18. Thermal Properties of Matter

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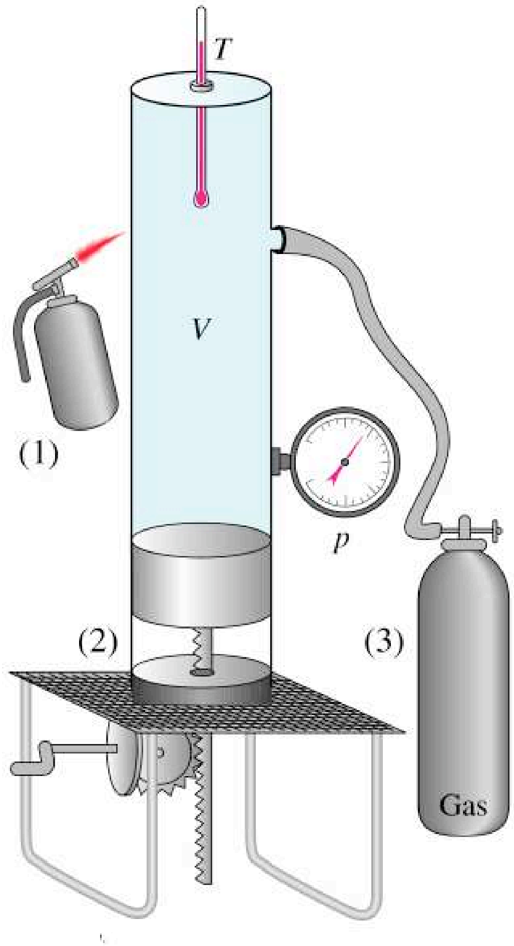


Ástandsbreytur (gas): p, V, T, n

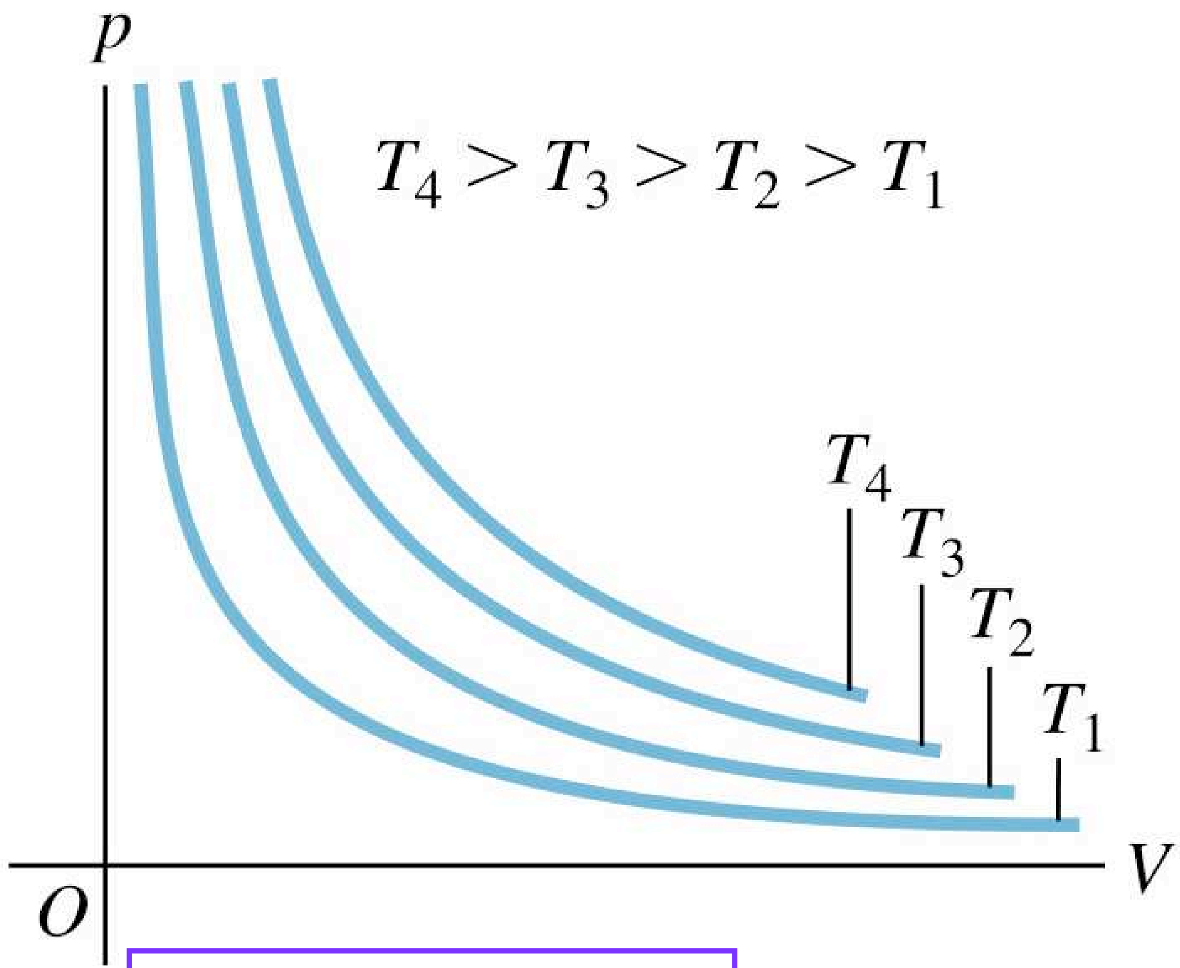
Ástandsjafna, fast efni:

$$V = V_0 \left[1 + \beta \left(T - T_0\right) - k\left(p - p_0\right)\right]$$

β: rúmþanstuðull (coefficient of volume expansion)

k: þjappanleiki (compressibility)

$k=1/B$ rýmisfjaðurstuðull (bulk modulus)



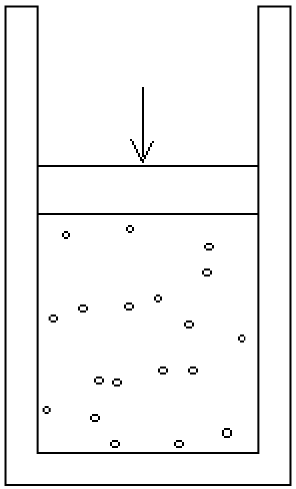
Kjörgas: $pV = nRT$

Jafnhitalínur (isotherms)

R = 8,314 J/mol·K (gasfasti)

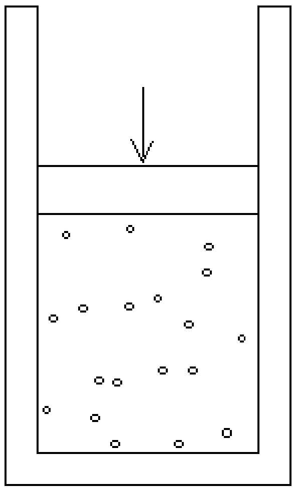
Kjörgas er í geymi með hreyfanlegu loki.
Rúmmálið er V_0, $p_0 = 1\ atm$, $T_0 = 300$ K.
Nú er lokinu ýtt niður þannig að rúmmálið er á eftir $V_0/2$, á sama tíma er hitastigið lækkað niður í 150 K.

Hver verður þrýstingurinn?



1. 1 atm
2. 2 atm
3. 4 atm
4. 0,5 atm

Kjörgas er í geymi með hreyfanlegu loki.
Rúmmálið er V_0, $p_0 = 1\ atm$, $T_0 = 300$ K.
Nú er lokinu ýtt niður þannig að rúmmálið er á eftir $V_0/2$, á sama tíma er hitastigið lækkað niður í 150 K.
Hver verður þrýstingurinn?

