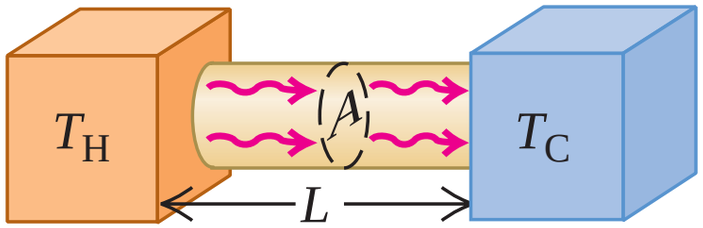
第三章

近平衡态的输运过程

Prepared by Jiang Xiao

热传导



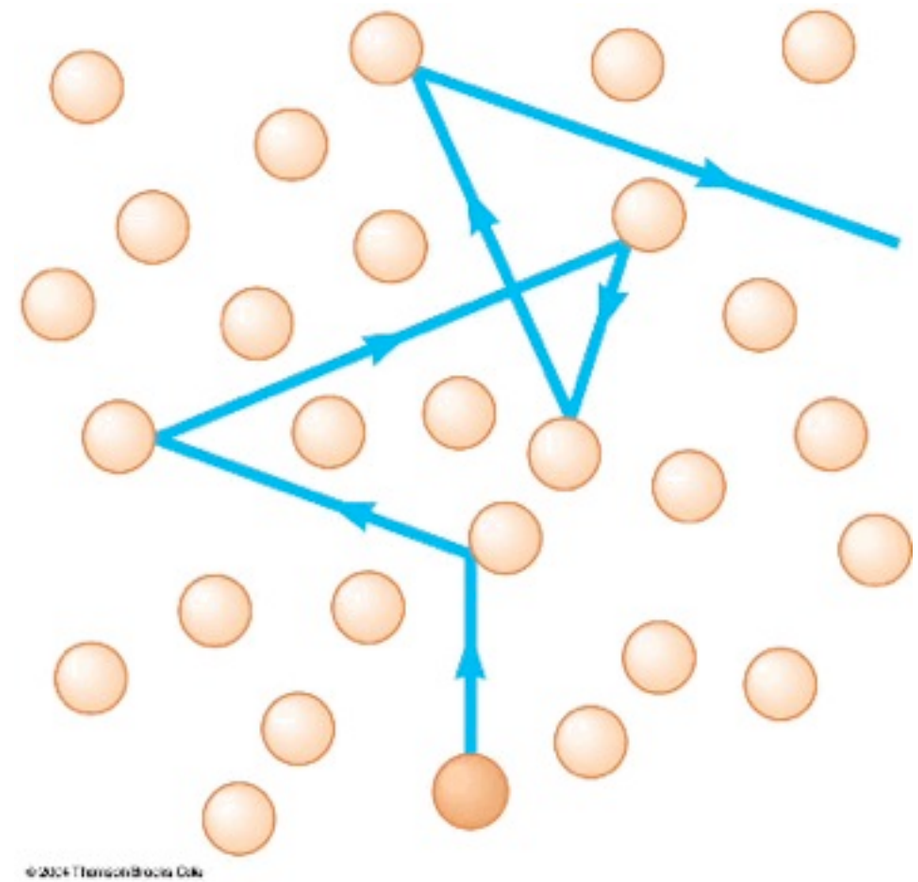
$$\Phi = \frac{\Delta Q}{\Delta t}$$

$$= \kappa A \frac{T_H - T_C}{L} = -\kappa A \frac{dT}{dx}$$

Substance	k (W/m·K)
Metals	
Aluminum	205.0
Brass	109.0
Copper	385.0
Lead	34.7
Mercury	8.3
Silver	406.0
Steel	50.2
Solids (representative values)	
Brick, insulating	0.15
Brick, red	0.6
Concrete	0.8
Cork	0.04
Felt	0.04
Fiberglass	0.04
Glass	0.8
Ice	1.6
Rock wool	0.04
Styrofoam	0.027
Wood	0.12–0.04
Gases	
Air	0.024
Argon	0.016
Helium	0.14
Hydrogen	0.14
Oxygen	0.023

