FERMILAB
ENGINEERING NOTE

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SUBJECT

NAME	
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Physics 2C 2/4

① C_v vs. C_p

② Adiabatic Processes

③ Heat Transfer Mechanisms

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① 1st lesson : $\boxed{C_p = C_v + R}$

(const. vol)
$Q = n C_v \Delta T$
$Q = n C_p \Delta T$
(const. press.)

2nd lesson: Q depends on path

Note for const. vol.

$$\Delta E_{th} = \cancel{W}^{\,0} + Q_{\substack{const.\\ vol}} = n C_v \Delta T$$

but ΔE_{th} depends <u>only</u> on endpoints

so $\boxed{\Delta E_{th} = n C_v \Delta T}$ for all processes (even if not const. vol.)

<u>Prelude to</u> Ch. 20

$C_v = \frac{3}{2} R$ monoatamic

$C_v = \frac{5}{2} R$ diatomic

(only @ "medium" temp)

$$\gamma = \frac{C_p}{C_v} = \begin{cases} 5/3 & \text{mono.} \\ 7/5 & \text{dia.} \end{cases}$$

$\boxed{\text{Why?}}$ ⟹ Ch. 20

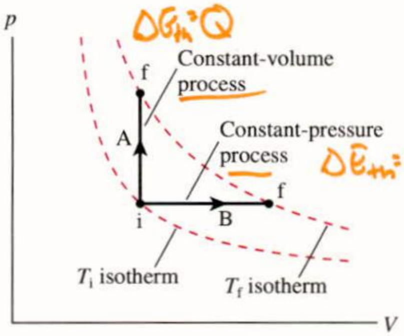
(microscopic degrees of freedom)

Two copies of the same amount of the same gas undergo two processes A and B below. Which gas had more "heat delivered" to it?

$Q = nC_V \Delta T$

A) Gas A
B) Gas B
C) Same
D) I don't know

$\Delta E_{th} = Q$



$\Delta E_{th} = Q + W$

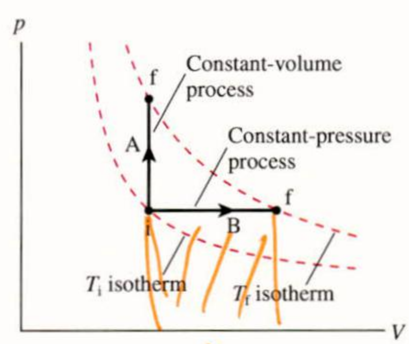
ΔT same

$C_p > C_V$.

In the previous problem, you saw gas B had more heat delivered. $(Q_B - Q_A) > 0$ is equal to the area underneath line B, $-W_{\text{on}}$ (why?). Find two formulae for this work, first in terms of pressure and ΔV and second in terms of ΔT.

(prove $C_p = C_V + R$)

Given: n, C_P, C_V, and p_0



$-W_B$

$\Delta E_{th,A} = \Delta E_{th,B}$

$Q_A = Q_B + W_B$

$nC_V \Delta T = nC_p \Delta T - p_0 \Delta V$

$= nC_p \Delta T - nR\Delta T$

$\Rightarrow \boxed{C_V = C_p - R}$

adiabatic
$Q = 0$

11. The gas cylinder in **FIGURE Q19.11** is well insulated on all sides. The piston can slide without friction. Many small masses on top of the piston are removed one by one until the total mass is reduced by 50%.

   a. During this process, are (i) ΔT, (ii) W, and (iii) Q greater than, less than, or equal to zero? Explain.

   b. Draw a pV diagram showing the process.

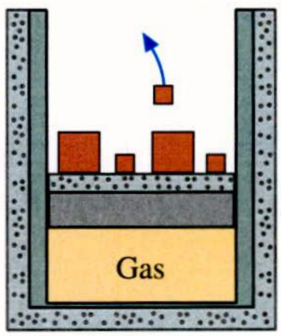
(a) $\boxed{Q = 0}$

gas expands

$\boxed{W < 0}$

$\Delta E_{th} = \cancel{Q}^{0} + W$

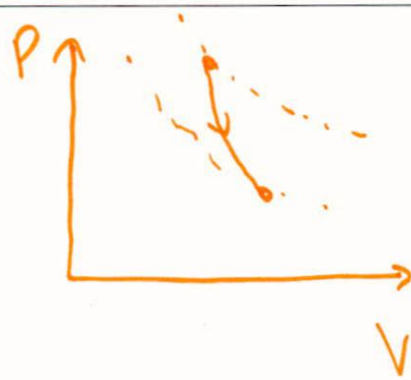
$\Rightarrow \boxed{\Delta T < 0}$



$P_f V_f = nRT_f$

$P_0 V_0 = nRT_0$

Q	0
W	−
ΔT	−



adiabatic expansion

$W_{ab} = -7\text{ J} \Rightarrow Q_{ab} = 7\text{ J}$

$W_{bc} = -5\text{ J}$

$Q_{bc} = 0$

In the pV diagram below, the gas does 7 J of work when taken along isotherm *ab* and 5 J when taken along adiabat *bc*. For which of the three paths is the net heat added to the gas the greatest?