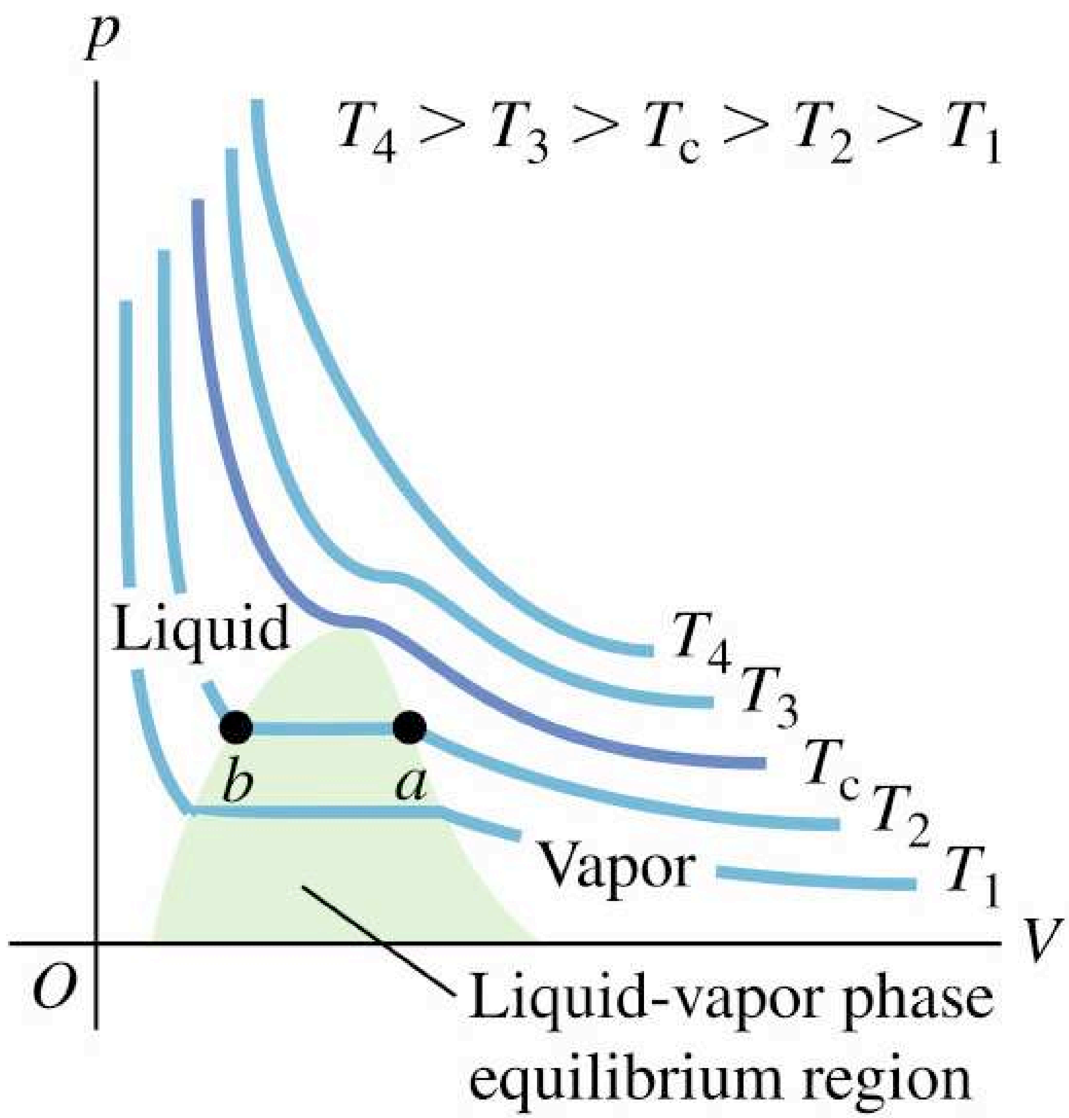


1. **1 atm**
2. 2 atm
3. 4 atm
4. 0,5 atm

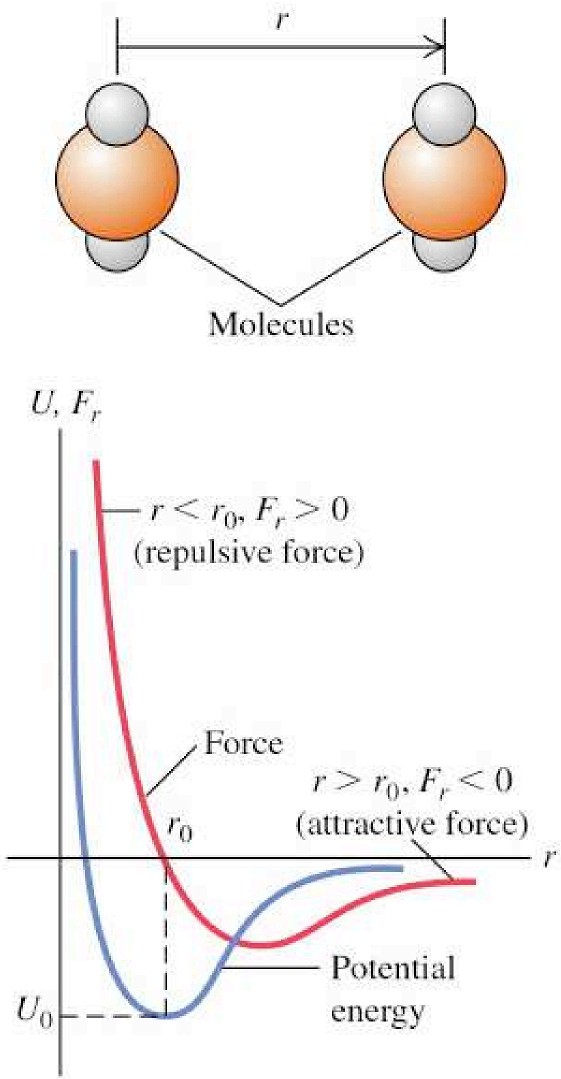
$pV = nRT$!

Gasjafna van der Waals:

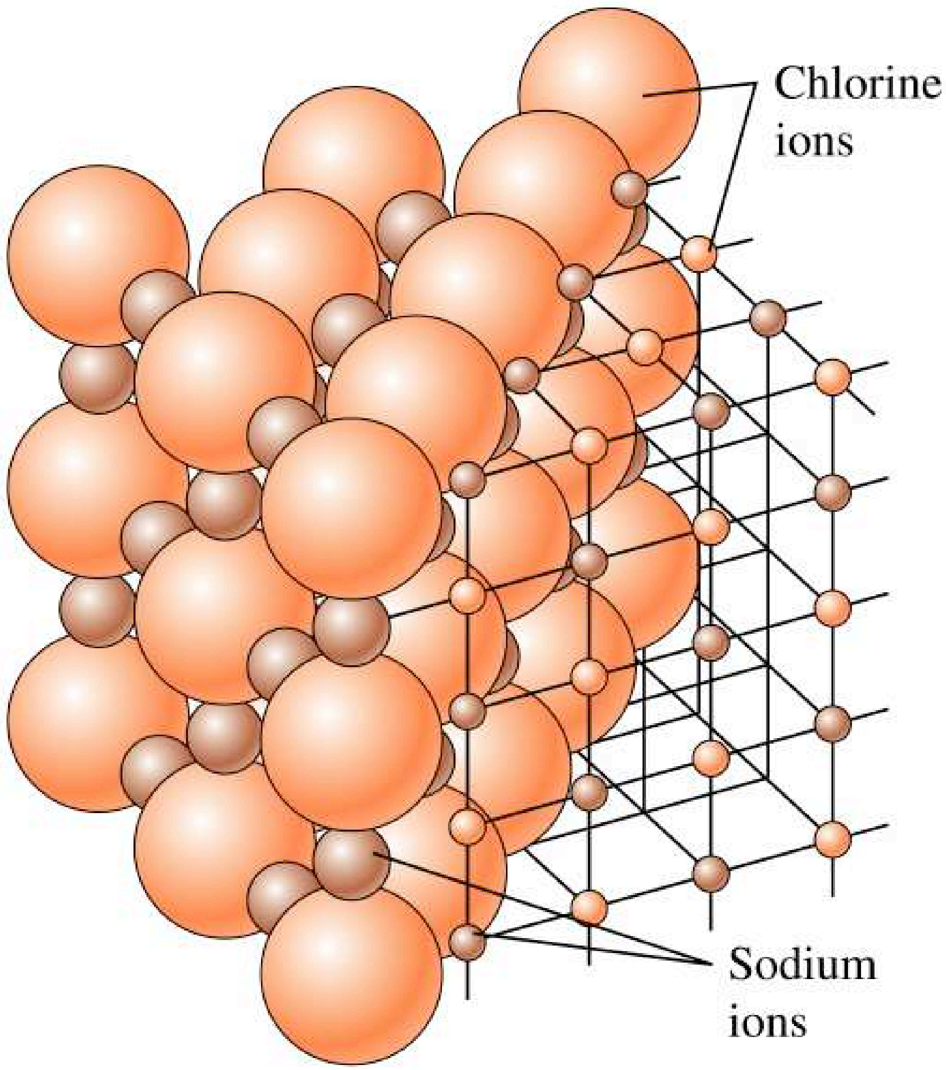
$$\boxed{(p + an^2/V^2)(V - nb) = nRT}$$



p
$T_4 > T_3 > T_c > T_2 > T_1$
Liquid
b
a
T_4
T_3
T_c
T_2
T_1
Vapor
V
O
Liquid-vapor phase
equilibrium region



Mættisgryfja (potential well)   Vökvi



Föst efni: Saltkristall sem dæmi,

jónirnar sveiflast fram og tilbaka á sama stað

$$M = N_\mathrm{A}\, m$$

m: massi sameindar

M: mólmassi

$N_\mathrm{A} = 6{,}02 \cdot 10^{23}$ *sameindir*: Avogadros tala

$6{,}02 \cdot 10^{23}$

Fæddur 9/8 1776 í Turin á Norður-Ítalíu

Dáinn 9/7 1856 (79 ára)

Periodic Table of the Elements

New / Original

- Alkali metals
- Alkaline earth metals
- Transition metals
- Lanthanide series
- Actinide series
- Poor metals
- Nonmetals
- Noble gases

C Solid · Br Liquid · H Gas · Tc Synthetic

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H Hydrogen 1.00794																	2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.8457	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.409	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
6	55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 to 71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89 to 103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium

Atomic masses in parentheses are those of the most stable or common isotope.