气体分子的碰撞频率和平均自由程

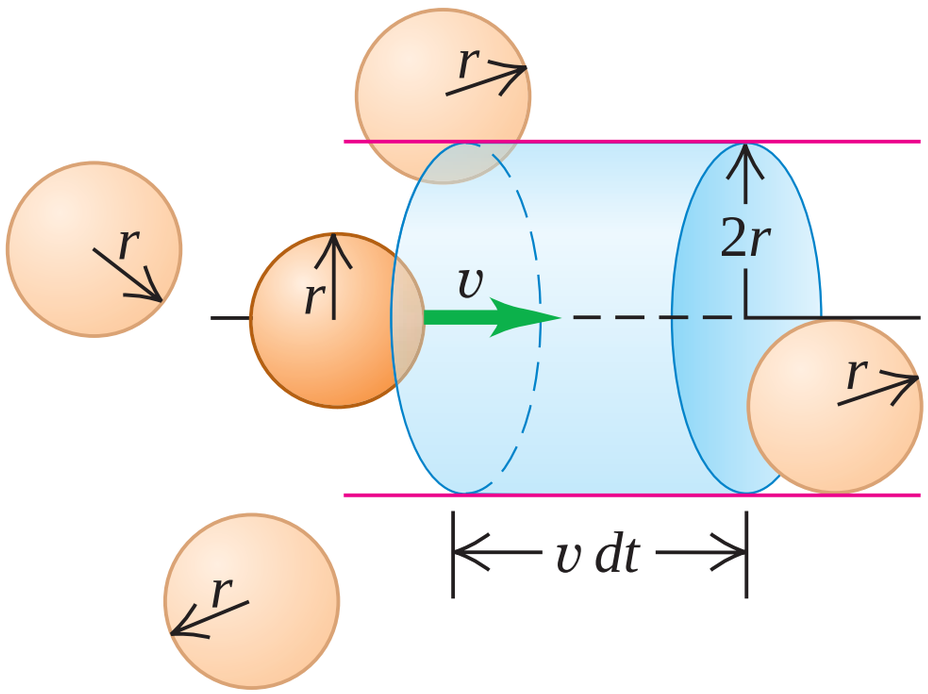
$$v_{\mathrm{rms}}(N_2) = 493\ \mathrm{m/s}$$
$$v_{\mathrm{rms}}(O_2) = 461\ \mathrm{m/s}$$
$$v_{\mathrm{rms}}(H_2) = 1845\ \mathrm{m/s}$$

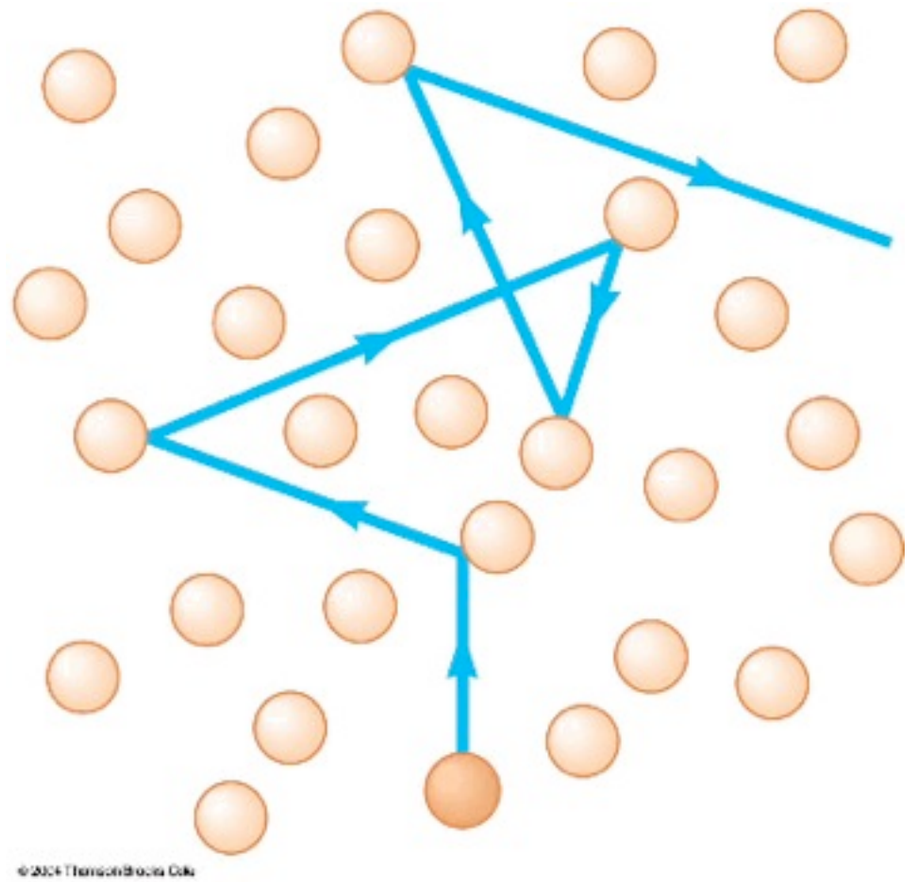


空气中声速：332 m/s

砸碎一瓶香水，是先听见声音还是先问到气味？

气体分子的碰撞频率和平均自由程





假设其他分子不动：

$$n\pi r^2 \bar{\lambda} = 1 \quad \Rightarrow \quad \bar{\lambda} = \frac{1}{n\pi r^2}$$

平均自由程

考虑其他分子运动：

$$\bar{\lambda} = \frac{1}{\sqrt{2} n\pi r^2}$$

气体分子的碰撞频率和平均自由程

气体	$\bar{\lambda}$ (nm)	r (nm)
H_2	1123	0.27
N_2	599	0.37
O_2	547	0.36
He	179.8	0.22
Ar	666	0.32

