Copyright statement

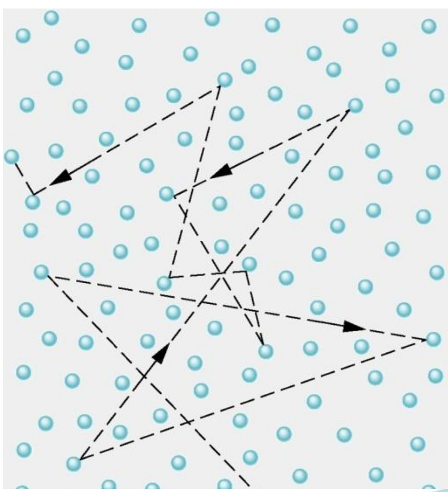
- The images and the pictures in this lecture are provided by the CDs accompanied by the books
  1. University Physics, Bauer and Westfall, McGraw-Hill, 2011.
  2. Principles of Physics, Halliday, Resnick, and Walker, Wiley, 8th and 9th Ed.
- The rest is made by me.

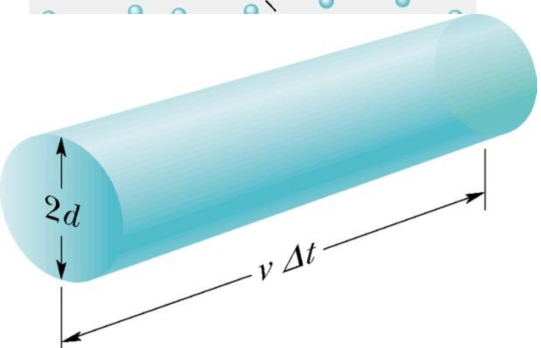
Translational kinetic energy

$$K_{\text{avg}} = \frac{1}{2}m(v^2)_{\text{avg}} = \frac{1}{2}mv_{\text{rms}}^2 = \left(\frac{1}{2}m\right)\frac{3RT}{M} = \frac{3}{2}kT$$

Mean free path

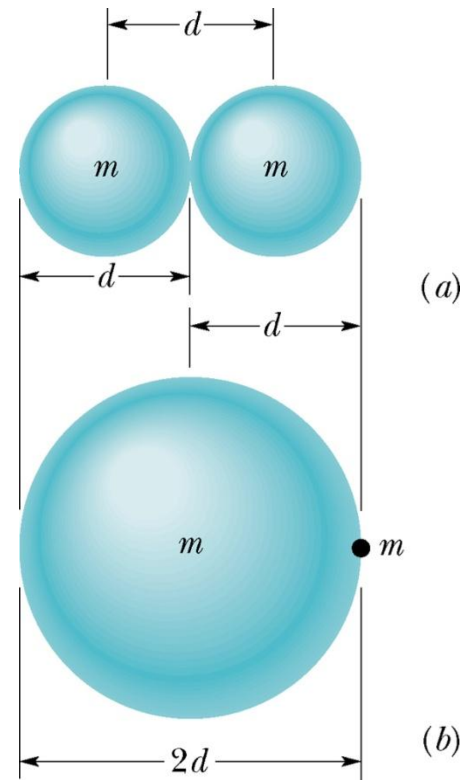
$$\lambda = \frac{1}{\sqrt{2}\pi d^2 N/V}$$





$$\lambda = \frac{v\Delta t}{\pi d^2 v \Delta t N/V} = \frac{1}{\pi d^2 N/V}$$

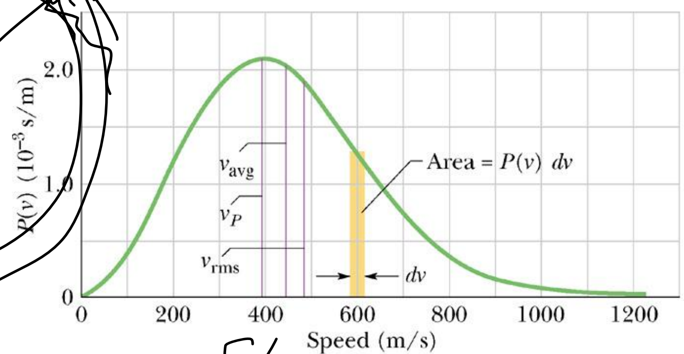
$$v_{\text{rel}} = \sqrt{2}v_{\text{avg}}$$