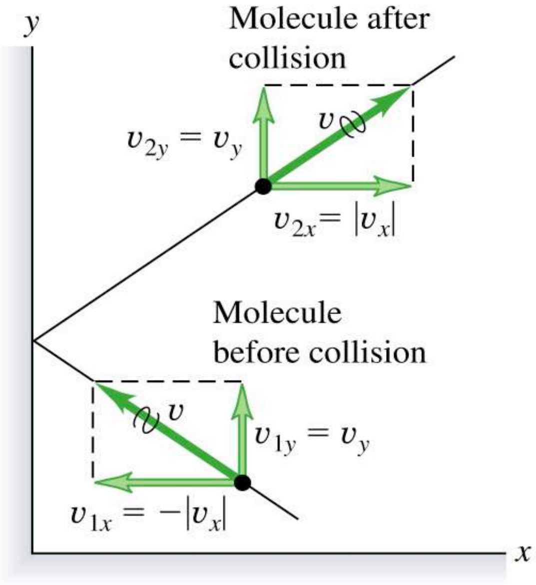
57 La Lanthanum 138.9055	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA		
						He Helium 4.002602	
	5 B Boron 10.811 2 3	6 C Carbon 12.0107 2 4	7 N Nitrogen 14.00674 2 5	8 O Oxygen 15.9994 2 6	9 F Fluorine 18.9984032 2 7	10 Ne Neon 20.1797 2 8	K L
	13 Al Aluminum 26.981538 2 8 3	14 Si Silicon 28.0855 2 8 4	15 P Phosphorus 30.973761 2 8 5	16 S Sulfur 32.066 2 8 6	17 Cl Chlorine 35.453 2 8 7	18 Ar Argon 39.948 2 8 8	K L M
2 8 18 2	31 Ga Gallium 69.723 2 8 18 3	32 Ge Germanium 72.64 2 8 18 4	33 As Arsenic 74.92160 2 8 18 5	34 Se Selenium 78.96 2 8 18 6	35 Br Bromine 79.904 2 8 18 7	36 Kr Krypton 83.798 2 8 18 8	K L M N

Mastering Physics:

8.1 Characteristics of a Gas

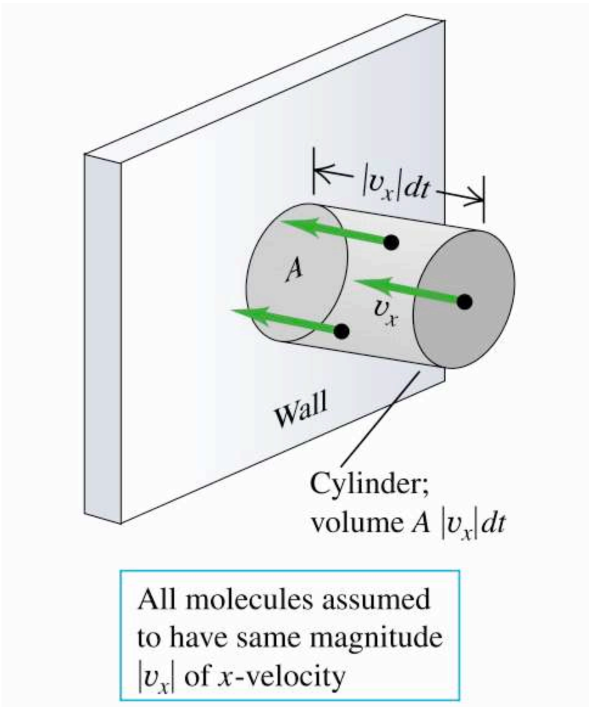


Kinetic-Molecular Model of an Ideal Gas

(Kvikfræði gasa)

Árekstur:

Breyting skriðþunga: $2m|v_x|$



Fjöldi sameinda sem rekast á vegginn:

$\frac{1}{2}(N/V)(A\,|v_x|\,dt)$

Breyting skriðþunga:

$dP_x = \frac{1}{2}(N/V)(A\,|v_x|)\,(2m|v_x|)\,dt$

Kraftur (2. lögmál Newtons):

$dP_x/dt = NAmv_x^2/V$

$p = F/A = Nmv_x^2/V$

$pV = 2/3\,N\,[\frac{1}{2}m(v^2)_{av}] = 2/3\,K_{tr}$

Útreikningur borinn saman við tilraun:

$pV = 2/3\ K_{tr}$

$pV = nRT$

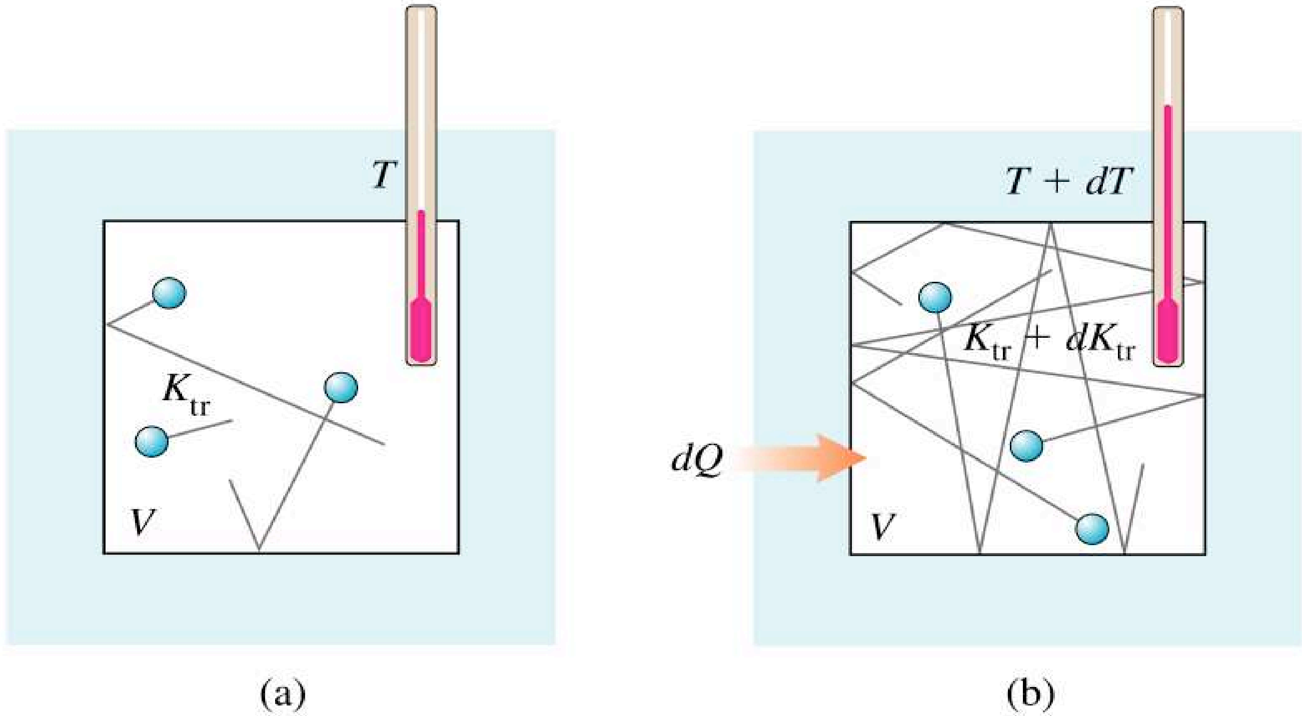
Þar af leiðir:

