Announcements

1. Reminder – 4th hour exam – Monday 11/25 (Chapters 19-22)
2. Today's topic – Heat engines

Review of results from ideal gas analysis in terms of the specific heat ratio $\gamma \equiv C_P/C_V$:

$$\Delta E_{\text{int}} = \frac{n}{\gamma\text{-}1} R\Delta T = nC_V \Delta T \quad ; \; C_V = \frac{R}{\gamma\text{-}1}$$

$$C_P = \frac{\gamma R}{\gamma\text{-}1}$$

For an isothermal process, $\Delta E_{\text{int}} = 0$ ➔ Q=W

$$W = \int_{V_i}^{V_f} PdV = nRT \ln\left(\frac{V_f}{V_i}\right) = P_i V_i \ln\left(\frac{V_f}{V_i}\right)$$

For an adiabatic process, Q = 0

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

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

Extra credit:

Show that the work done by an ideal gas which has an initial pressure P_i and initial volume V_i when it expands *adiabatically* to a volume V_f is given by:

$$W = \int_{V_i}^{V_f} P dV = \frac{P_i V_i}{\gamma - 1}\left(1 - \left(\frac{V_i}{V_f}\right)^{\gamma-1}\right)$$

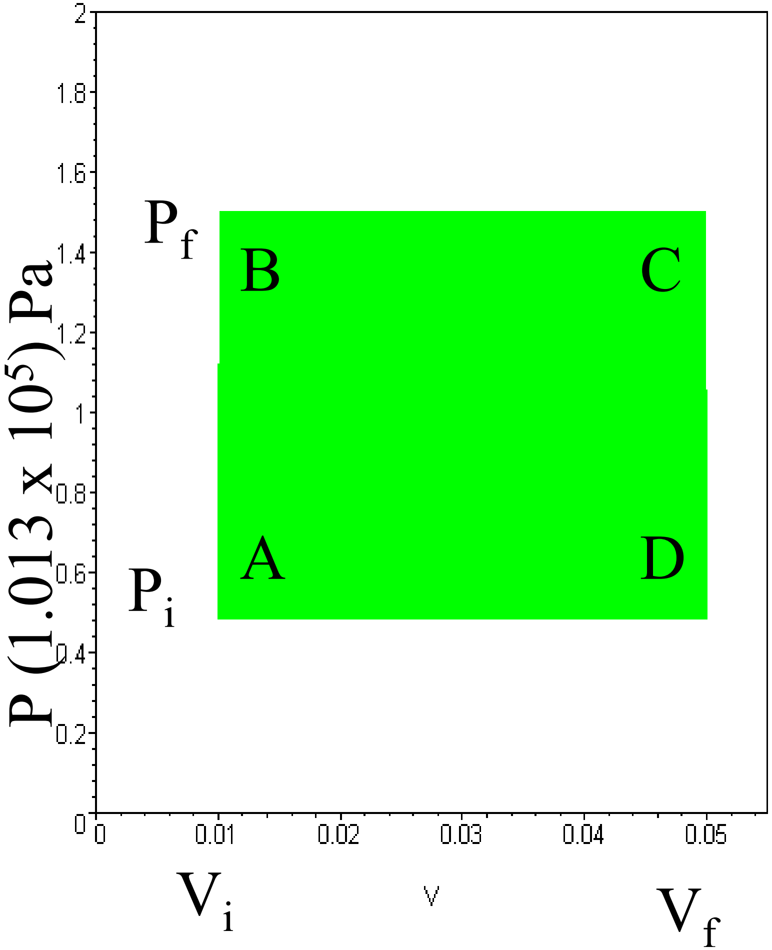
Peer instruction questions

Match the following types of processes of an ideal gas with their corresponding P-V relationships, assuming the initial pressures and volumes are P_i and V_i, respectively.

