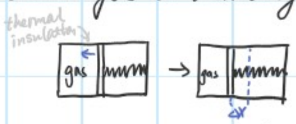
20.1 Thermal Interactions

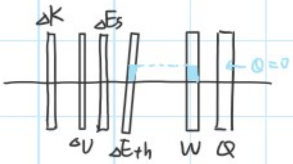
Thursday, March 7, 2019 12:11 PM

- Thermal interaction: the transfer of energy between two objects at different temperatures.
- Energy transferred thermally (Q)
  - Heat: the process of increasing the E_{th} of a system.
  - $Q > 0$ Energy transfer thermally into the system.

    $Q < 0$ Energy transfer thermally out of the system.
- Adiabatic process: A process that does not involve any thermal transfer of energy. ($Q = 0$)
  - Ideal gas is thermally insulated



- This is an adiabatic process since $Q=0$, $W>0$ for gas

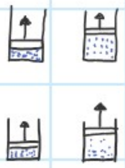


- $V_{gas}\downarrow$ $W>0$; $V_{gas}\uparrow$, $W<0$; $\frac{dV}{dt}=0$, $W=0$

  Work done on gas

  Volume doesn't change
- Process: Transformation of a system from one macrostate to another.
  - Quasistatic process: the system remains very closed to equilibrium at all instants during the process.

    e.g.



pull the piston gradually – quasistatic

pull the piston quickly – non-quasistatic

(P not equal everywhere)

- $Q > 0$, $\Delta S > 0$

  $Q < 0$, $\Delta S < 0$

  } when W doesn't change

- $Q > 0,\ \Delta S > 0$
  $Q < 0,\ \Delta S < 0$ } When W doesn't change

  - $\Delta S = 0$ When a system undergoes a quasistatic, adiabatic process.

Session 17383631

multiple choice question

A partition divides a thermally insulated container into two equal compartments, A and B. Initially compartment A contains a gas of distinguishable particles and compartment B is empty. The partition is removed and the gas is allowed to expand into the volume V of the container. Is this process quasistatic and is it adiabatic?

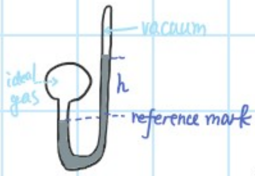
Adiabatic only.

(It is a sudden change, so no quasistatic)

20.2 Temperature Measurement

Thursday, March 7, 2019 12:44 PM

- REM $P = Nk_BT/V$ ($PV = Nk_BT$)
- Ideal gas therometer



  - $T = 0$, $h = 0$

    $h \propto T$

  - $T_{tp} \equiv 273.16K$, triple point (for water)
  - $T_C = \frac{1°C}{1K} - 273.15°C$

  - Absolute zero $T = 0$ (K), $S = 0$, E_{th} minimum
  - $h = c \cdot T$, c is a constant

20.3 Heat Capacity

Thursday, March 7, 2019 12:54 PM

- Heat capacity SI unit : J/K
  - Extensive
- Specific heat capacity c, SI unit J/(K·kg)
  - c might change
  - $Q = cm\Delta T$ → in K
  - intensive
  - $c_{water} = 4.181 \times 10^3$ J/(K·kg)
- degree of freedom : the motion along each axis.
- Particle's equipartition energy share of energy

$$\boxed{\frac{d}{2} k_B T}$$

★★★

Session 92209434

multiple choice question

For nitrogen molecules the quantum of energy associated with rotation is $E_{rot}=4.0\times10^{-23}$ J and the quantum of energy associated with vibration is $E_{vib}=4.7\times10^{-20}$ J. At a temperature of 1000 K can we excite rotation and vibrations in nitrogen?
Note $k_B=1.38\times10^{-23}$ J/K.

A.

We can excite neither vibrations or rotations

B.

We can excite vibrations but not rotations

C.

We can excite rotations but not vibrations

D.

We can excite both vibrations and rotations

N_2 : $d = 5$

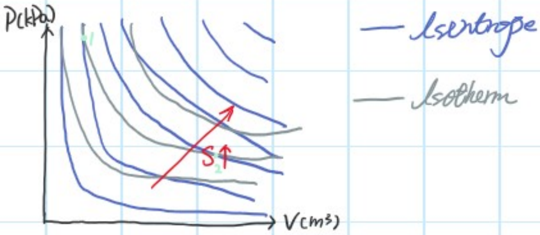
$\frac{d}{2} k_B T = 3.45 \times 10^{-20}$ J $\frac{1}{2} k_B T = 6.9 \times 10^{-21}$ J   C.

$> E_{rot}$ ← each degree of freedom.