$K_{tr} = 3/2\ nRT$

$\frac{1}{2}m(v^2)_{av} = 3/2\ kT$

$(k = R/N_A = 1{,}381 \cdot 10^{-23}\ \mathrm{J/sameind \cdot K})$

k : Boltzmann fasti



Tvær fyrri niðurstöður bornar saman:

$$dK_{tr} = 3/2\ nR\ dT$$

$$dQ = n\ C_v\ dT$$

Þar af leiðir:

$$C_v = 3/2\ R$$

Table 18.1 Molar Heat Capacities of Gases

Type of Gas	Gas	C_V (J/mol·K)
Monatomic	He	12.47
	Ar	12.47
Diatomic	H_2	20.42
	N_2	20.76
	O_2	21.10
	CO	20.85
Polyatomic	CO_2	28.46
	SO_2	31.39
	H_2S	25.95

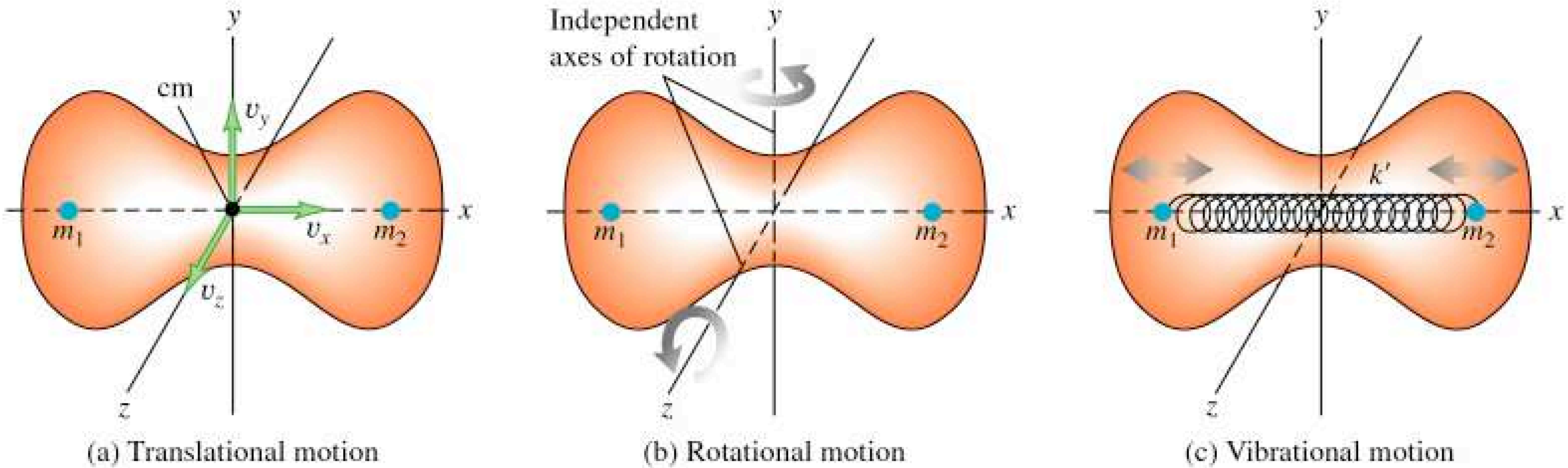
$$C_V = 3/2\, R = 12{,}47 \text{ J/mol·K}$$

Mól-varmarýmd við fast rúmmál

Jafnskipting orkunnar (equipartition of energy):

$\frac{1}{2}\,kT$ á hverja svigrúmsvídd (degree of freedom)!

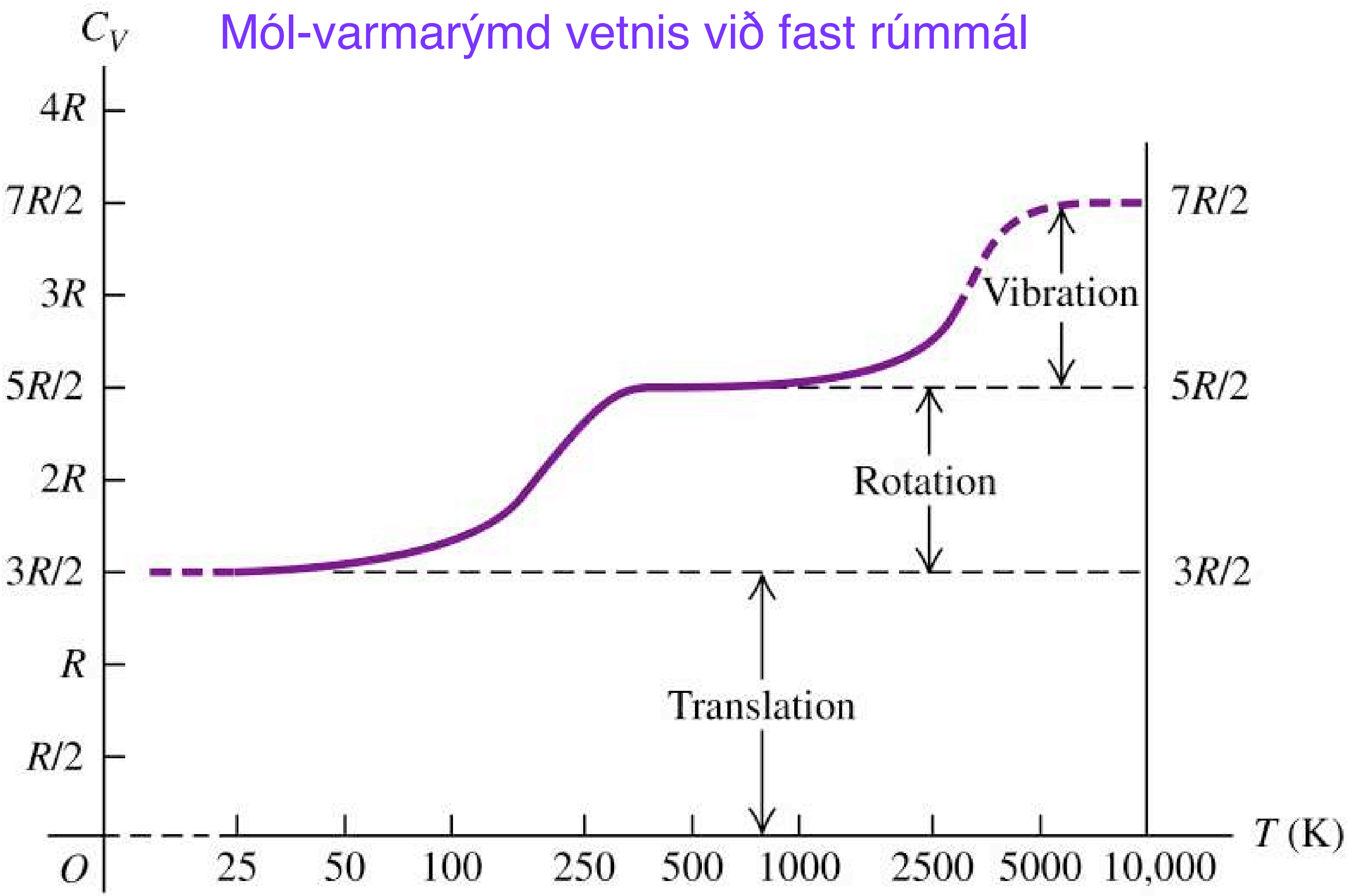
Fleiri svigrúmsvíddir, frítölur
(degrees of freedom)!



Hliðrun (færsla) Snúningur Sveifla

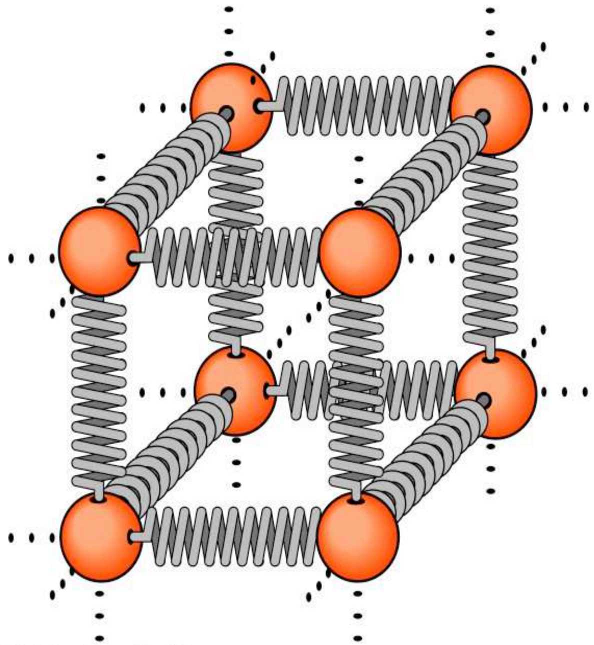
$C_v = 5/2\ R$ fyrir tveggja frumeinda sameind

Mól-varmarýmd vetnis við fast rúmmál



Skammtafræði: Orka tekin upp í skömmtum.