1. Isothermal
2. Isovolumetric
3. Isobaric
4. Adiabatic

(A) $P=P_i$ (B) $V=V_i$ (C) $PV=P_iV_i$ (D) $PV^\gamma=P_iV_i^\gamma$

Examples process by an ideal gas:

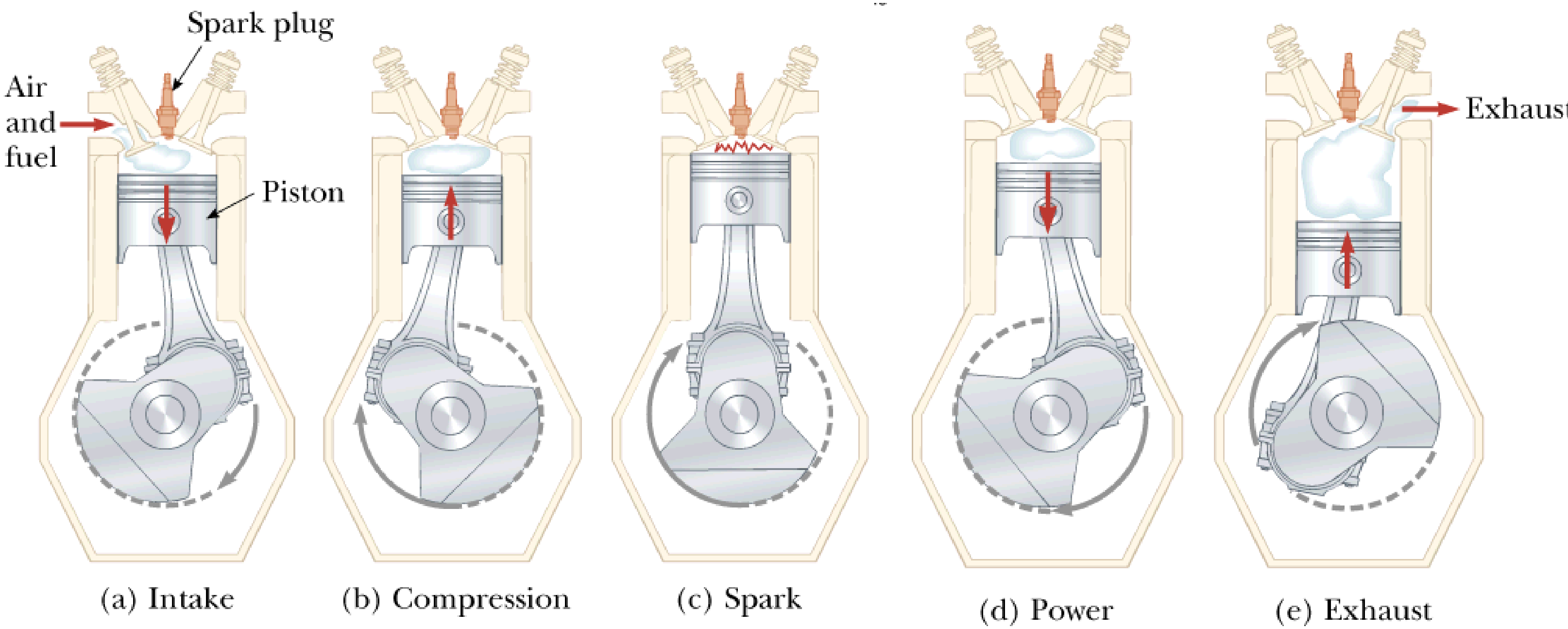


	A→B	B→C	C→D	D→A
Q	$\frac{V_i(P_f-P_i)}{\gamma-1}$	$\frac{\gamma P_f(V_f-V_i)}{\gamma-1}$	$\frac{-V_f(P_f-P_i)}{\gamma-1}$	$\frac{-\gamma P_i(V_f-V_i)}{\gamma-1}$
W	0	$P_f(V_f-V_i)$	0	$-P_i(V_f-V_i)$
ΔE_{int}	$\frac{V_i(P_f-P_i)}{\gamma-1}$	$\frac{P_f(V_f-V_i)}{\gamma-1}$	$\frac{-V_f(P_f-P_i)}{\gamma-1}$	$\frac{-P_i(V_f-V_i)}{\gamma-1}$