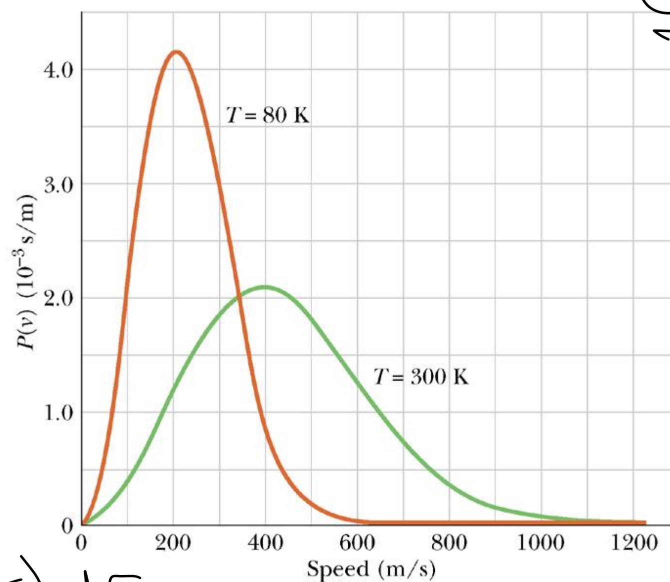
$P(\vec{v}) = A e^{-\frac{Mv^2}{2RT}}$

분자의 속력분포

$e^{-\frac{\frac{1}{2} N_A m v^2}{N_A RT}} = e^{-\frac{Mv^2}{2RT}}$



(a)



(b)

$P(E) = \frac{e^{-E/kT}}{\sum_E e^{-E/kT}}$

$P(E)dE$

Maxwell 속력분포법칙

$$P(v) = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} v^2 e^{-Mv^2/2RT}$$

$P(E) \propto e^{-E/kT}$

Boltzmann distribution

$$\int_0^\infty P(v)dv = 1$$

$1 = \int d^3v\, P(\vec{v}) = \int 4\pi v^2 dv\, P(\vec{v})$

Average speed $$v_{\text{avg}} = \int_0^\infty vP(v)dv = \sqrt{\frac{8RT}{\pi M}}$$

$\frac{8}{\pi} = 2.\cdots$

rms speed $$(v^2)_{\text{avg}} = \int_0^\infty v^2 P(v)dv = \frac{3RT}{M} \rightarrow v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