Stór skammtaskref fyrir sveiflu; þess vegna er sveifla flestra sameinda í grunnástandi við venjuleg hitastig og það breytist ekki fyrr en hitastigið hækkar verulega.



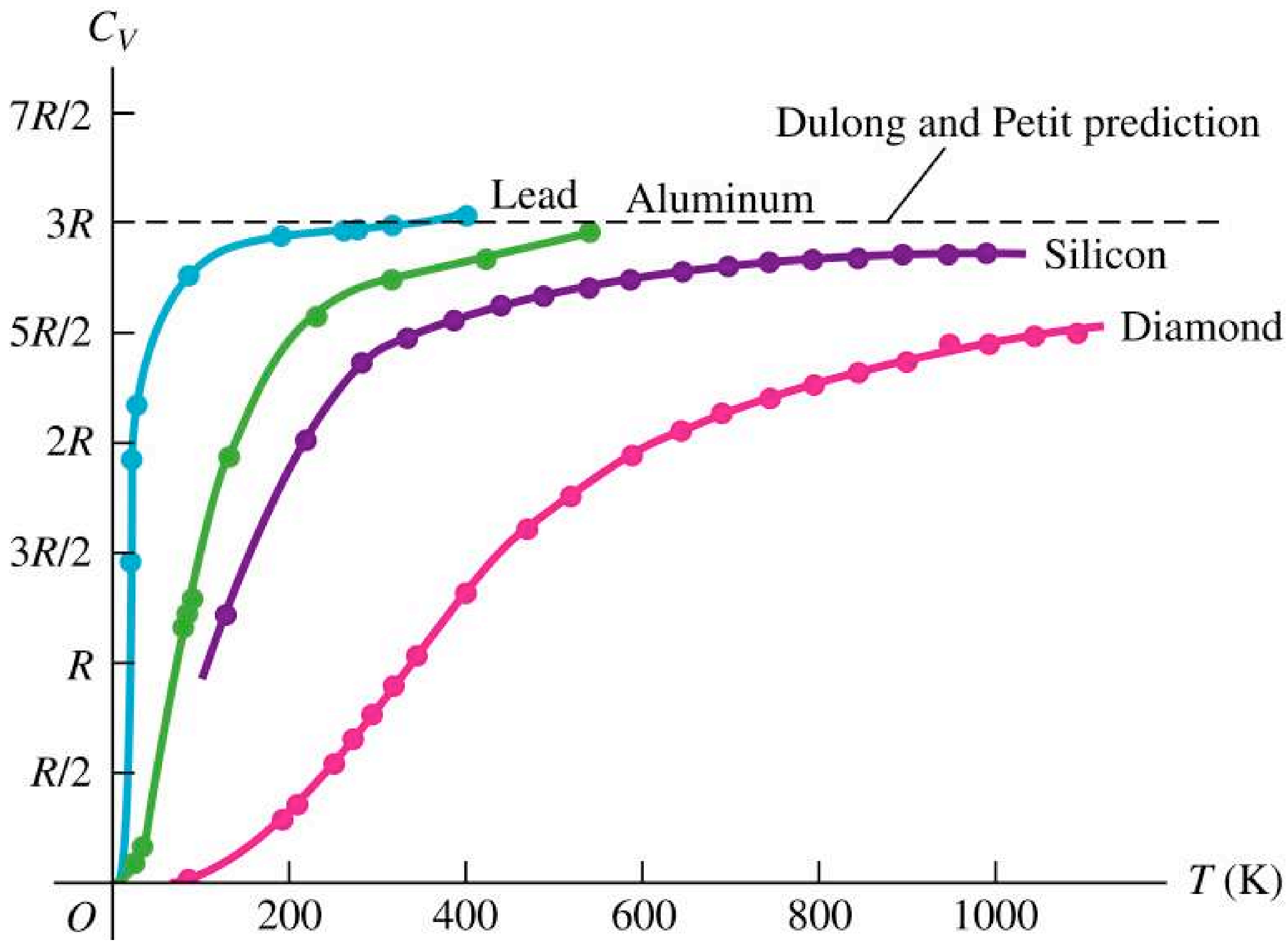
Varmarýmd (eðlisvarmi) fast efnis:

3 sveifluvíddir hver með sína stöðuorku.

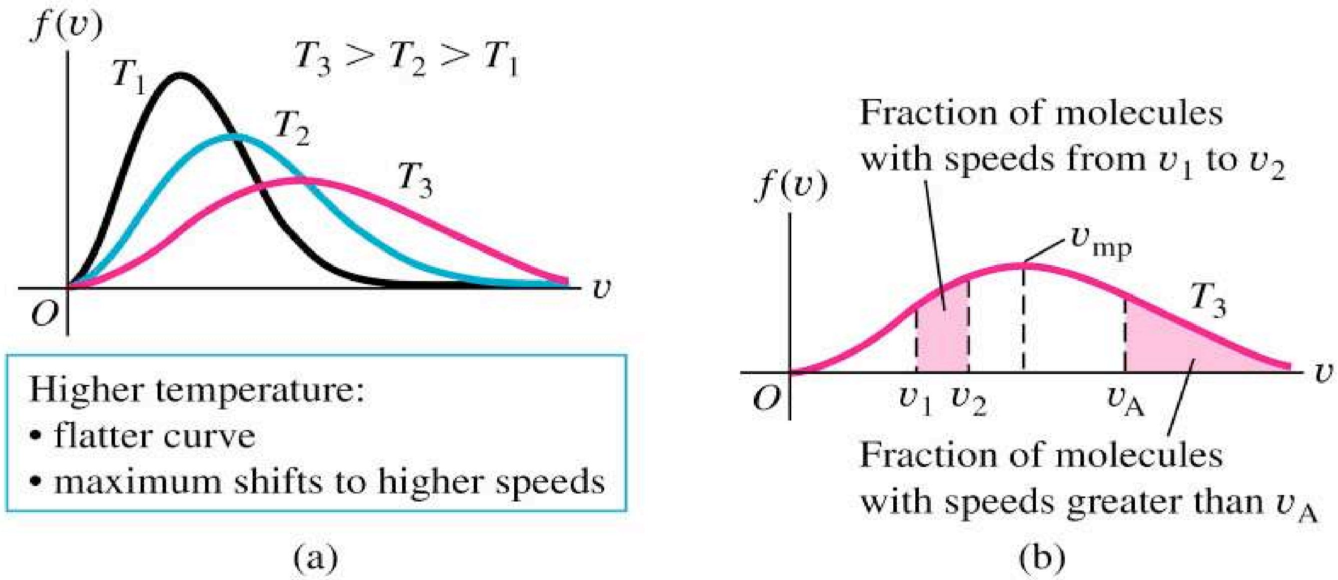
Í allt 6 frítölur:

$E_{tot} = N \cdot 6 \cdot \frac{1}{2} kT \quad \rightarrow \quad C_V = 3R = 24{,}9 \text{ mol/K}$

Regla Dulongs og Petits!



C_V
7R/2
3R
5R/2
2R
3R/2
R
R/2
O
Dulong and Petit prediction
Lead
Aluminum
Silicon
Diamond
200
400
600
800
1000
T (K)



Hraðadreifing sameinda:

$$f(v) = 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2kT}$$

(Maxwell-Boltzmann dreifing)

[8.2 Maxwell-Boltzmann Distribution--Conceptual Analysis]()

Dæmi 18.8 á síðu 625:

(loftsameindir við herbergishita):

Mean free path, meðalspölur milli árekstra: $5{,}8 \cdot 10^{-8}$ m

Mean free time, meðaltími milli árekstra: $1{,}2 \cdot 10^{-10}$ s

10^{10} árekstrar á sekúndu!!

