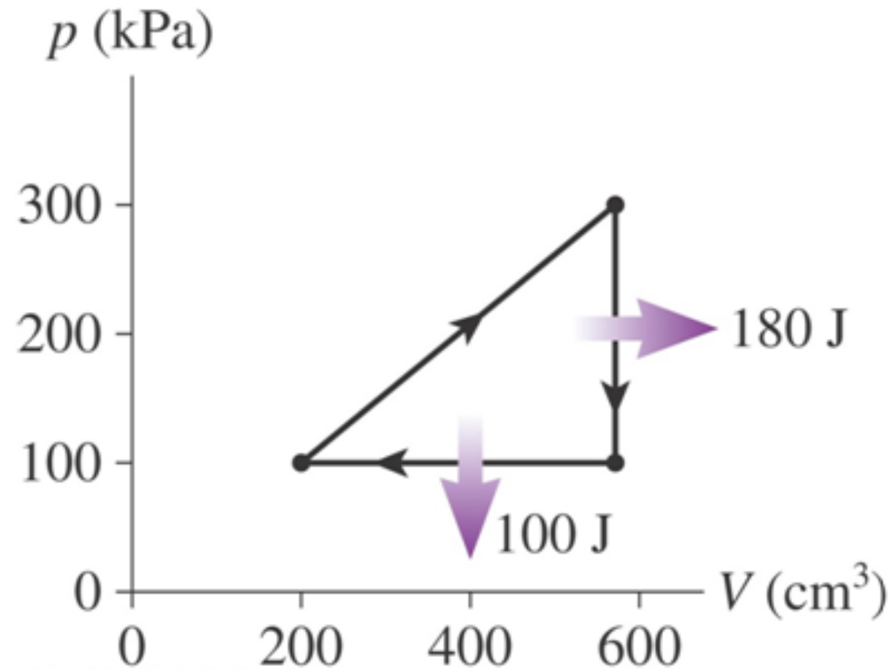


Efficiency?   e = 20/242.7=8.2 %

$$e = \frac{W_{out}}{Q_H} = \frac{|Q_H| - |Q_C|}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$$

What is the thermal efficiency of this heat engine?

A. 10.0%
B. 12.5%
C. 14.5%
D. 40.0%
E. 55.5%
F. None of the above.



$$e = \frac{W_{out}}{Q_H} = \frac{|Q_H| - |Q_C|}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$$

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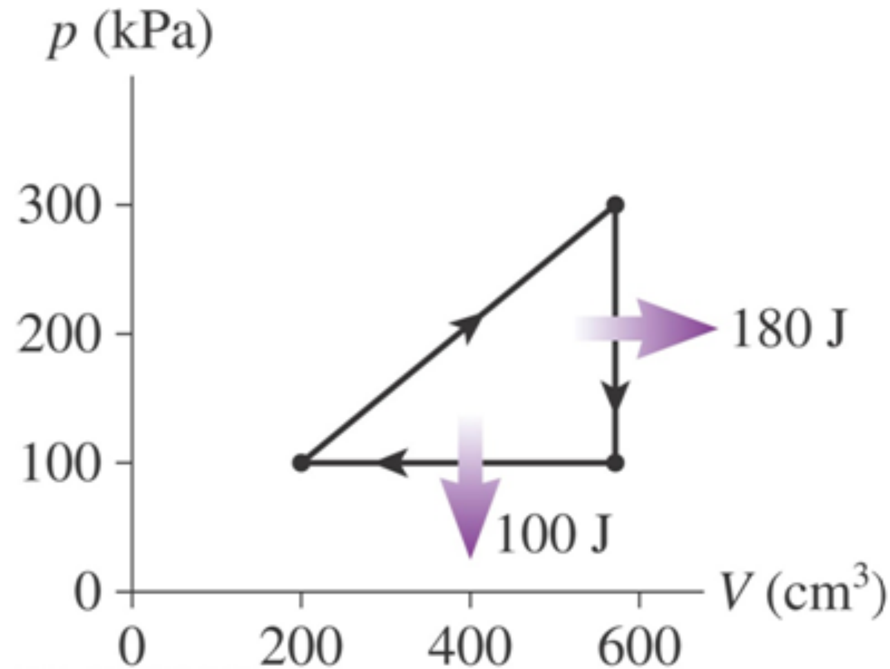