假设其他分子不动：

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平均自由程

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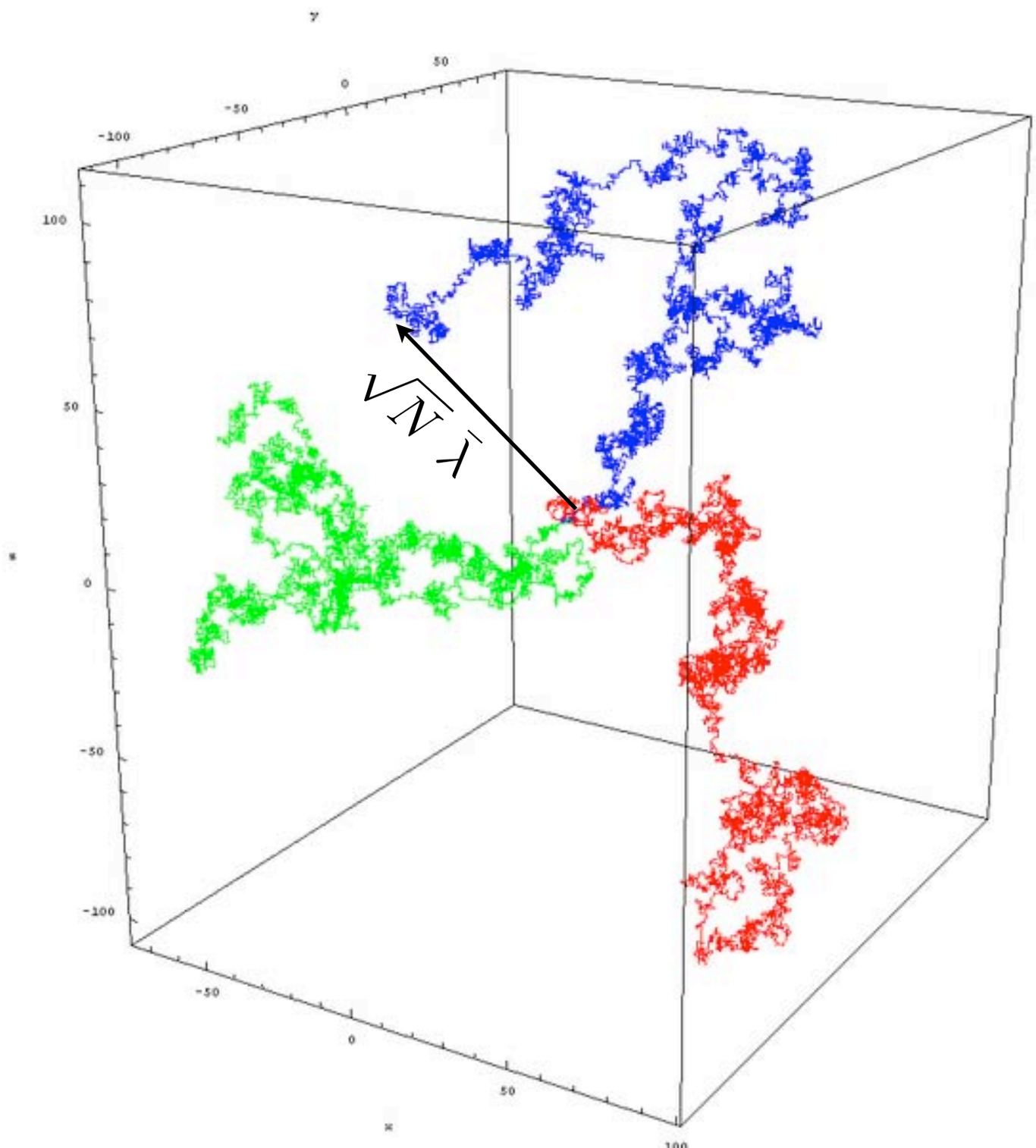
气体分子的碰撞频率和平均自由程



N次碰撞之后： $l = \sqrt{N}\ \bar{\lambda}$

$$v_{\text{effective}} = \frac{\sqrt{N}\ \bar{\lambda}}{N\bar{\lambda}/\bar{v}} = \frac{\bar{v}}{\sqrt{N}}$$