Hraðadreifing sameinda:

$$f\left(v\right) = 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2kT}$$

(Maxwell-Boltzmann dreifing)

$$\mathrm{E} = mv^2/2$$

$$f\left(\mathrm{E}\right) = \frac{8\pi}{m}\left(\frac{m}{2\pi kT}\right)^{3/2} \mathrm{E}e^{-\mathrm{E}/kT}$$

(Activation energy - Espunarorka)

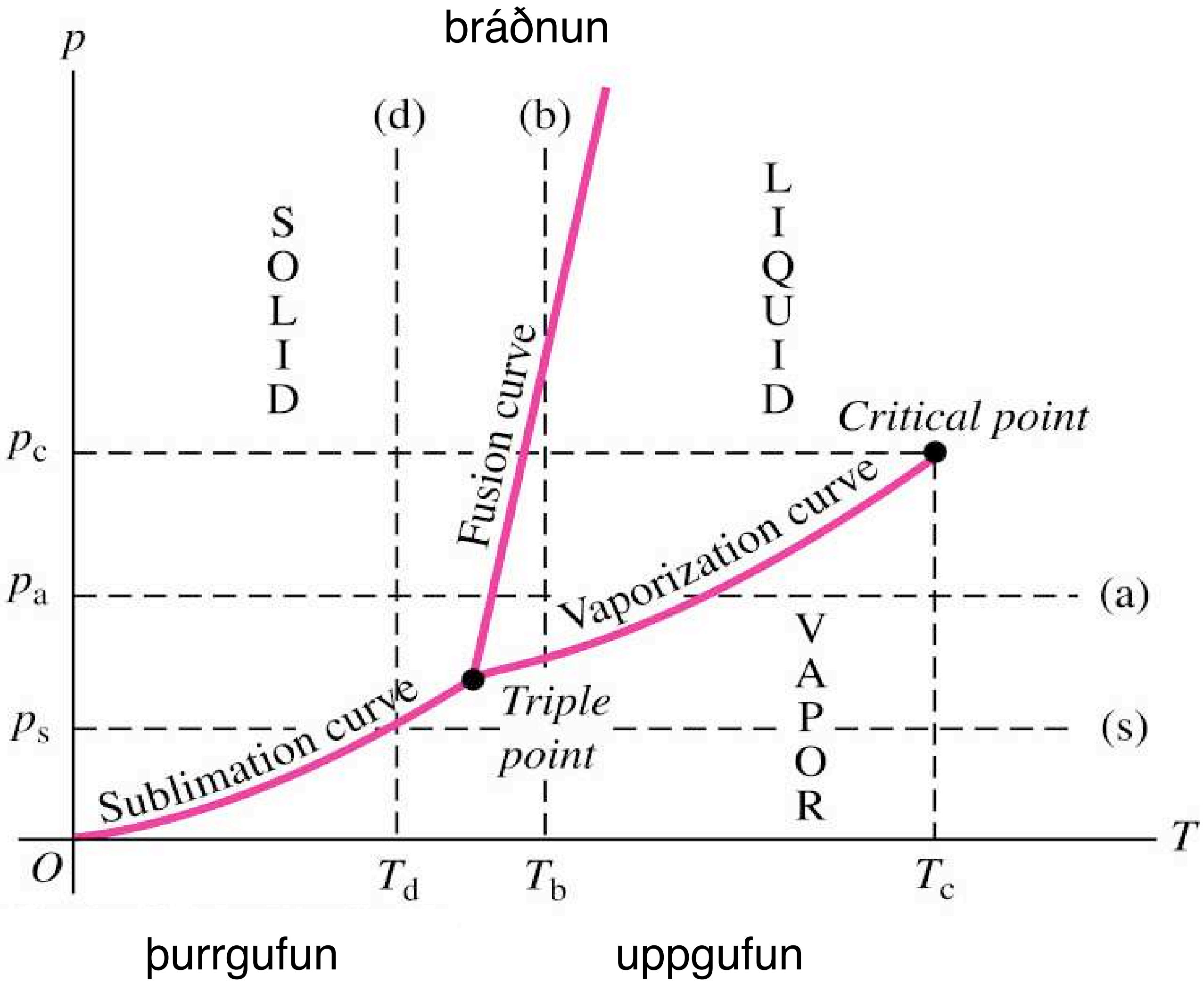
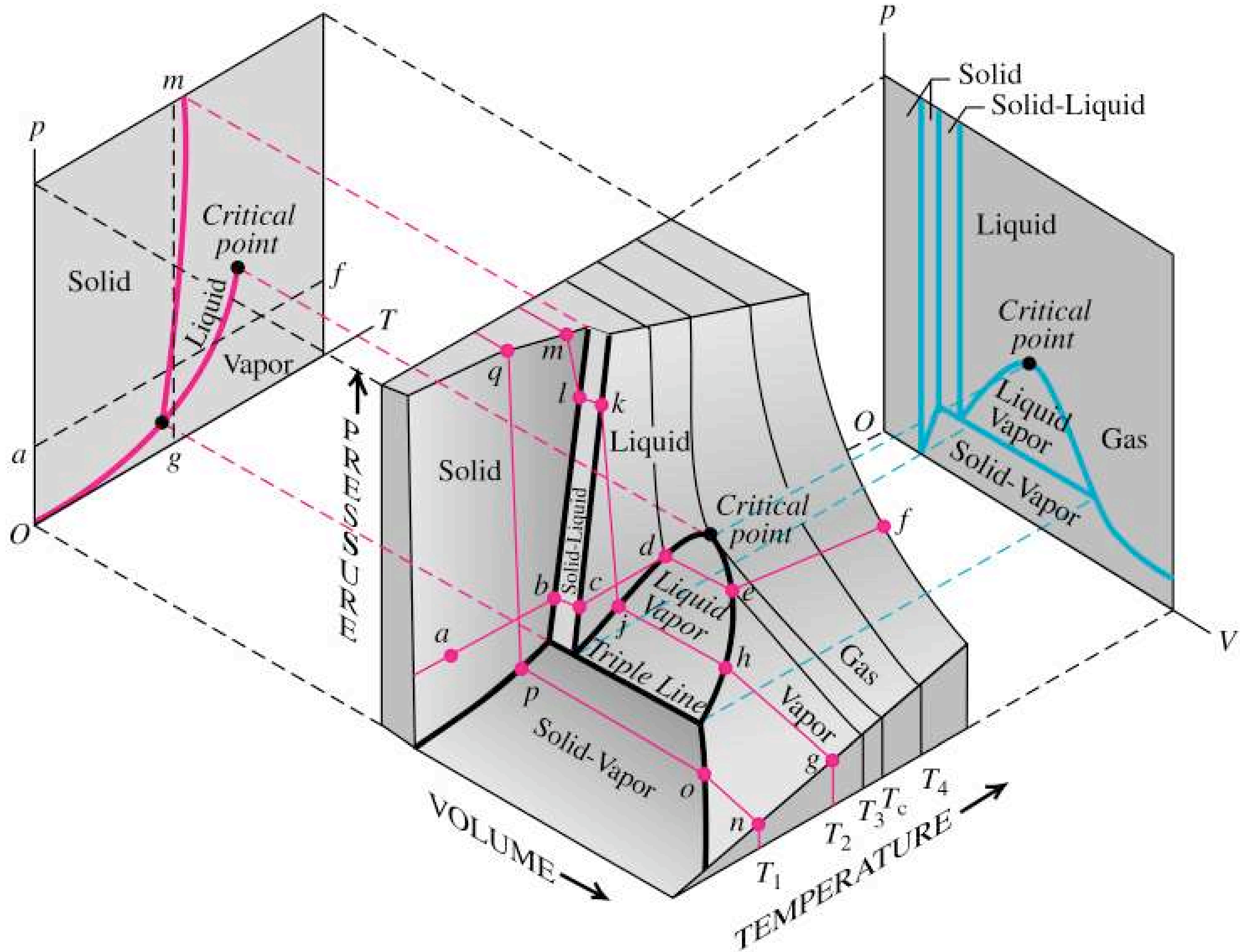

bráðnun
p
(d)
(b)
SOLID
LIQUID
Fusion curve
Critical point
p_c
Vaporization curve
p_a
(a)
VAPOR
Triple point
p_s
(s)
Sublimation curve
O
T_d
T_b
T_c
T
þurrgufun
uppgufun