$\Delta E_{ac} = \Delta E_{abc}$

$Q_{ac} + W_{ac} = \cancel{\Delta E_{ab}}^{\,0} + \Delta E_{bc} = \cancel{Q_{bc}}^{\,0} + W_{bc}$

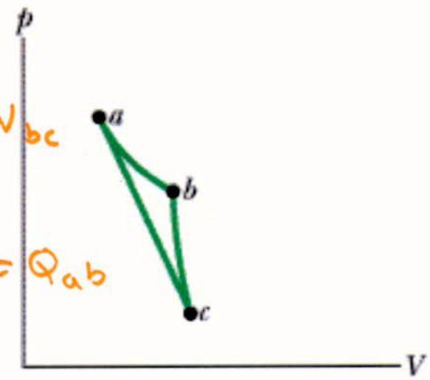
$Q_{ac} = W_{bc} - W_{ac}$

$-W_{ac} < -W_{ab} - W_{bc}$

$< 12\text{ J}$

$Q_{ac} < 7\text{ J} = Q_{ab}$

A) a → b
~~B)~~ b → c
C) a → c



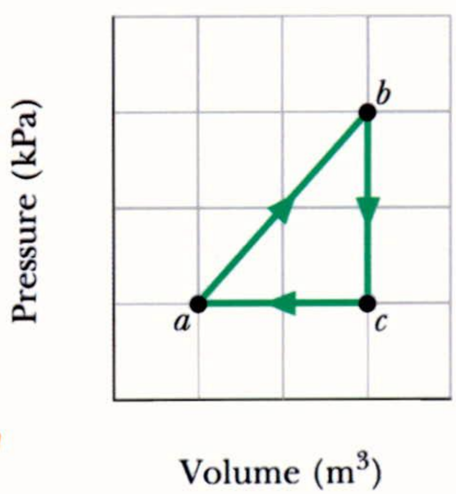
After filling in the following table, how many minus signs are there?

A) 1 B) 2 C) 3 D) 4 E) 5

Sum to zero

	Q	W	ΔEth
a → b	+	−	+
b → c	−	0	−
c → a	−	+	−

$\Delta E_{th} = Q + W$



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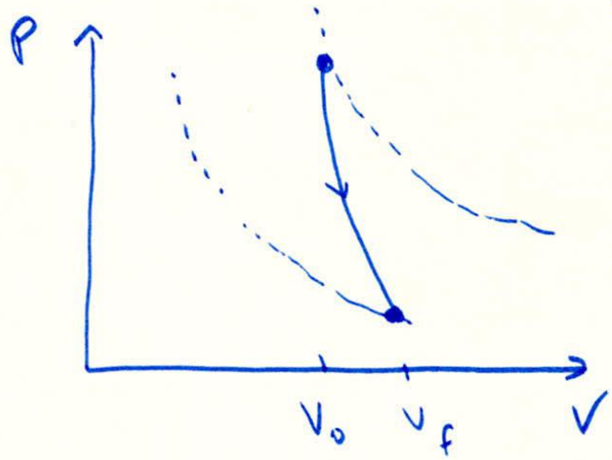
② Adiabatic Processes $(Q = 0)$ * "thermally insulated"
* "quickly"
No heat exchange



$$\Delta E_{th} = \cancel{Q}^{0} + W$$

1st Law

$$dE_{th} = n C_v\, dT = -p\, dV$$

$$n\, dT = \frac{-p\, dV}{C_v}$$

IGL:

$$n\, dT = \frac{p\, dV + V\, dp}{R}$$

$$n\, dT = \frac{p\, dV + V\, dp}{C_p - C_v}$$

$$\gamma = \frac{C_p}{C_v}$$

$$\left(\frac{1}{\frac{1}{C_v}}\right)\left(\frac{1}{pV}\right) \frac{p\, dV + V\, dp}{C_p - C_v} = -\frac{p\, dV}{C_v}\left(\frac{1}{pV}\right)\cdot\left(\frac{1}{\frac{1}{C_v}}\right)$$