$W = area\ of\ triangle$

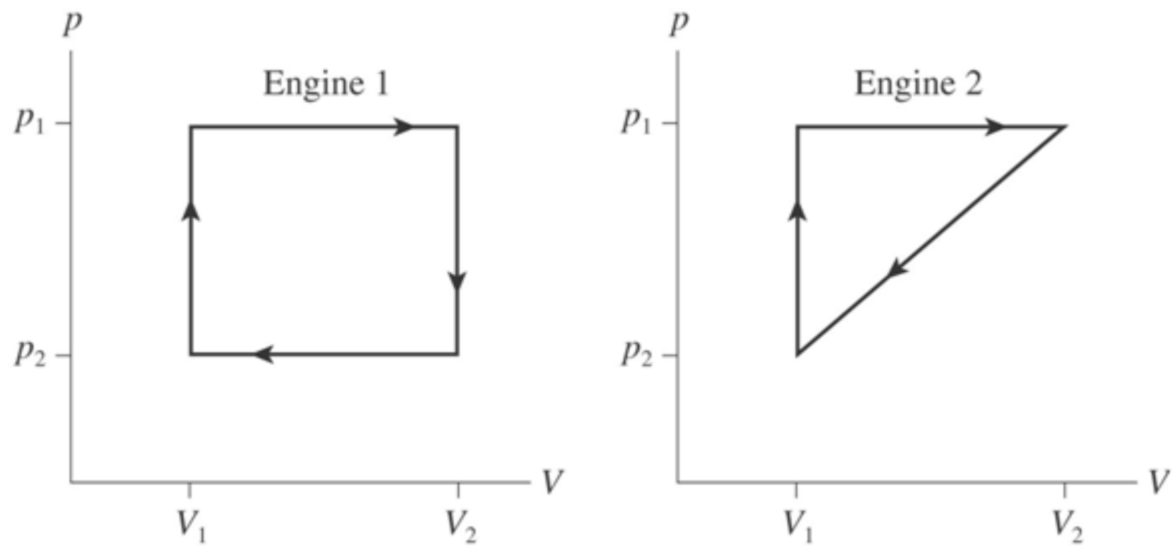
$= \frac{1}{2} \times 400 \times 10^{-6} \times 200 \times 10^{3} = 40J$

$Q_H - Q_C = W \Rightarrow Q_H = 40 + 180 + 100 = 320J$

$e = \frac{W}{Q_H} = \frac{1}{8}$

$$e = \frac{W_{out}}{Q_H} = \frac{|Q_H| - |Q_C|}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$$

Which of the heat engine has the larger thermal efficiency?