Table 18.3 Triple-Point Data

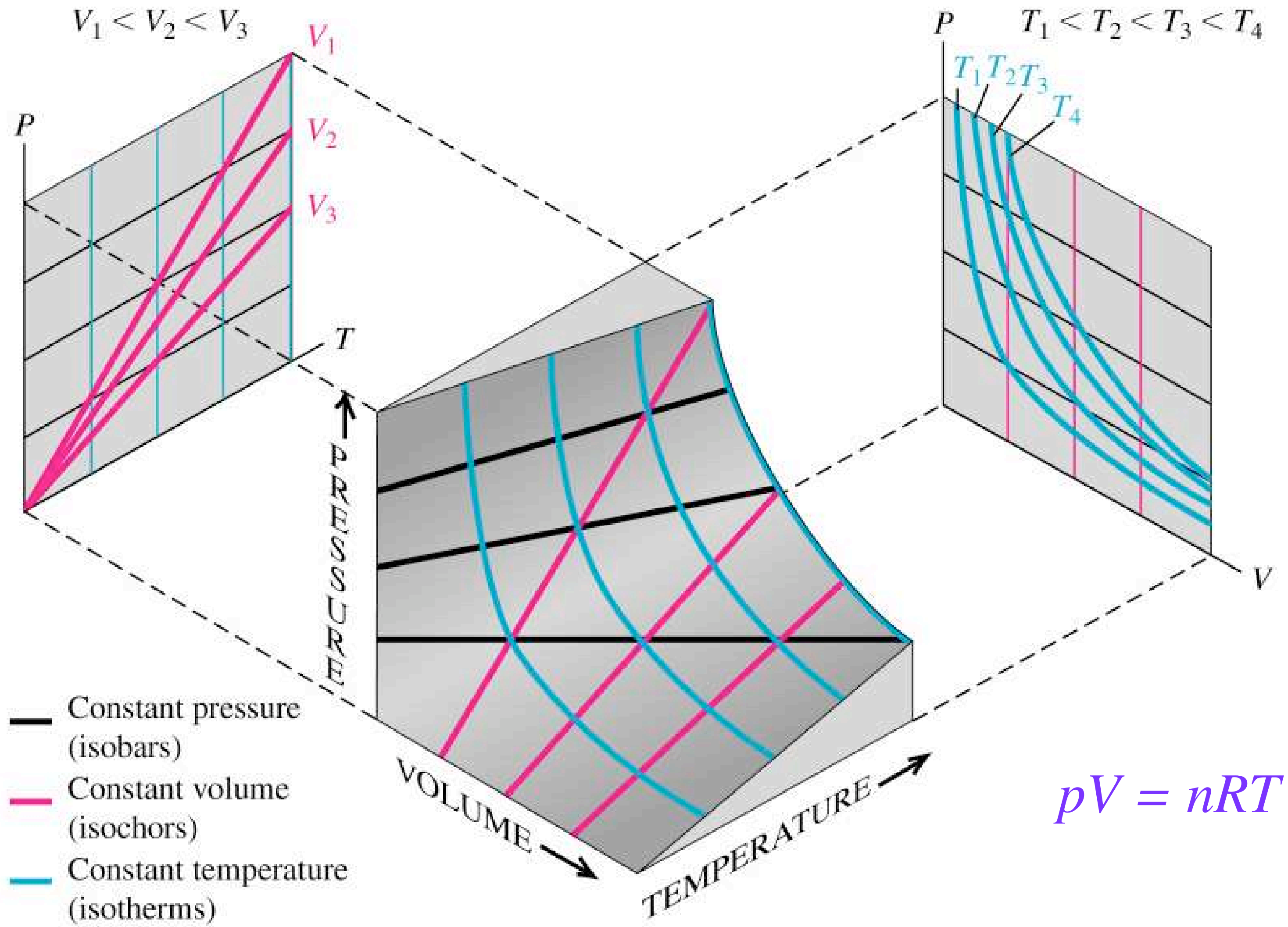
Substance	Temperature (K)	Pressure (Pa)
Hydrogen	13.80	0.0704×10^5
Deuterium	18.63	0.171×10^5
Neon	24.56	0.432×10^5
Nitrogen	63.18	0.125×10^5
Oxygen	54.36	0.00152×10^5
Ammonia	195.40	0.0607×10^5
Carbon dioxide	216.55	5.17×10^5
Sulfur dioxide	197.68	0.00167×10^5
Water	273.16	0.00610×10^5

Kritískur punktur fyrir vatn:

647,4 K	$221{,}2 \cdot 10^5$ Pa
374,2 °C	218 atm



p
m
Critical point
Solid
Liquid
Vapor
f
T
a
g
O
PRESSURE
Solid
q
m
l
k
Liquid
Solid-Liquid
Critical point
d
b
c
e
Liquid Vapor
j
a
h
Triple Line
p
Gas
Vapor
Solid-Vapor
g
o
n
VOLUME
T_1
T_2
T_3
T_c
T_4
TEMPERATURE
f
p
Solid
Solid-Liquid
Liquid
Critical point
Liquid Vapor
O
Gas
Solid-Vapor
V

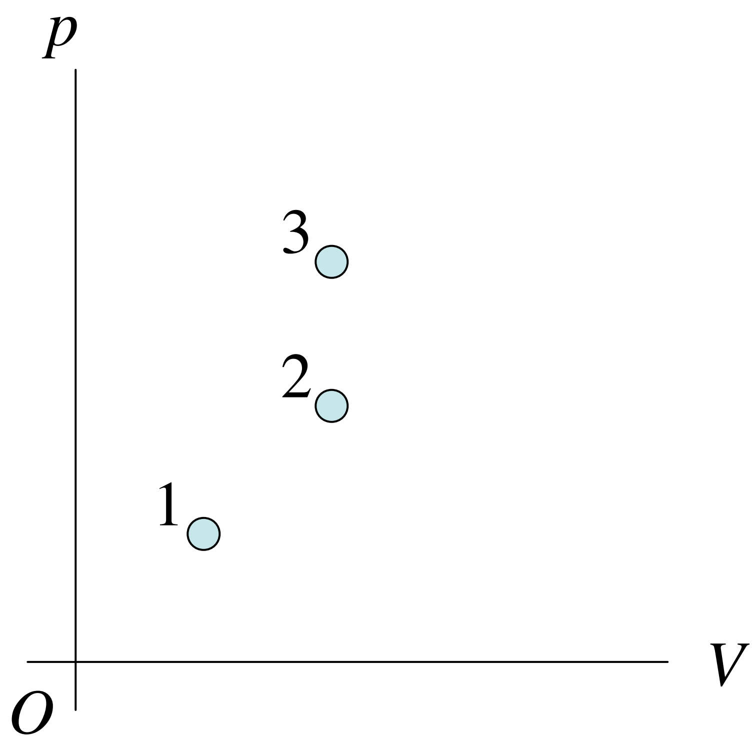


$pV = nRT$

Kjörgas: jafnþrýstilínur, jafnrýmislínur, jafnhitalínur

This pV–diagram shows three possible states of a certain amount of an ideal gas.

Which state is at the *highest* temperature?



1) state #1

2) state #2

3) state #3

4) Two of these are tied for highest temperature.

5) All three of these are at the same temperature.

This *pV*–diagram shows three possible states of a certain amount of an ideal gas.

Which state is at the *highest* temperature?

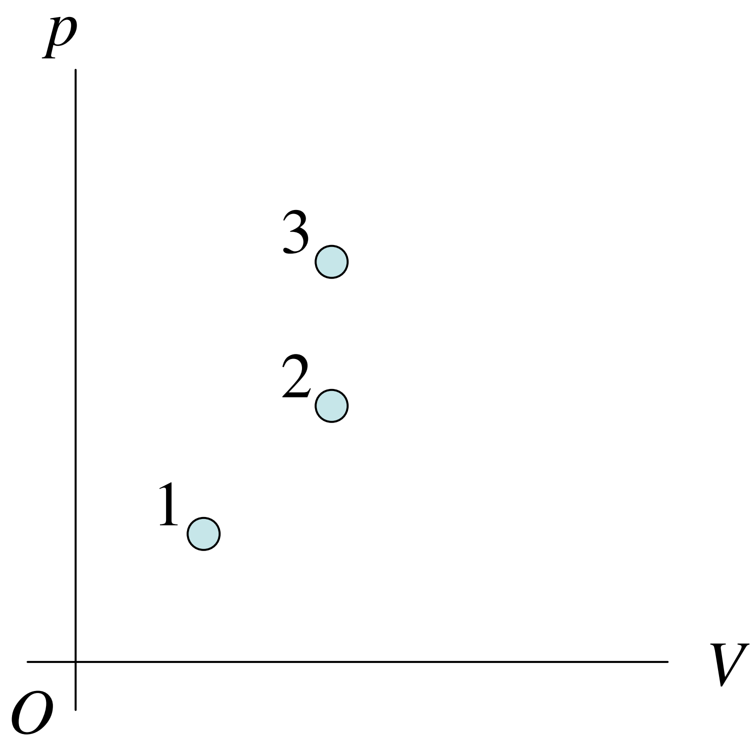
1) state #1

2) state #2

3) state #3

4) Two of these are tied for highest temperature.