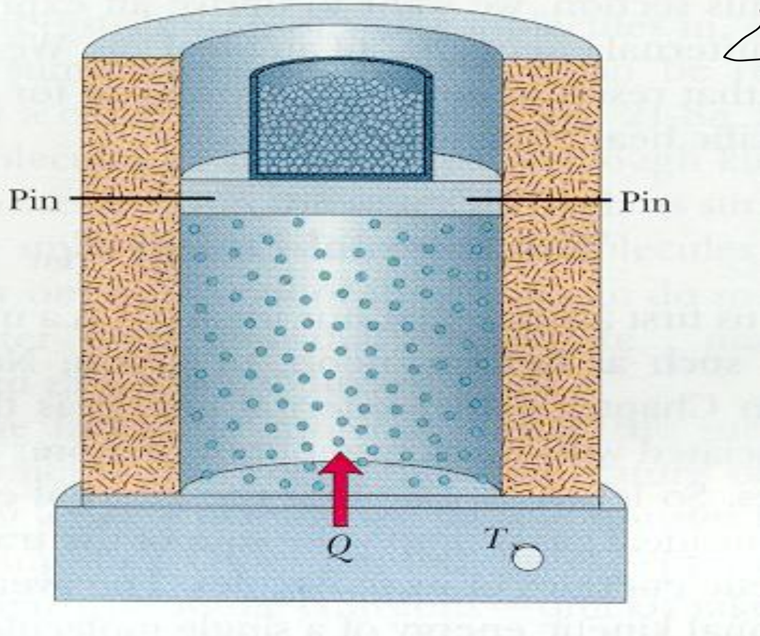
3

The most probable speed $$\frac{dP}{dv} = 0 \rightarrow v_P = \sqrt{\frac{2RT}{M}}$$

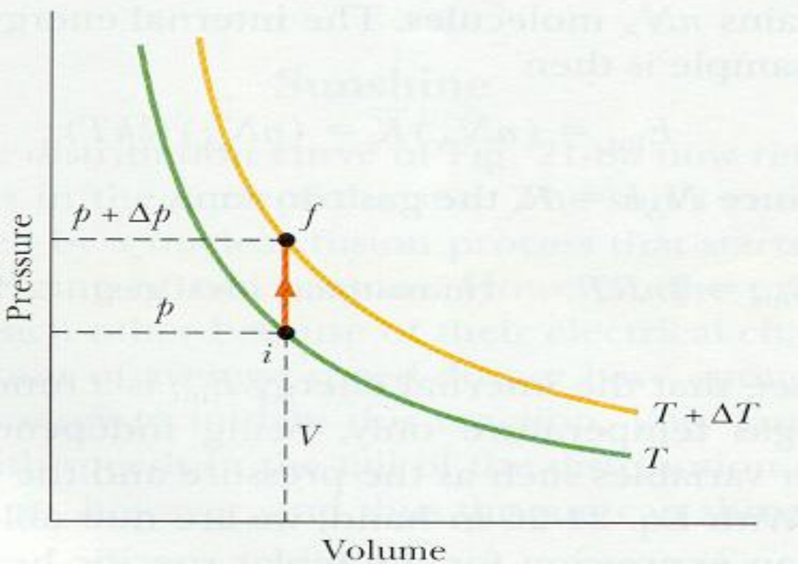
2

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

등적비열



(a)



(b)