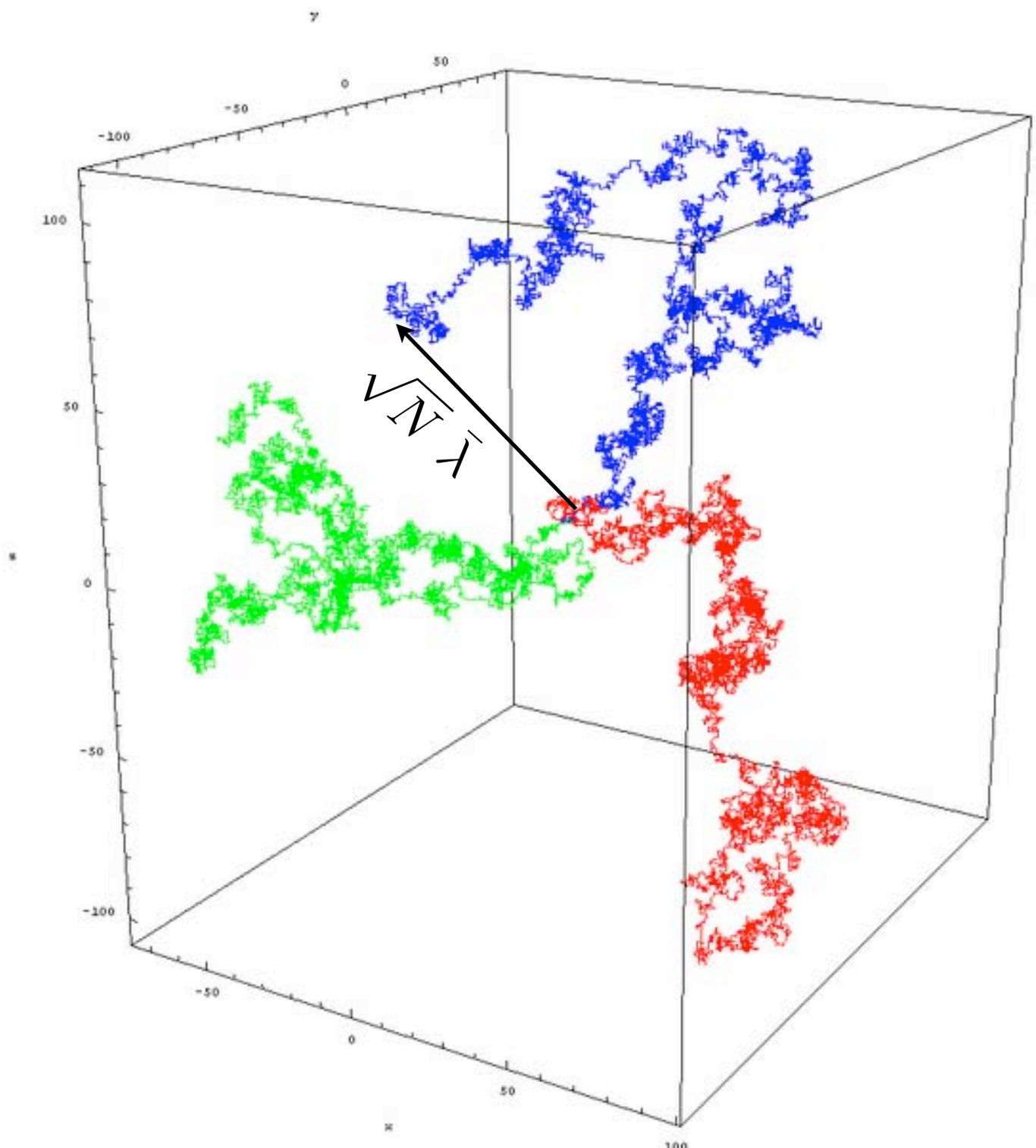
$$\bar{\lambda} \sim 600\ \text{nm}$$

$$\bar{v} \sim 400\ \text{m/s}$$

$$\sqrt{N}\ \bar{\lambda} \sim 1\ \text{m} \ \Rightarrow\ \sqrt{N} \sim 10^5$$

$$v_{\text{effective}} \sim 0.04\ \text{m/s}$$

气体分子的碰撞频率和平均自由程



太阳内的光子的平均自由程：

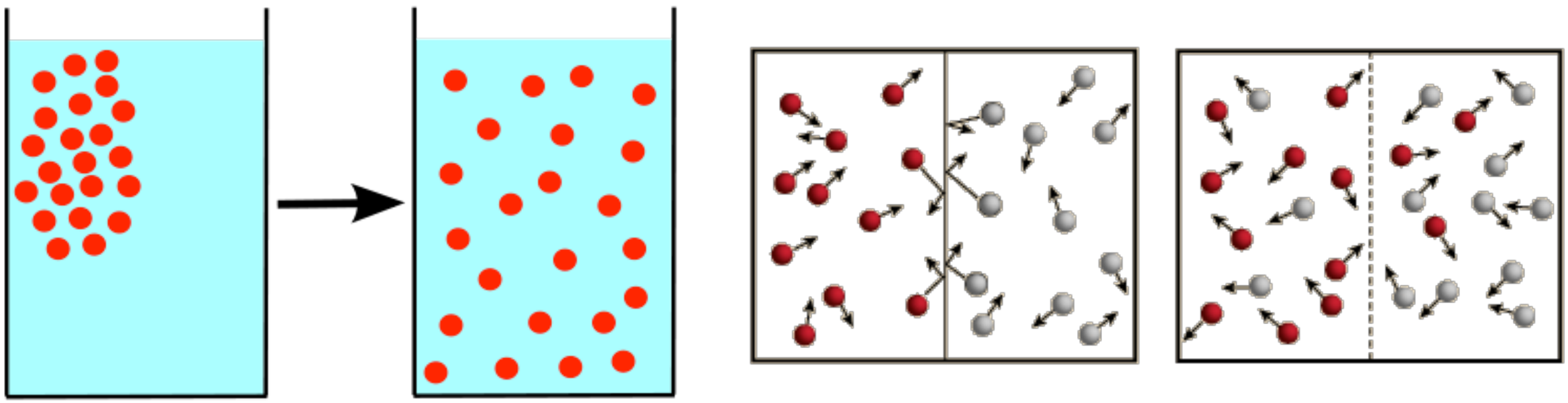
$$\bar{\lambda} = 1 \text{ cm}$$

太阳半径：R = 0.7 x 10^6 km

$$\sqrt{N}\,\bar{\lambda} = R \Rightarrow N = \frac{R^2}{\bar{\lambda}^2}$$

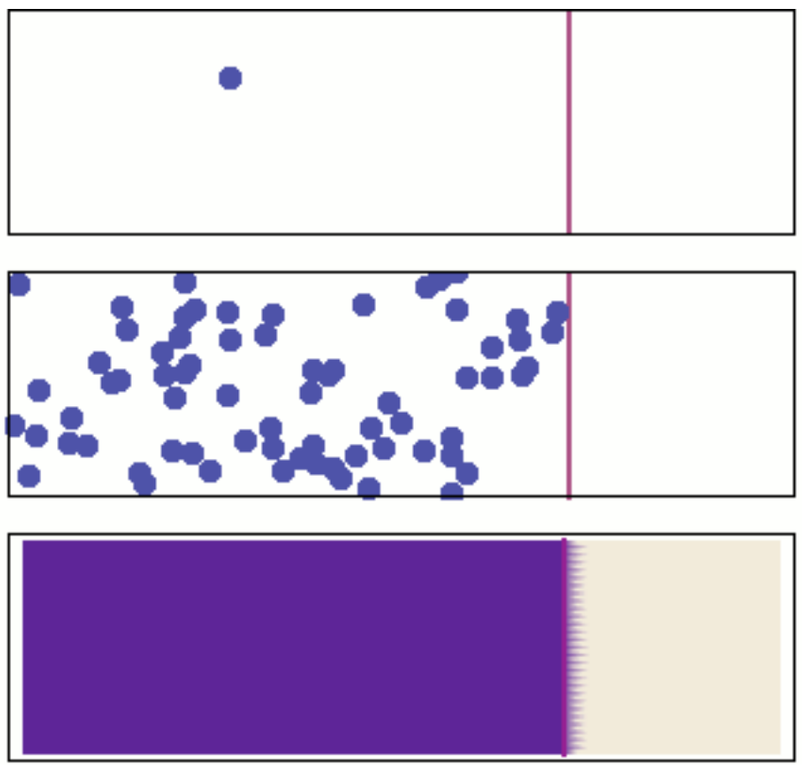
$$t = \frac{N\bar{\lambda}}{c} = \frac{R^2}{\bar{\lambda}c} \sim 10^4 \text{ year}$$