5) All three of these are at the same temperature.



You have a quantity of ideal gas in a cylinder with rigid walls that prevent the gas from expanding or contracting. If you double the rms speed of molecules in the gas, the gas pressure

1) increases by a factor of 16.

2) increases by a factor of 4.

3) increases by a factor of 2.

4) increases by a factor of $2^{1/2}$.

You have a quantity of ideal gas in a cylinder with rigid walls that prevent the gas from expanding or contracting. If you double the rms speed of molecules in the gas, the gas pressure

1) increases by a factor of 16.

2) increases by a factor of 4.

3) increases by a factor of 2.

4) increases by a factor of $2^{1/2}$.

You have 1.00 mol of an ideal monatomic gas and 1.00 mol of an ideal diatomic gas whose molecules can rotate. Initially both gases are at room temperature. If the same amount of heat flows into each gas, which gas will undergo the greatest increase in temperature?

1) the monatomic gas

2) the diatomic gas

3) Both will undergo the same temperature change.

4) The answer depends on the molar masses of the gases.

You have 1.00 mol of an ideal monatomic gas and 1.00 mol of an ideal diatomic gas whose molecules can rotate. Initially both gases are at room temperature. If the same amount of heat flows into each gas, which gas will undergo the greatest increase in temperature?

1) the monatomic gas

2) the diatomic gas

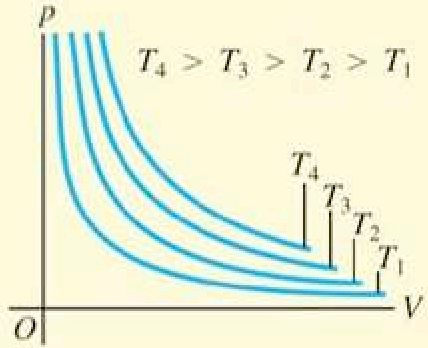
3) Both will undergo the same temperature change.

4) The answer depends on the molar masses of the gases.

Equations of state: The pressure p, volume V, and absolute temperature T of a given quantity of a substance are called state variables. They are related by an equation of state. This relationship pertains only to equilibrium states, in which p and T are uniform throughout the system. The ideal-gas equation of state relates p, V, T, and the number of moles n through a constant R that is the same for all gases.
(See Examples 18.1–18.4.)

$$pV = nRT \quad (18.3)$$

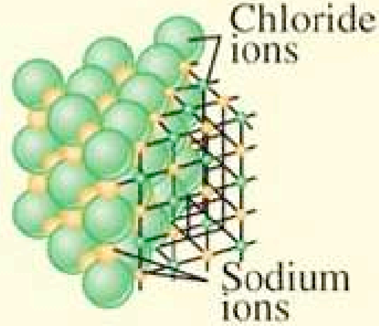
A pV-diagram is a set of graphs, called isotherms, each showing pressure as a function of volume for a constant temperature.



Molecular properties of matter: The molar mass M of a pure substance is the mass per mole. The mass m_{total} of a quantity of substance equals M multiplied by the number of moles n. Avogadro's number N_A is the number of molecules in a mole. The mass m of an individual molecule is M divided by N_A. (See Example 18.5.)

$$m_{total} = nM \qquad (18.2)$$

$$M = N_A m \qquad (18.8)$$



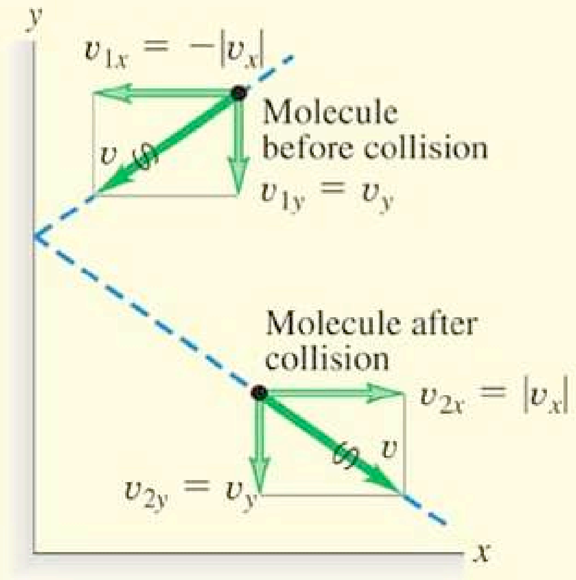
Kinetic-molecular model of an ideal gas: In an ideal gas, the total translational kinetic energy of the gas as a whole (K_{tr}) and the average translational kinetic energy per molecule $[\frac{1}{2}m(v^2)_{av}]$ are proportional to the absolute temperature T. The root-mean-square speed of molecules in an ideal gas is proportional to the square root of T. These expressions involve the Boltzmann constant $k = R/N_A$.
(See Examples 18.6 and 18.7.)
The mean free path λ of molecules in an ideal gas depends on the number of molecules per volume (N/V) and the molecular radius r. (See Example 18.8.)

$$K_{tr} = \frac{3}{2}nRT \tag{18.14}$$

$$\frac{1}{2}m(v^2)_{av} = \frac{3}{2}kT \tag{18.16}$$

$$v_{rms} = \sqrt{(v^2)_{av}} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}} \tag{18.19}$$

$$\lambda = vt_{mean} = \frac{V}{4\pi\sqrt{2}r^2N} \tag{18.21}$$

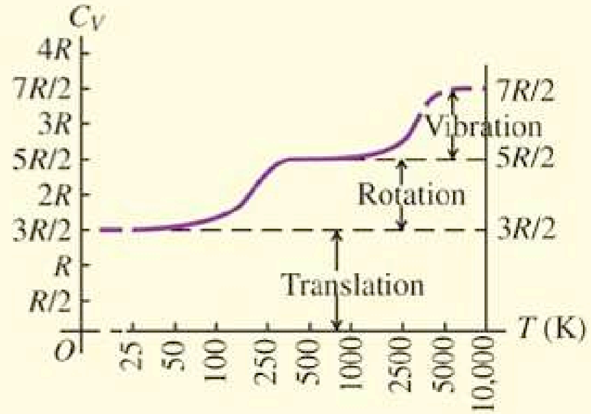


Heat capacities: The molar heat capacity at constant volume C_V can be expressed as a simple multiple of the gas constant R for certain idealized cases: an ideal monatomic gas [Eq. (18.25)]; an ideal diatomic gas including rotation energy [Eq. (18.26)]; and an ideal monatomic solid [Eq. (18.28)]. Many real systems are approximated well by these idealizations.

$$C_V = \frac{3}{2}R \qquad \text{(monatomic gas)} \qquad (18.25)$$

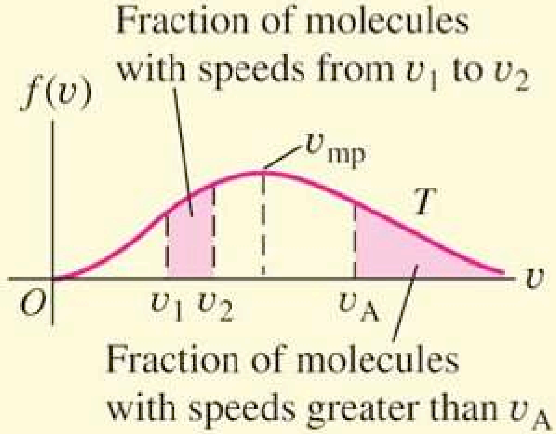
$$C_V = \frac{5}{2}R \qquad \text{(diatomic gas)} \qquad (18.26)$$

$$C_V = 3R \qquad \text{(monatomic solid)} \qquad (18.28)$$



Molecular speeds: The speeds of molecules in an ideal gas are distributed according to the Maxwell–Boltzmann distribution $f(v)$. The quantity $f(v)\,dv$ describes what fraction of the molecules have speeds between v and $v + dv$.

$$f(v) = 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2kT} \quad (18.32)$$



Phases of matter: Ordinary matter exists in the solid, liquid, and gas phases. A phase diagram shows conditions under which two phases can coexist in phase equilibrium. All three phases can coexist at the triple point. The vaporization curve ends at the critical point, above which the distinction between the liquid and gas phases disappears.