$$\boxed{C_V = \frac{1}{n}\left(\frac{\Delta Q}{\Delta T}\right)_V}$$

$$E_{\text{int}} = nN_A K_{\text{avg}} = nN_A \frac{3}{2}kT = \frac{3}{2}nRT$$

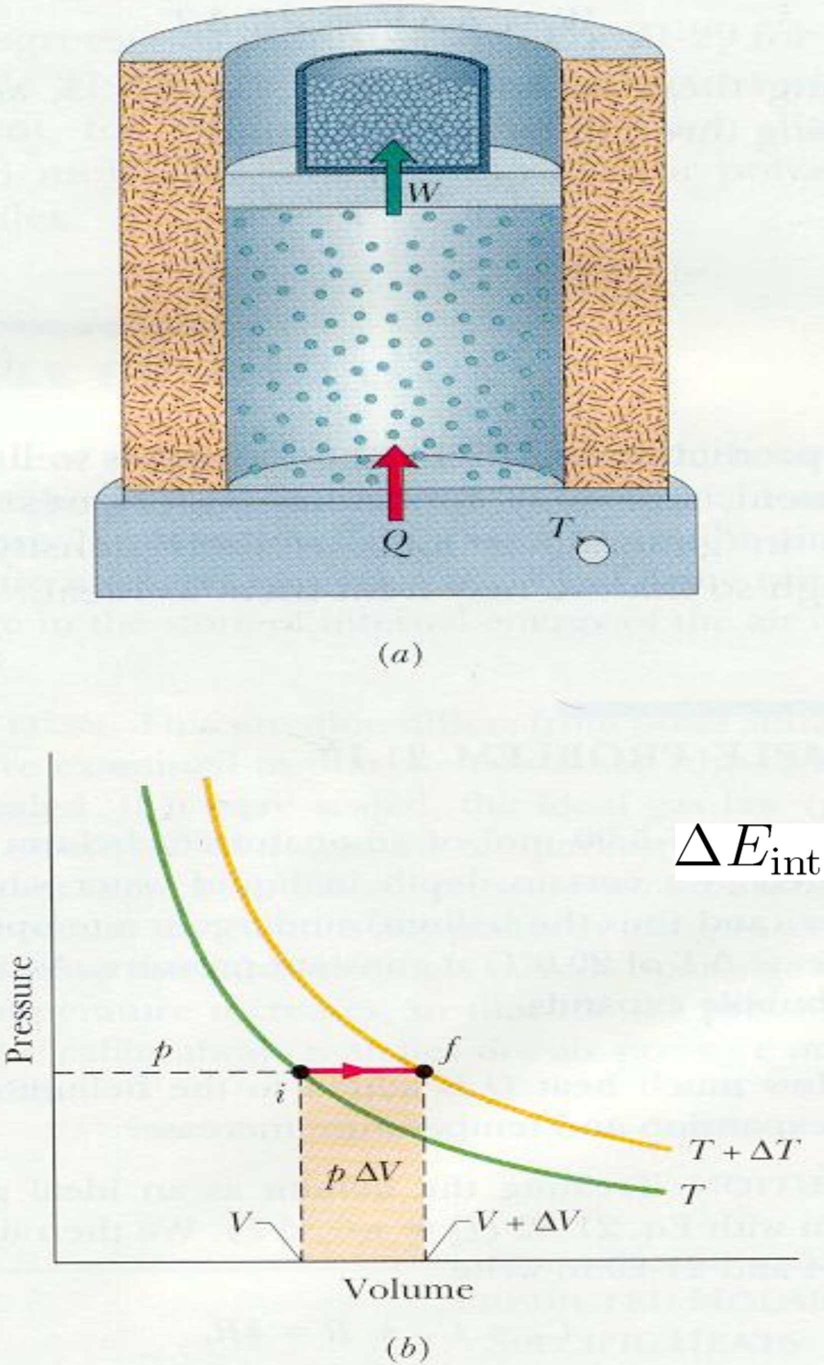
$$\Delta Q = nC_V \Delta T$$

$$\Delta E_{\text{int}} = nC_V \Delta T - W = nC_V \Delta T$$

$$= \frac{3}{2} nR\Delta T$$

$$\boxed{C_V = \frac{3}{2}R}$$

단원자 기체



등압비열

$$C_p = \frac{1}{n}\left(\frac{\Delta Q}{\Delta T}\right)_p$$

$$\Delta Q = nC_p\Delta T$$

$pV = nRT$

$\underline{p\Delta V = nR\Delta T}$

$$\Delta E_{\text{int}} = \Delta Q - \Delta W = \Delta Q - p\Delta V = \Delta Q - nR\Delta T$$