气体的输运 - 扩散



扩散：http://v.youku.com/v_show/id_XMzkyMDQ0ODYw.html

气体的输运 - 扩散



$$j_n = \frac{dn}{dt} = -D\frac{dn}{dx}$$

粒子流

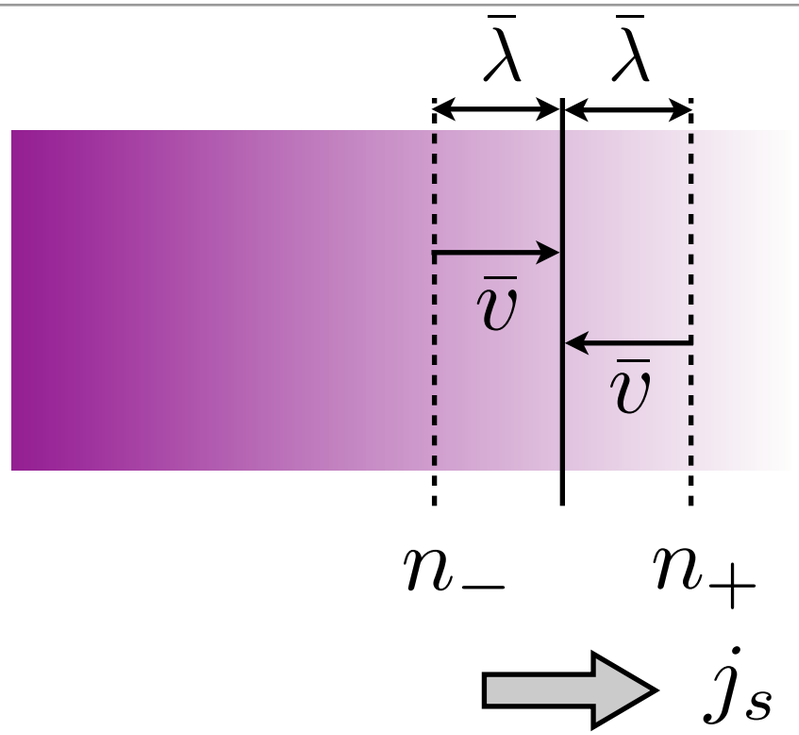
扩散系数

$$j_Q = \frac{dQ}{dt} = -\kappa\frac{dT}{dx}$$

能量流

热传导系数

气体的输运 - 扩散



$$j_n = \frac{dn}{dt} = -D\frac{dn}{dx}$$

粒子流

扩散系数

$$s = 1 \qquad D = \frac{1}{3}\bar{v}\bar{\lambda}$$

$$j_s = \frac{n_- s_-}{6}\bar{v} - \frac{n_+ s_+}{6}\bar{v}$$
$$= -\frac{1}{6}\bar{v}\frac{d(ns)}{dx}2\bar{\lambda}$$
$$= -\frac{1}{3}\bar{v}\bar{\lambda}\frac{d(ns)}{dx}$$