A. Engine 1
B. Engine 2
C. The same
D. Can't tell

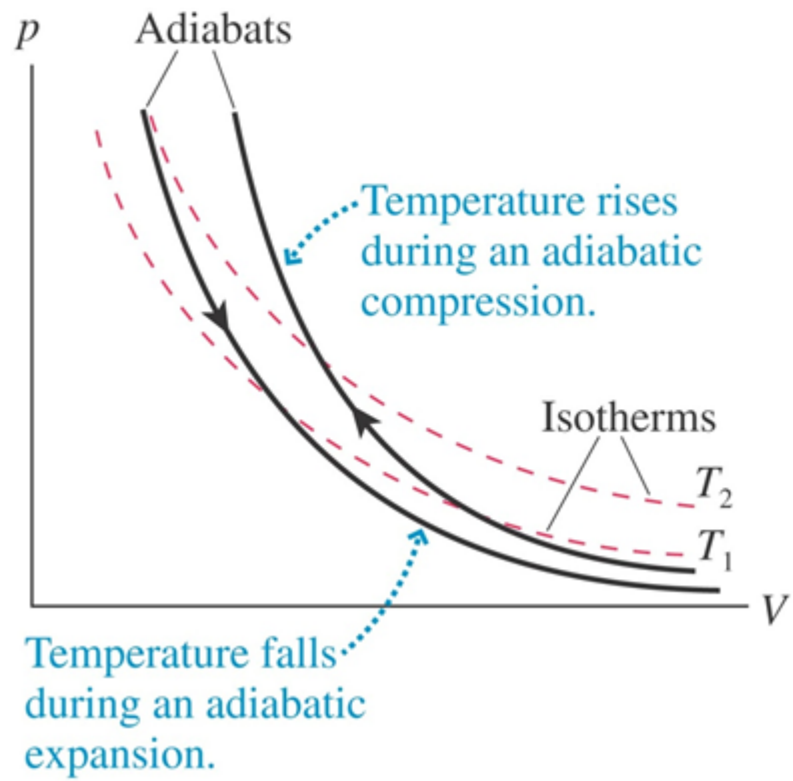
Adiabatic Process

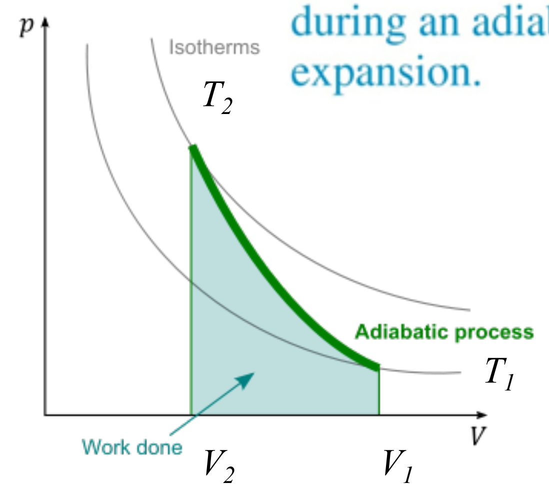
$$\Delta U = W_{onGas} + Q = W$$

$$W = nC_V \Delta T$$

$$T_f V_f^{\gamma - 1} = T_i V_i^{\gamma - 1}$$

$$P_f V_f^{\gamma} = P_i V_i^{\gamma}$$





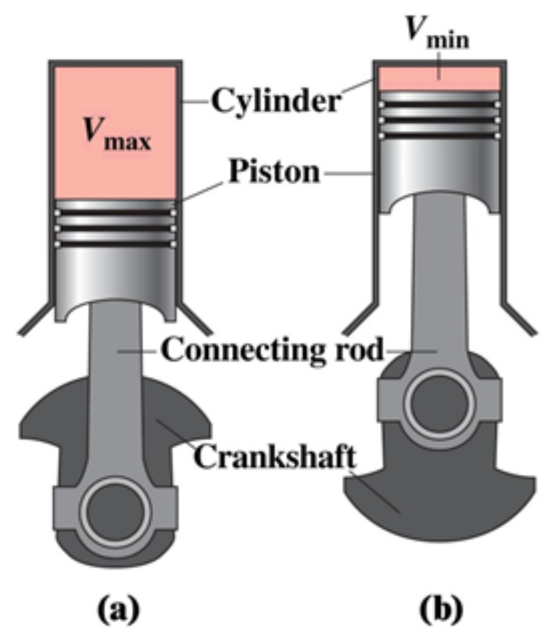
In the "compression stroke" of an internal combustion engine, air-fuel mixture at 20 °C and 1.0 atm is compressed until its volume is 1/10 of its original volume. The compression is so rapid that it can be assumed to be adiabatic. Find the final pressure and temperature.