$$\left(\frac{1}{\gamma - 1}\right)\left(\frac{dV}{V} + \frac{dp}{p}\right) = -\frac{dp}{p}$$

$$\frac{dp}{p} + \gamma \frac{dV}{V} = 0$$

$$\ln\left(pV^{\gamma}\right) = \text{const.}$$

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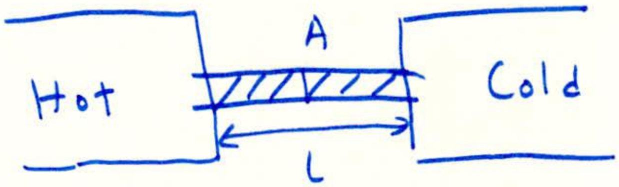
③ Conduction : "Direct" touching by material

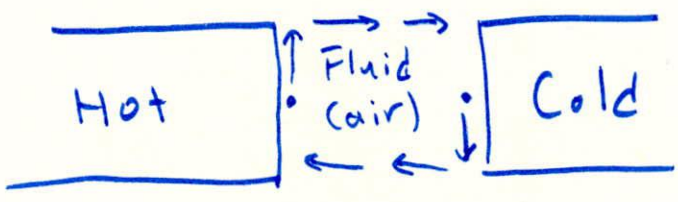


$$\frac{\text{energy}}{\text{time}} = P_{cond} = K \frac{A}{L} (\Delta T)$$

K: coefficient of thermal conductivity of material

SI units $\left[\frac{W}{m \cdot K}\right]$

Convection (hard to model!)



Radiation Everything "glows"! By how much?

$$\boxed{P_{rad} = e \sigma A T^4}$$

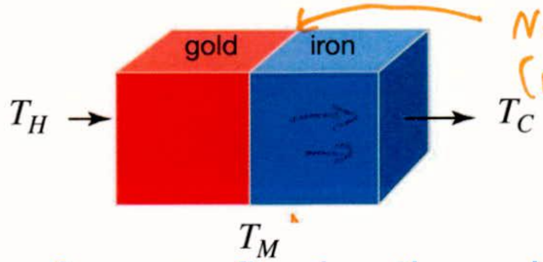
e: emissivity, $e \in [0, 1]$

σ: $5.67 \times 10^{-8}\ W/m^2K^4$ Stefan-Boltzmann cnst.

A: surface area

T: absolute temp. (K)

A composite slab is made up of two different materials of the same dimensions. The left end (gold) has been touching a very hot thermal reservoir at high temperature; the right end (iron) is touching a cold one. Which of the following is true?



Not changing temp (no net energy flow to it)

A) The rate of energy flowing through the gold slab is the same is the same as the rate of energy flowing through the iron slab

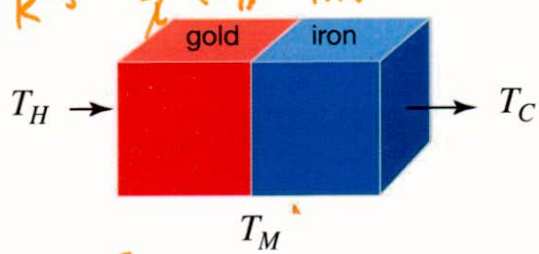
~~B)~~ $T_H - T_M = T_M - T_C$

~~C)~~ Both of the above are true

Given $k_{gold} = 5k_{iron}$, what is T_M?

$$P_{cond}^{(gold)} = P_{cond}^{(iron)}$$

$$k^{(gold)} \frac{A}{L} (T_H - T_M) = k^{(iron)} \frac{A}{L} (T_M - T_C)$$



$$\Rightarrow \quad 5(T_H - T_M) = T_M - T_c$$

$$\boxed{T_M = \frac{5}{6} T_H + \frac{1}{6} T_c}$$

One copper rod of dimensions $L \times w \times h$ radiates at temperature T with net power P. Suppose you have a second copper rod, of dimensions $2L \times 2w \times 2h$ at temperature T. What is the net power radiated by the second rod?

$P \propto A$

surf. area inc. by 4x

A) P
B) 2P
C) 4P
D) 8P
E) 16P

One copper rod of dimensions $L \times w \times h$ radiates at temperature T with net power P. Suppose you have a second copper rod, of dimensions $L \times w \times h$ at temperature $2T$. What is the net power radiated by the second rod?

$P \propto T^4$

A) P
B) 2P
C) 4P
D) 8P
E) 16P