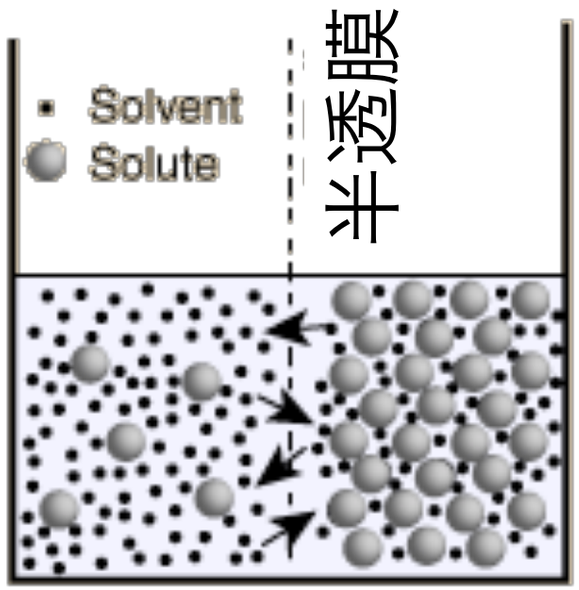
$$j_Q = \frac{dQ}{dt} = -\kappa\frac{dT}{dx}$$

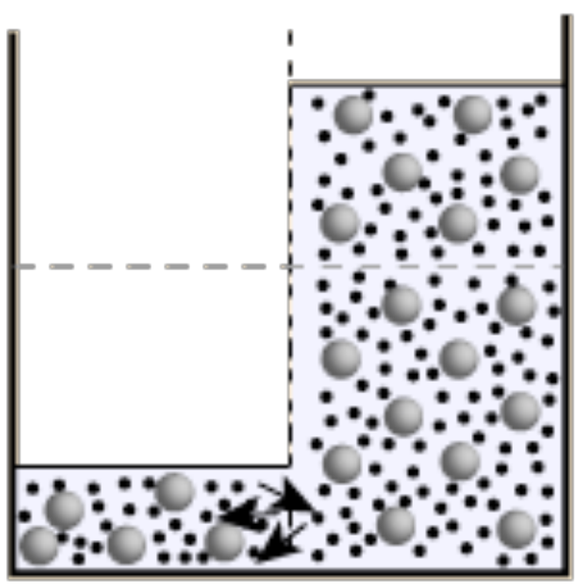
能量流

热传导系数

$$s = mc_v T \qquad \kappa = \frac{1}{3}\rho c_v \bar{v}\bar{\lambda}$$