$= nC_V\Delta T$

$\Delta Q = n(C_V + R)\Delta T$

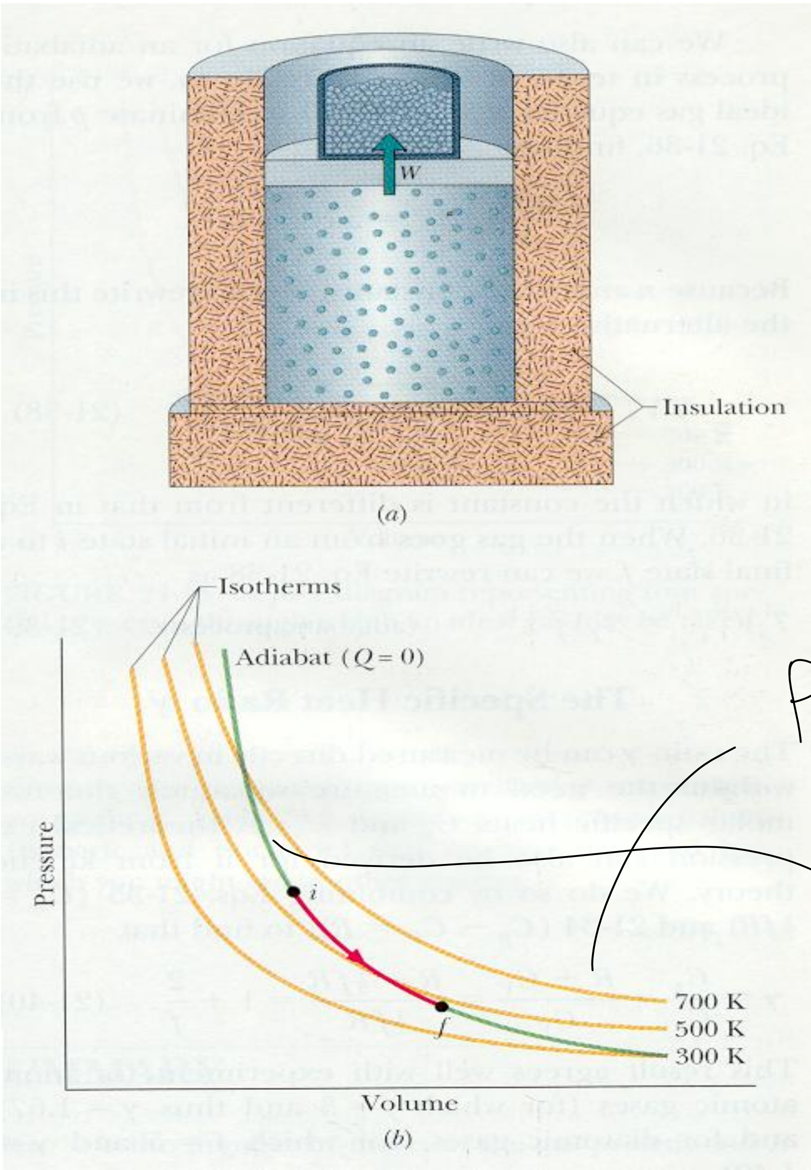
$$\boxed{C_p = C_V + R}$$

$C_p = \frac{1}{n}\left(\frac{\Delta Q}{\Delta T}\right)_p$

$= C_V + R$

Adiabatic expansion

$\Delta Q = \Delta E_{int} + \Delta W = 0$



$P \propto \frac{1}{V}$

$P \propto \frac{1}{V^{\gamma}}$

$$dE_{\text{int}} = nC_V dT = Q - pdV = -pdV$$

$$ndT = -\frac{p}{C_V}dV$$

$$pV = nRT \longrightarrow pdV + V\,dp = nRdT = n(C_p - C_V)dT$$

$$(p+dp)(V+dV) = nR(T+dT)$$

$$ndT = \frac{pdV + V\,dp}{C_p - C_V}$$

$$-\frac{p}{C_V}dV = \frac{pdV+Vdp}{C_p-C_V}$$

$$C_p\frac{pdV}{V} + C_V\frac{dp}{p} = 0$$

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

$$\boxed{\frac{dp}{p} + \frac{C_p}{C_V}\frac{dV}{V} = 0}$$

$$\ln p + \gamma \ln V = \text{constant}$$

$$-pdV(C_p - C_V) = C_V(pdV + Vdp)$$

$$pV^\gamma = \text{constant}, \quad \gamma = \frac{C_p}{C_V}$$

$$p = \frac{\text{const}}{V}T$$

$$V = \frac{T}{p}\text{const}$$

$$PV^\gamma = \text{const} = TV^{\gamma-1} = p\left(\frac{T}{p}\right)^\gamma = T^\gamma p^{1-\gamma}$$