States	P	V	T
i	1 atm	V_0	293.15K
f	?	$V_0/10$	?

$$Q = 0$$

$$P_f V_f^{\gamma} = P_i V_i^{\gamma}$$

$$T_f V_f^{\gamma-1} = T_i V_i^{\gamma-1}$$



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Treat the gas mixture as approximately diatomic gasses:

$$C_V = \tfrac{5}{2}R \quad C_P = \tfrac{7}{2}R$$

$$\gamma = \tfrac{7}{5} = 1.4$$

$$P_f V_f^{\gamma} = P_i V_i^{\gamma}$$

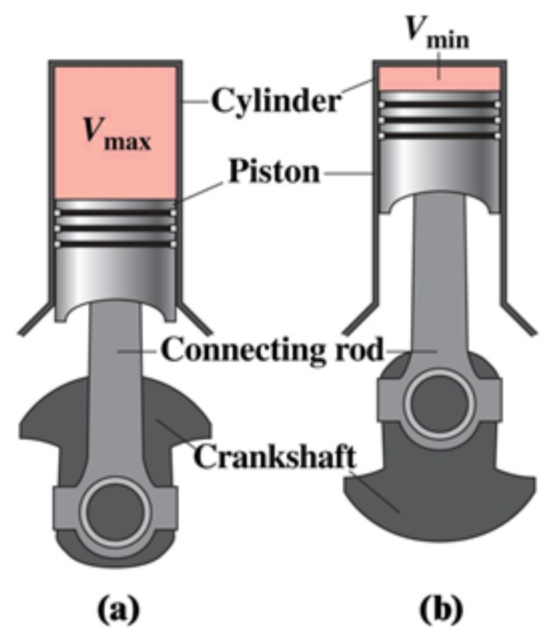
$$\frac{P_f}{P_i} = \left(\frac{V_i}{V_f}\right)^{\gamma} = 10^{\gamma} = 10^{1.4} = 25.12$$

$$P_f = 25.12\ atm$$

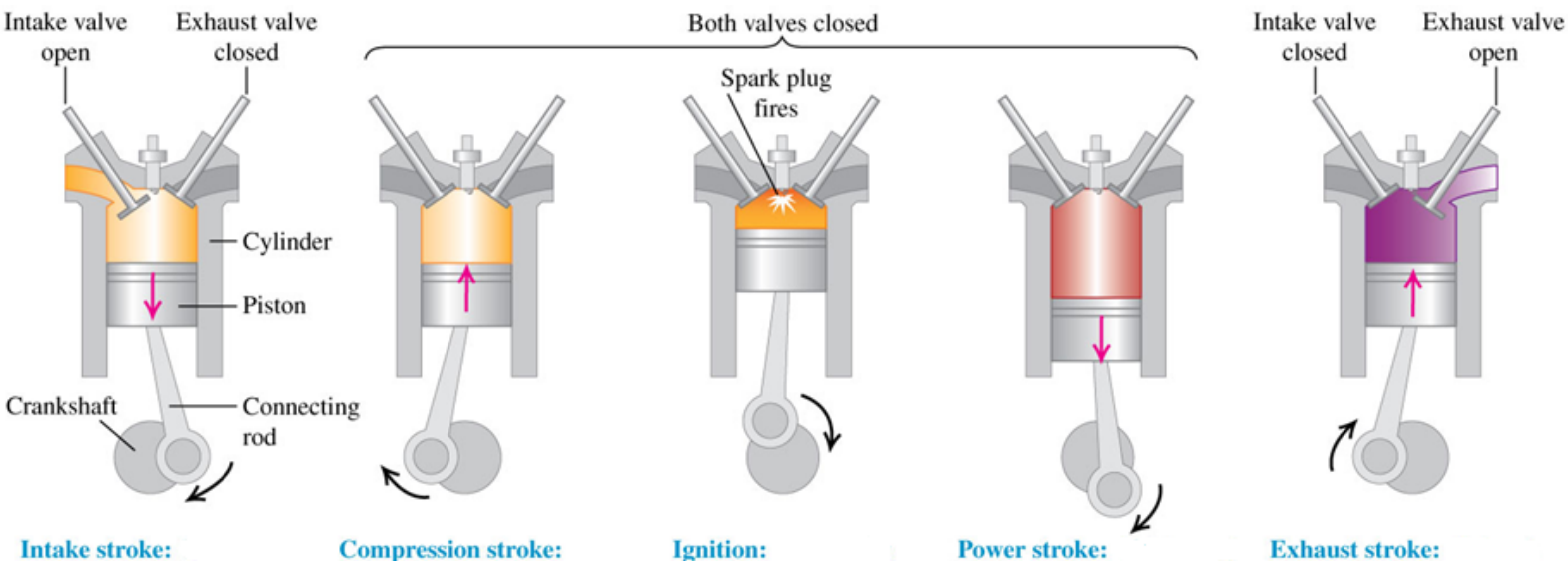
$$T_f V_f^{\gamma-1} = T_i V_i^{\gamma-1}$$