$< E_{vib}$

20.4 PV Diagrams

Thursday, March 7, 2019 12:58 PM

- Phase transition: during which Q doesn't change T, but goes toward changing the state.
- Any point on PV diagram represents an equilibrium state in which the gas has a well defined T, Eth, and S
- 

    - Isotherm: T equals.
        - $h_{isotherm}$ ↑, T ↑, Eth ↑
    - Isentropes: S equals.
        - Steeper than isotherm
        - $h_{isentropes}$ ↑ S↓
    - Compare P, V, T, S in 1 and 2

      $P_1 > P_2$, $V_1 < V_2$, $T_1 = T_2$

      $S \propto \ln(T^{\frac{3}{2}}V)$ $\therefore S_1 < S_2$
- During a quasistatic process, the system remains near equilibrium at all instants. Such a process can be represented by a continuous path on a PV diagram.
- When an ideal gas is transformed from one equilibrium to another

  ΔEth and ΔS are independent of path

  Area under the curve ↑ |W| ↑,
    - direction: in increasing the volume, W<0

      in decreasing the volume, W>0

· direction: in increasing the volume, $W<0$

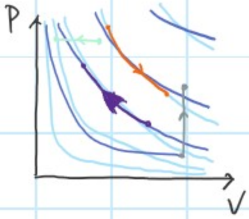
in decreasing the volume, $W>0$

○ $E_{th} = Q + W$

for process with the same path, E_{th} same, $W\uparrow$,

then Q is also different.

•



— isobaric process P fixed

— isochoric process V fixed $W=0$

— isothermal process T fixed $\Delta E_{th}=0$

— isentropic S fixed $Q=0$
(adiabatic)

(Determine $W, Q, \Delta E_{th}, \Delta S$ of the process on the graph.)

isobaric: $PV=nRT$ P fixed, $V\downarrow$, $T\downarrow$

$\Delta E_{th}<0$, $\Delta S<0$, $W<0$, $Q<0$?

isochoric $W=0$, $PV=nRT$, $P\uparrow$, $T\uparrow$

$\Delta E_{th}>0$, $\Delta S>0$, $W=0$, $Q>0$

isothermal $\Delta E_{th}=0$, $PV=nRT$, $V\downarrow$, $P\uparrow$

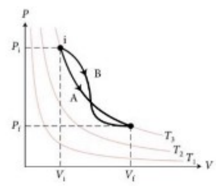
$W<0$ $\therefore Q>0$

isentropic $Q=0$, $PV=nRT$ $V\uparrow$, $P\downarrow$

$W \cancel{>} < 0$ $\therefore \Delta E_{th} \cancel{>} <0$ $\Delta S=0$

many choice question

The figure shows two processes, A and B, carried out on an ideal gas. Compare the change in thermal energy and change in entropy of the two processes.



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

B. $\Delta E_{th,A} > \Delta E_{th,B}$

C. $\Delta E_{th,A} < \Delta E_{th,B}$

D. $\Delta S_A = \Delta S_B$

E. $\Delta S_A > \Delta S_B$

F. $\Delta S_A < \Delta S_B$

When transfer to another equilibrium AD

(from one eq.) ΔS and ΔE_{th} are independent of path.

When transfer to another equilibrium st

(from one eq.) ΔS and ΔE_{th} are independent of path.

20.5,6,7 Change in Energy and Work

Tuesday, March 12, 2019 11:49 AM

- $\Delta E = W + Q$
  - when $\Delta K = \Delta U = \underbrace{\Delta E_s}_{\text{Source energy}} = 0$, $\Delta E_{th} = W + Q$
- Quasistatic isobaric process $W = -P\Delta V = -P(V_f - V_i)$

  $W = \int F dx = -\int PA\,dx = -\int P dV = -P\int dV = -P\Delta V$

- Heat capacity per particle $C_V \equiv \frac{Q}{N\Delta T}$ (constant volume)

  $= \frac{d}{2} k_B$ ($\because Q = \frac{d}{2} N k_B \Delta T$, isochoric)

- $\boxed{\Delta E_{th} = N C_V \Delta T}$ (any ideal gas process)

  C_V is a constant
- $\Delta E_{th} = W$ (isentropic quasistatic process)

  $\Delta S = 0 \Rightarrow Q = 0 \Rightarrow \Delta E_{th} = W$.

  isentropic process, $\Delta E_{th} = W = N C_V \Delta T$
- Heat capacity per particle $C_P \equiv \frac{Q}{N\Delta T}$ (constant pressure)
  - $Q = N C_P \Delta T$ (isobaric)

    $W = -P\Delta V = -N k_B \Delta T$ (isobaric)
- $N C_V \Delta T = -N k_B \Delta T + N C_P \Delta T$ (ideal gas) $= \Delta E_{th}$