Degrees of freedom and molar heat

$K_{av} = \frac{3}{2}kT$

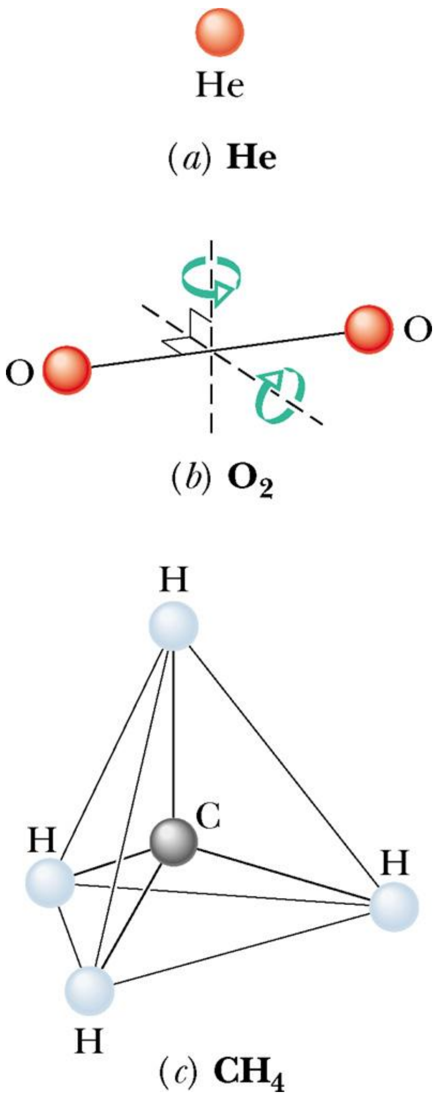
에너지 등분배 법칙 (energy equipartition theorem):

분자당 자유도 당 $\frac{1}{2}kT$

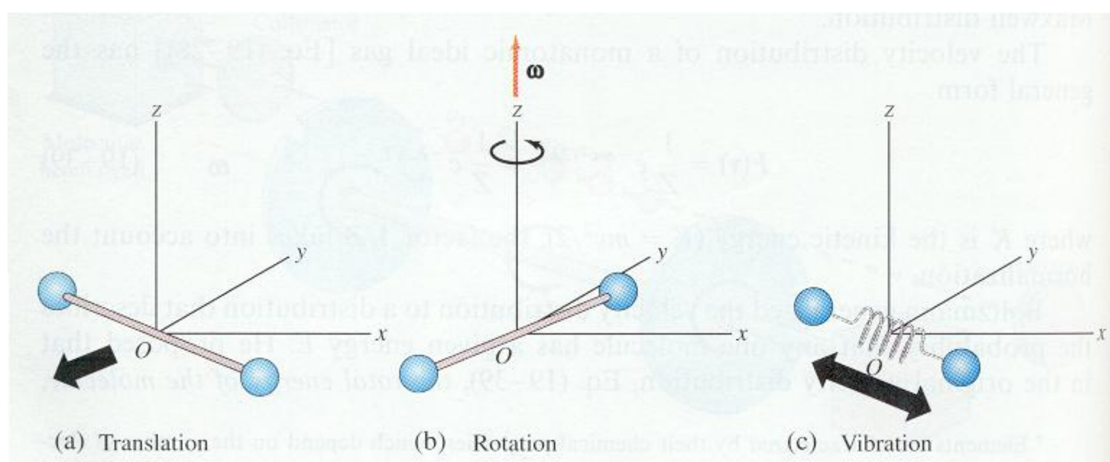
몰 당 $\frac{1}{2}RT$

의 에너지를 갖는다.