$$\frac{T_f}{T_i} = \left(\frac{V_i}{V_f}\right)^{\gamma-1} = 10^{\gamma-1} = 10^{0.4} = 2.51$$

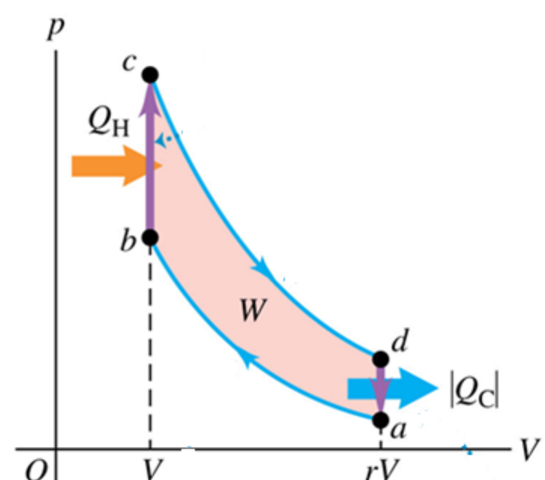
$$T_f = T_i \times 2.51 = 293.15 \times 2.51 = 736\ K°$$

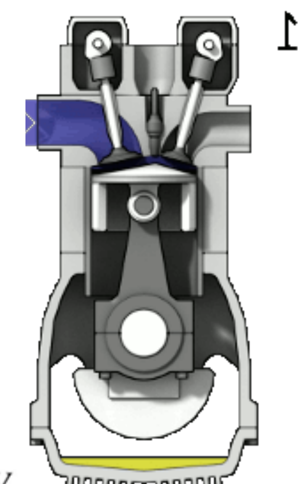


Practical Heat Engine: Otto Cycle (ICE)



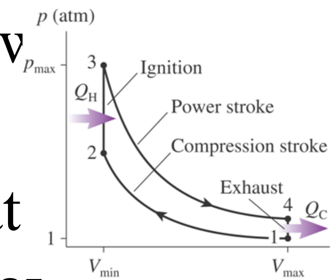
Process
ab: adiabatic compression
bc: isochoric heating
cd: adiabatic expansion
da: isochoric cooling





Gasoline Engine—Otto Cycle

A fuel-air mixture is sprayed into the cylinder at point 1, where the piston is at its farthest distance from the spark plug. This mixture is compressed as the piston moves tov



the spark plug during the adiabatic *compression stroke.*

The spark plug fires at point 2, releasing heat energy that been stored in the gasoline. The fuel burns so quickly that the piston doesn't have time to move, so the heating is an isochoric process.

The hot, high-pressure gas then pushes the piston outward during the *power stroke.*

Finally, an exhaust value opens to allow the gas temperature and pressure to drop back to their initial values before starting the cycle over again.

A Heat Engine Example