  $C_P = C_V + k_B$

  heat capacity ratio $\gamma = \frac{C_P}{C_V} = \frac{(\frac{d}{2}+1)k_B}{\frac{d}{2}k_B} = 1 + \frac{2}{d}$
- Thermal reservoir not a part of the system & keep the temperature constant by thermally exchange energy with it
- $Q = -W = N k_B T \ln(\frac{V_f}{V_i})$

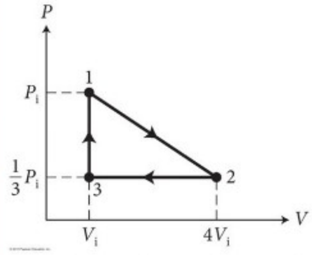
Process	Constraint	W	Q	ΔE_{th}	Energy law for ideal gas
isochoric	V fixed	0	$N C_V \Delta T$	\	$\Delta E_{th} = Q$
isentropic	S fixed	\	0	$N C_V \Delta T$	$W = \Delta E_{th}$

isochoric	V fixed	0	$NC_v\Delta T$		$\Delta E_{th} = Q$
isentropic	S fixed	\	0	$NC_v\Delta T$	$W = \Delta E_{th}$
isobaric	P fixed	$-Nk_B\Delta T$	$NC_p\Delta T$	$NC_v\Delta T$	$\Delta E_{th} = W + Q$
isothermal	T fixed	$-Nk_BT\ln(\frac{V_f}{V_i})$	\	0	$Q = -W$

Session 92209434

numerical question

An ideal gas undergoes the process represented in the diagram, where the gas is in state 1 when the process begins and again in state 1 at the finish. The initial pressure is 100×10^3 Pa, and the initial volume is 10^{-4} m^3. Determine the work done on the gas during the process. Enter answer in J, but only enter number.



1→2: Negative

W = -10W

2→3: positive

take area of triangle = -10

many choice question

An ideal gas is in a chamber with a plunger on top. The chamber is placed in a large pool of water and the plunger is pushed down slowly. Which of the following statements are correct?

A. $\Delta E_{th} > 0$

B. $\Delta E_{th} < 0$

C. $\Delta E_{th} = 0$

D. $W > 0$

E. $W < 0$

F. $W = 0$

G. $Q > 0$

H. $Q < 0$

I. $Q = 0$

W > 0, Q < 0

CDH

$\Delta E_{th} = N \cdot C_v\Delta T$

pool large ⇒ isothermal (keep temperature the same)

Session 92209434

many choice question

An ideal gas is in a chamber with a plunger on top. While a constant force is applied to the plunger the chamber is heated by a flame. Which of the following statements are correct?

A.

$\Delta E_{th} > 0$

B.

$\Delta E_{th} < 0$

C.

$\Delta E_{th} = 0$

D.

$W > 0$

E.

$W < 0$

F.

$W = 0$

G.

$Q > 0$

H.

$Q < 0$

I.

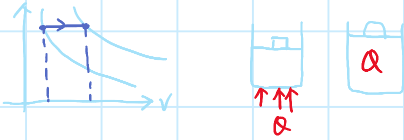
$Q = 0$

Q > 0

AEG

F constant, P constant

∴ T↑, move to right, V↑



at first, force and gas equilibrium.

20.8 Entropy change in ideal gas process

Tuesday, March 12, 2019 12:22 PM

- $S = N\ln V + \frac{d}{2} N \ln T + \text{constant}$ (ideal gas)

  $\Rightarrow \Delta S = N\ln\left(\frac{V_f}{V_i}\right) + \frac{d}{2} N\ln\left(\frac{T_f}{T_i}\right)$

- $P_i V_i^{\gamma} = P_f V_f^{\gamma}$ (isentropic process)

  $P_i^{\frac{1}{\gamma}} T_i = P_f^{\frac{1}{\gamma}} T_f$

numerical question

In a bicycle pump we compress 1.0 L of air at a pressure of 1.0 atm to a pressure of 7.0 atm. Assume the process is adiabatic and quasistatic and that air is an ideal gas of diatomic molecules, with 5 degrees of freedom. What is the final volume of the air? (If you finish early also calculate the final temperature assuming it starts at 20°C).