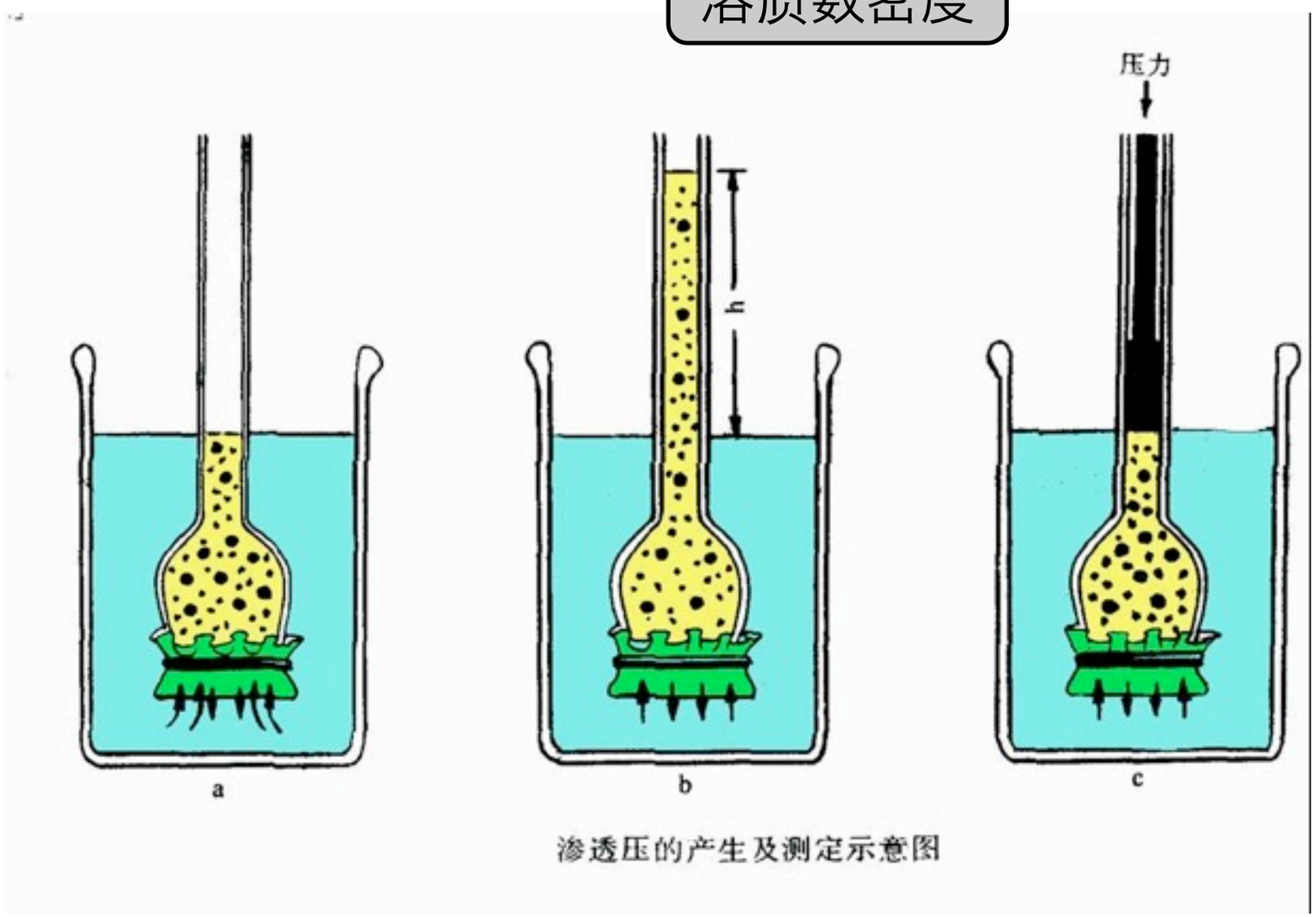
渗透与渗透压





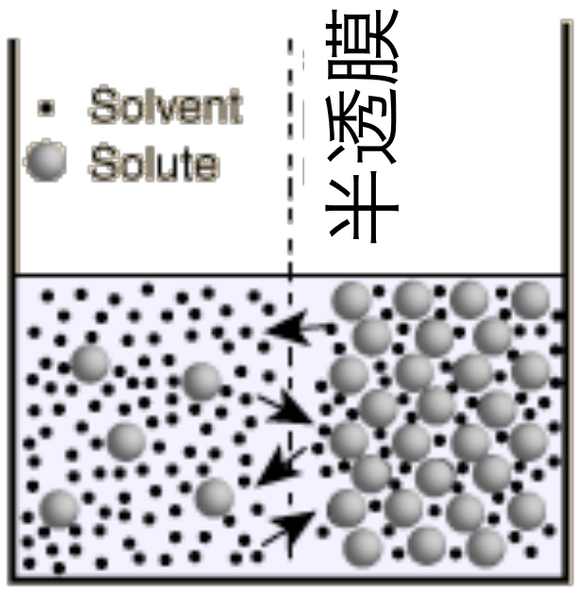
渗透压： $p = nkT$

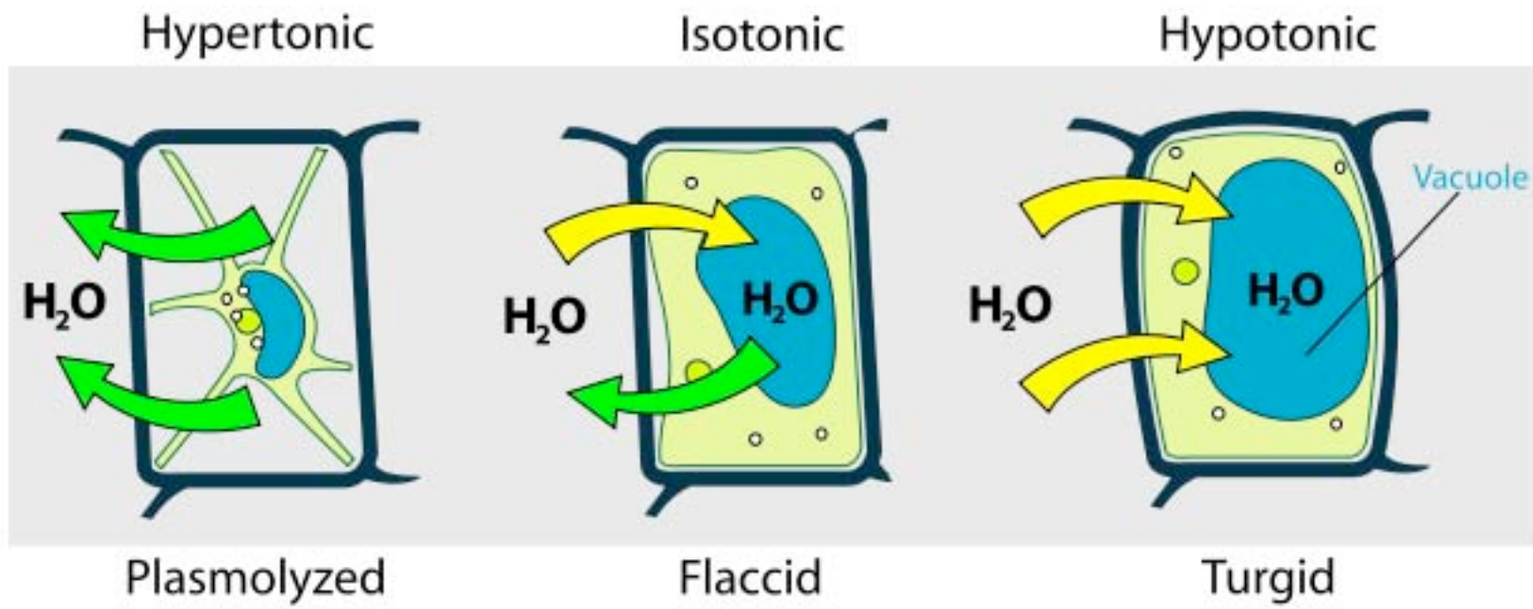
溶质数密度

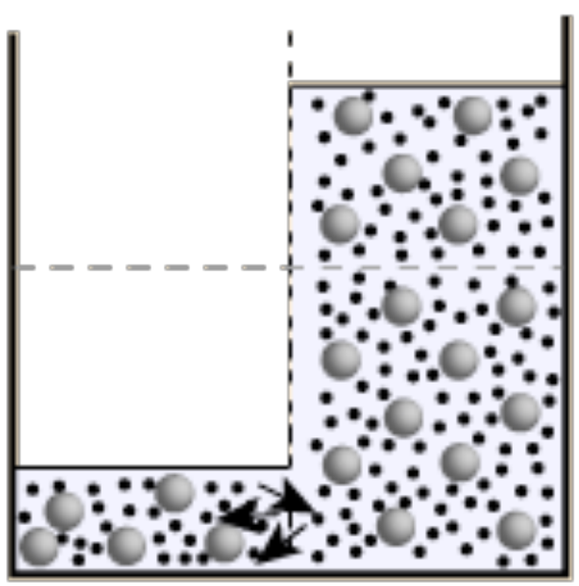