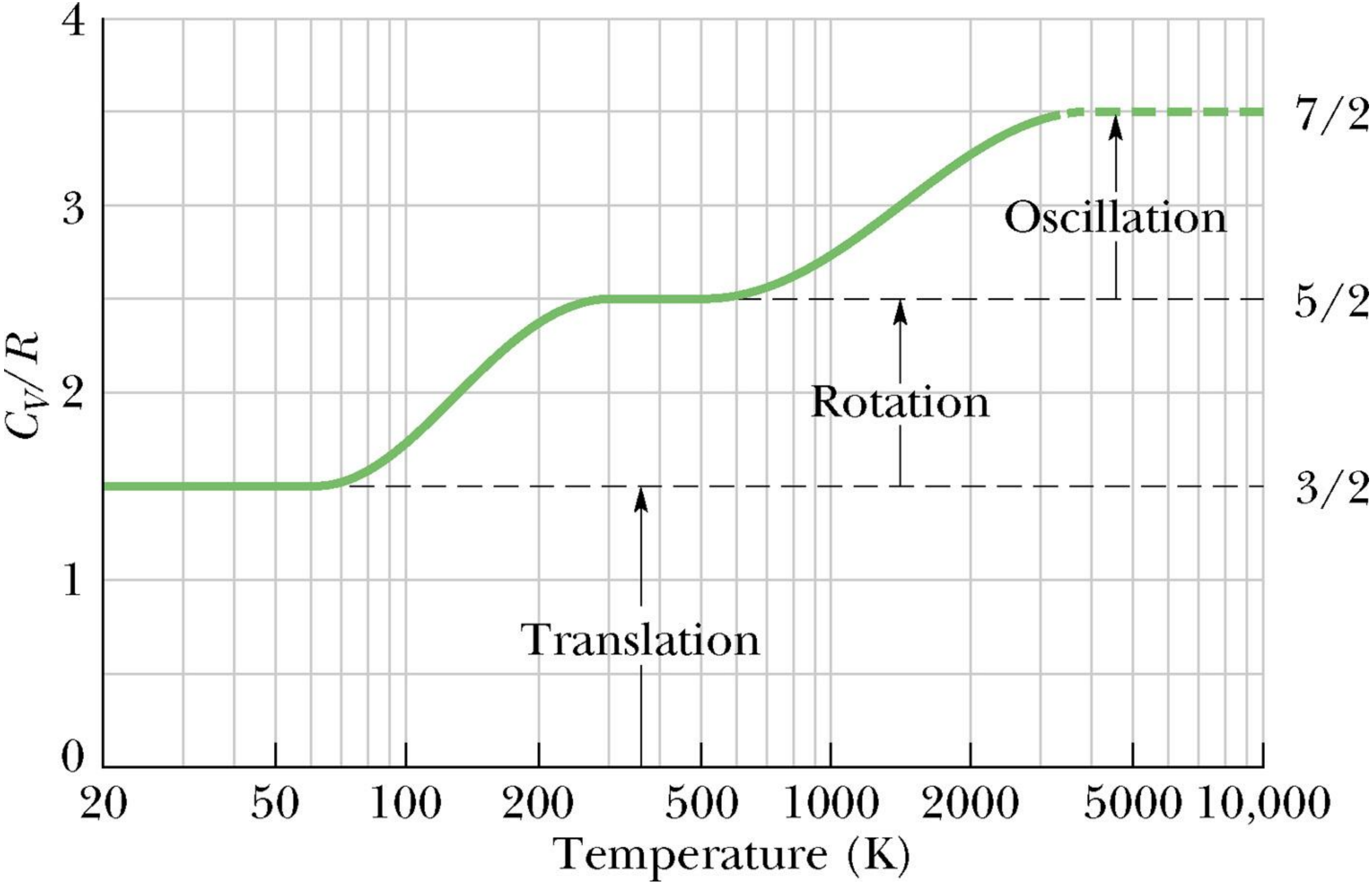
$e^{-E/kT}$



(a) He (b) O_2 (c) CH_4



(a) Translation (b) Rotation (c) Vibration

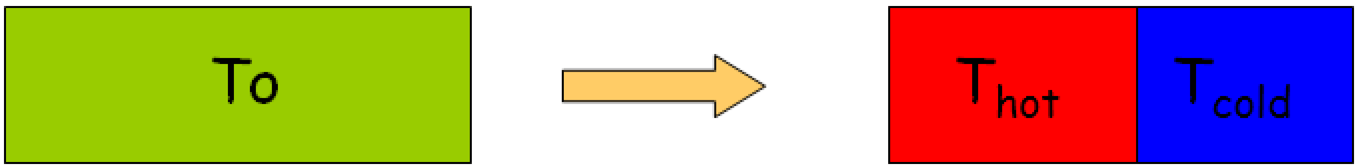


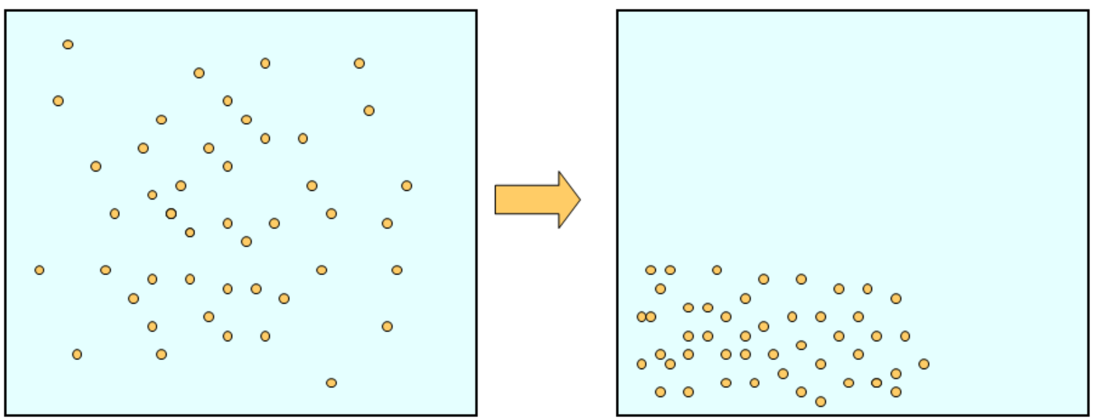
4
3
2
1
0
C_V/R
7/2
5/2
3/2
Oscillation
Rotation
Translation
20
50
100
200
500
1000
2000
5000
10,000
Temperature (K)

Ch. 20 The 2nd law of thermodynamics

Irreversible processes and entropy

다음과 같은 과정은 결코 자발적으로 일어나지 않는다.





$$F = ma = m\frac{d^2x}{dt^2}$$

닫힌 계에서 비가역과정이 일어날 때 엔트로피 S는 감소하지 않는다.

The 2nd law of thermodynamics

1) 계의 다른 변화 없이, 열이 온도가 낮은 곳에서 높은 곳으로 열이 이동할 수는 없다. (완벽한 냉장고는 없다.)

2) 계의 다른 변화 없이, 열을 몽땅 일로 바꾸는 것은 불가능하다. (완벽한 엔진은 없다.) 모두

3) 고립계의 열역학적 과정에서 엔트로피는 감소할 수 없다.

entropy

$dS = \frac{dQ}{T}$

$$\Delta S = S_f - S_i = \int_i^f \frac{dQ}{T}$$

자유팽창의 경우 – 등온과정을 고려

$$\begin{aligned} \Delta S &= S_f - S_i = \frac{1}{T}\int_i^f dQ = \frac{Q}{T} \\ &= \frac{nRT}{T}\ln\frac{V_f}{V_i} = nR\ln\frac{V_f}{V_i} \end{aligned}$$