$d=5$, $\therefore \gamma = 1 + \frac{2}{d} = \frac{7}{5}$

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

$\left(\frac{P_i}{P_f}\right)^{\frac{1}{\gamma}} = \frac{V_f}{V_i}$

$V_f = V_i \cdot \left(\frac{P_i}{P_f}\right)^{\frac{1}{\gamma}} = 0.25\ \text{L}$

20.9

Tuesday, March 12, 2019 12:29 PM

- Specific transformation energy

  $L \equiv \frac{Q}{m}$ (phase transition with $Q > 0$)

  - $L > 0$

    $\therefore L \equiv -\frac{Q}{m}$ (phase transition with $Q < 0$)

  - $\Delta S = -\frac{mL}{k_B T}$ (solidification / condensation)

- isothermal process

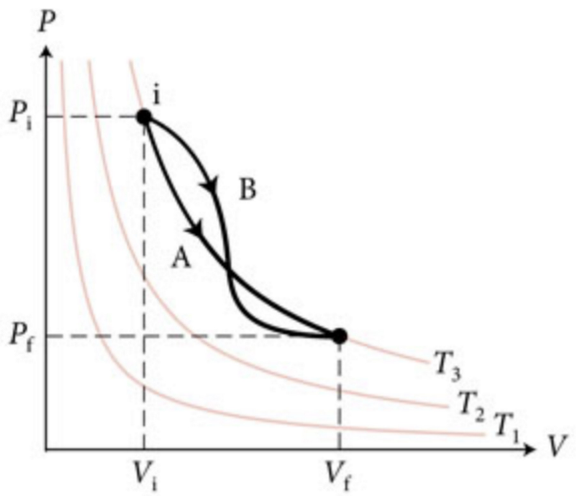
  $\Delta S = \frac{Q}{k_B T}$

  - Energy in soloid or liquid $\Delta E_{th} = Q = mc\Delta T$

Prob

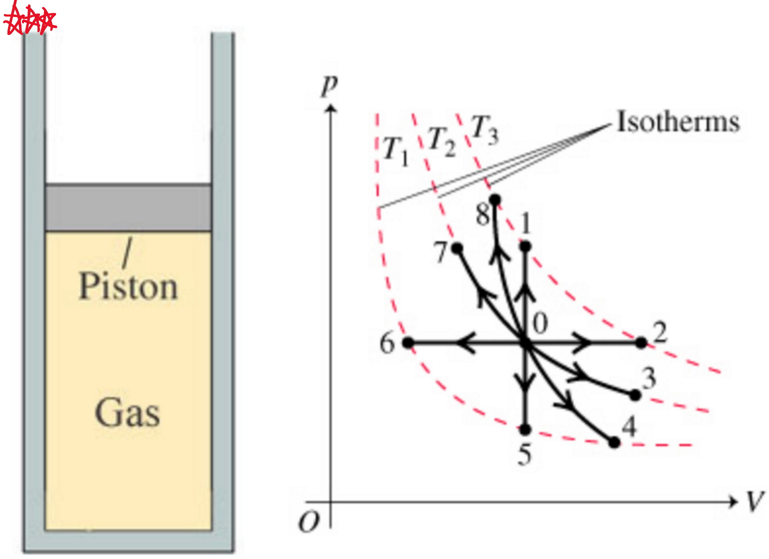
Wednesday, March 6, 2019 6:54 PM

(Figure 1) shows two processes, A and B, carried out on an ideal gas.



In which process was the amount of work done by the gas greater?

- The amount of work done by the gas is greater in process B.
- The amount of work done by the gas is the same in both processes.
- The amount of work done by the gas is greater in process A.

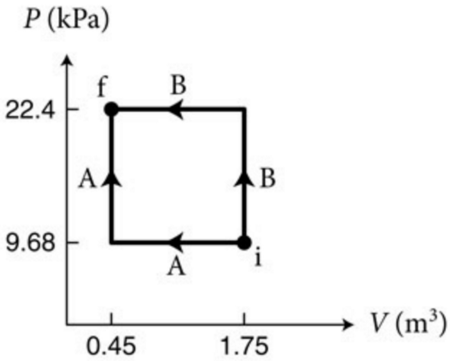


Starting from equilibrium at point 0, what point on the pV diagram will describe the ideal gas after the following process? "The piston is now insulated from its surroundings. Pull the piston head further out of the container."

▸ View Available Hint(s)

point 4

(Figure 1) shows two processes, A and B, for moving 3.45 $\times$ 10^{22} particles of a monatomic ideal gas from state i to state f.



Which process requires a smaller magnitude of the energy Q transferred thermally to the gas?

- process A
- process B
- Both processes require the same amount of energy.

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

$|W_A| < |W_B|$

$W_A, W_B < 0$ Notice the sign

$\therefore Q_A < Q_B$

By how much does the work done on the gas in process A differ from the work done on the gas in process B?

Express your answer with the appropriate units.

$W_B - W_A =$ 1.65×10⁴ J

$(1.75 - 0.45) \times (22.4 - 9.68) \times 10^3$