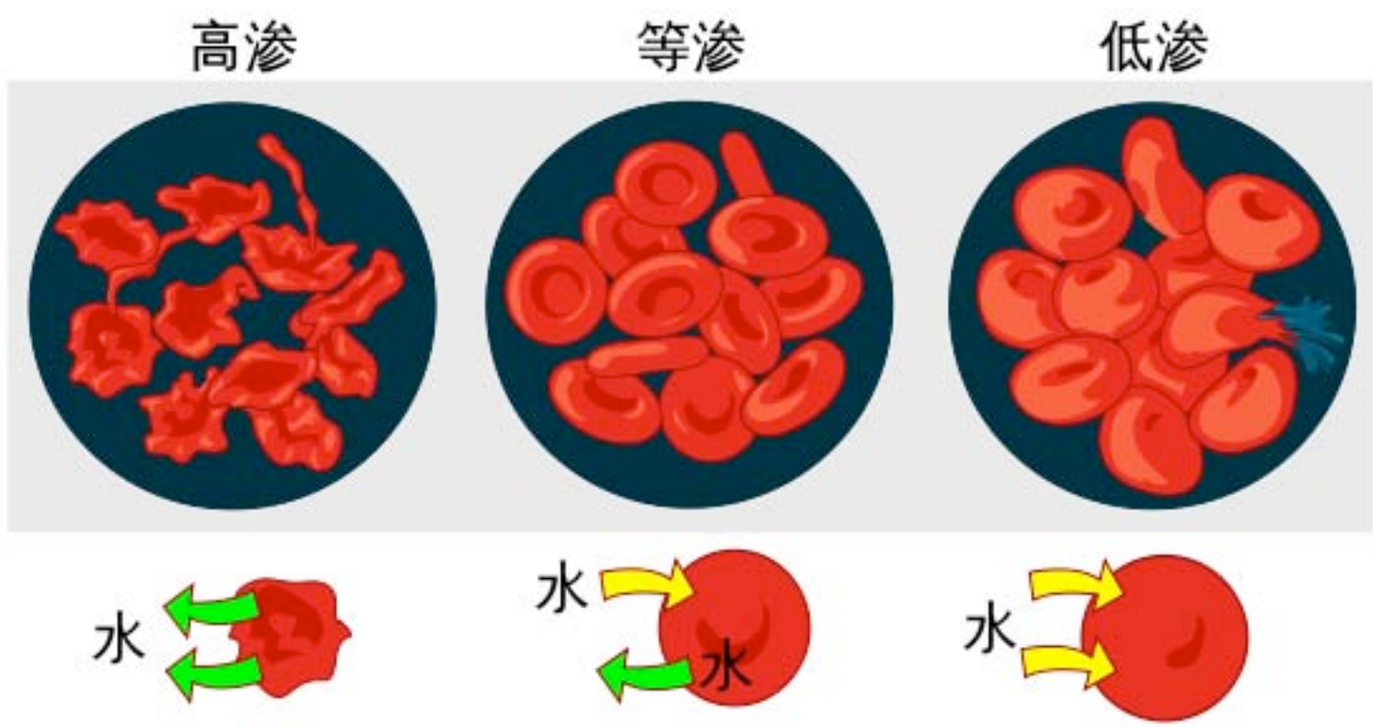
渗透压的产生及测定示意图

渗透与渗透压


Solvent
Solute
半透膜


Hypertonic
Isotonic
Hypotonic
H_2O
H_2O
H_2O
H_2O
H_2O
Vacuole
Plasmolyzed
Flaccid
Turgid




高渗
等渗
低渗
水
水
水
水