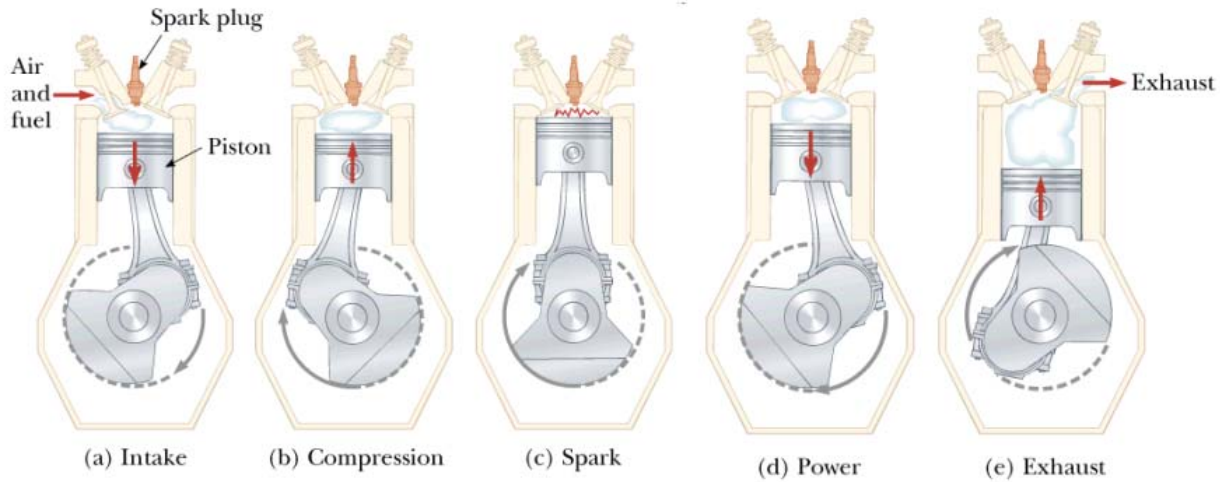
Efficiency as an engine:

$$e = W_{net/}\,Q_{input}$$

Otto cycle:


Spark plug
Air and fuel
Piston
Exhaust
(a) Intake
(b) Compression
(c) Spark
(d) Power
(e) Exhaust

Otto cycle:



Spark plug
Air and fuel
Piston
Exhaust
(a) Intake
(b) Compression
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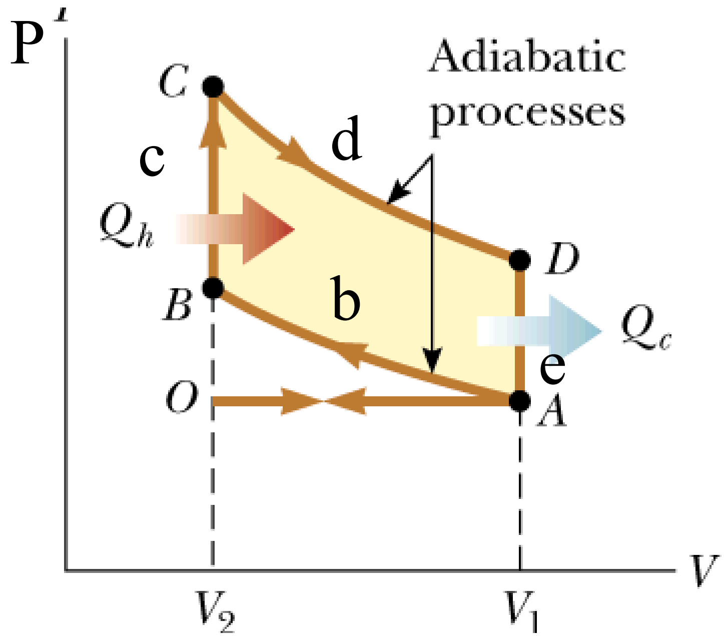
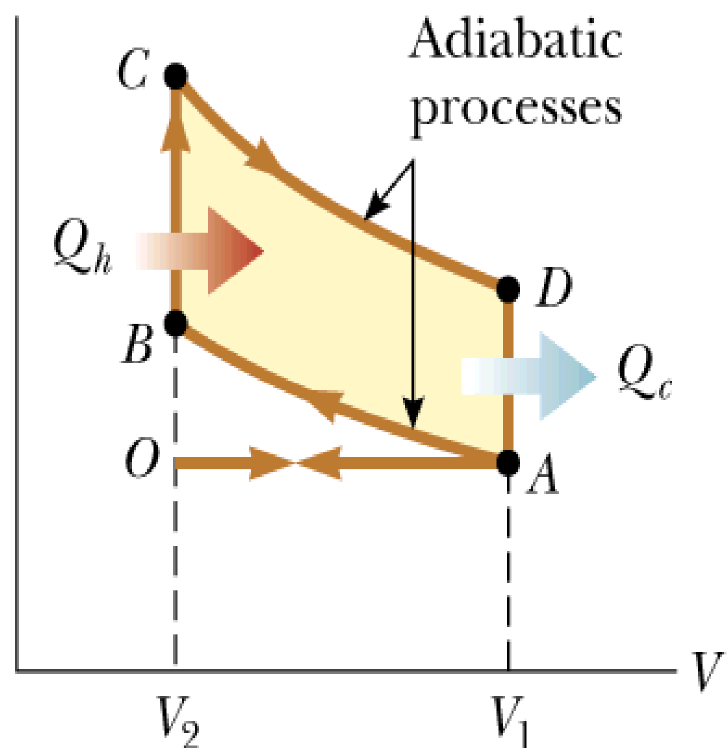


P
Adiabatic processes
C
D
B
O
A
c
d
b
e
Qh
Qc
V
V2
V1

P Otto cycle



$Q_{AB}=0$

$$Q_{BC} = \frac{V_2(P_C - P_D)}{\gamma - 1}$$

$Q_{CD}=0$

$$Q_{DA} = \frac{-V_1(P_D - P_A)}{\gamma - 1}$$

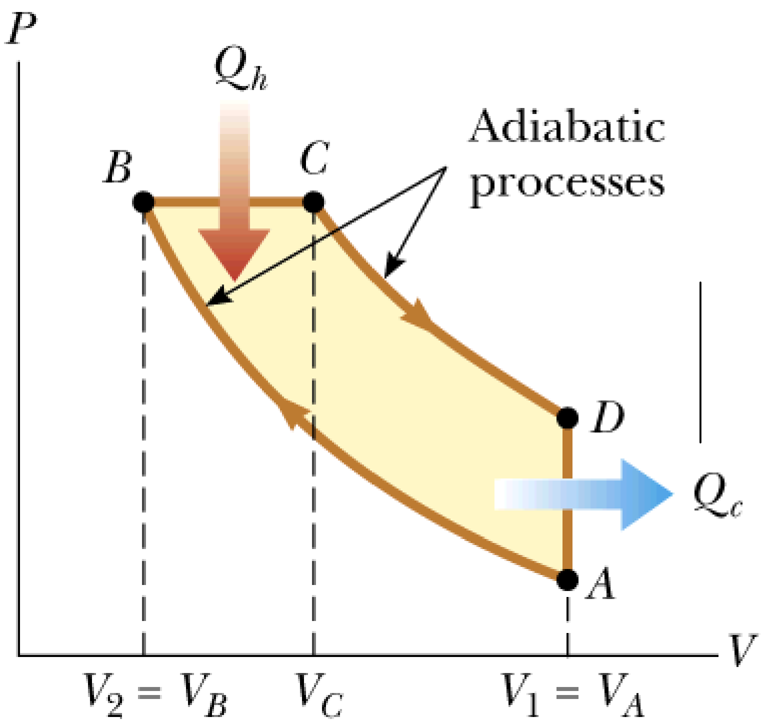
$$P_A V_1^\gamma = P_B V_2^\gamma ;$$

$$P_D V_1^\gamma = P_C V_2^\gamma$$

$$e = \frac{Q_{BC} + Q_{DA}}{Q_{BC}} = 1 + \frac{Q_{DA}}{Q_{BC}} = 1 - \frac{V_1(P_D - P_A)}{V_2(P_C - P_B)}$$

$$\Rightarrow e = 1 - \frac{1}{(V_1/V_2)^{\gamma - 1}}$$

Diesel cycle



$$Q_{AB}=0$$

$$Q_{BC} = \frac{\gamma P_B (V_C - V_B)}{\gamma - 1}$$

$$Q_{CD}=0$$

$$Q_{DA} = \frac{-V_D (P_D - P_A)}{\gamma - 1}$$

$$e = 1 - \frac{1}{\gamma}\left(\frac{\left[\frac{1}{V_D/V_C}\right]^{\gamma} - \left[\frac{1}{V_A/V_B}\right]^{\gamma}}{\left[\frac{1}{V_D/V_C}\right] - \left[\frac{1}{V_A/V_B}\right]} \right)$$

Carnot cycle

$$Q_{AB} = nRT_H \ln\left(\frac{V_B}{V_A}\right)$$

$Q_{BC}=0$

$$Q_{CD} = -nRT_C \ln\left(\frac{V_C}{V_D}\right)$$

$Q_{DA}=0$

$$e = \frac{Q_{AB}+Q_{CD}}{Q_{AB}} = 1-\frac{T_C}{T_H}$$