第2章

PROPERTIES OF FLUIDS

(流体的性质)

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液滴的形成?

A drop forms when liquid is forced out of a small tube. The shape of the drop is determined by a balance of pressure, gravity, and surface tension forces (压力、重力、表面张力).

引言

Property (性质): Any characteristic of a system.

Some familiar properties are *pressure P, temperature T, volume V, and mass m*.

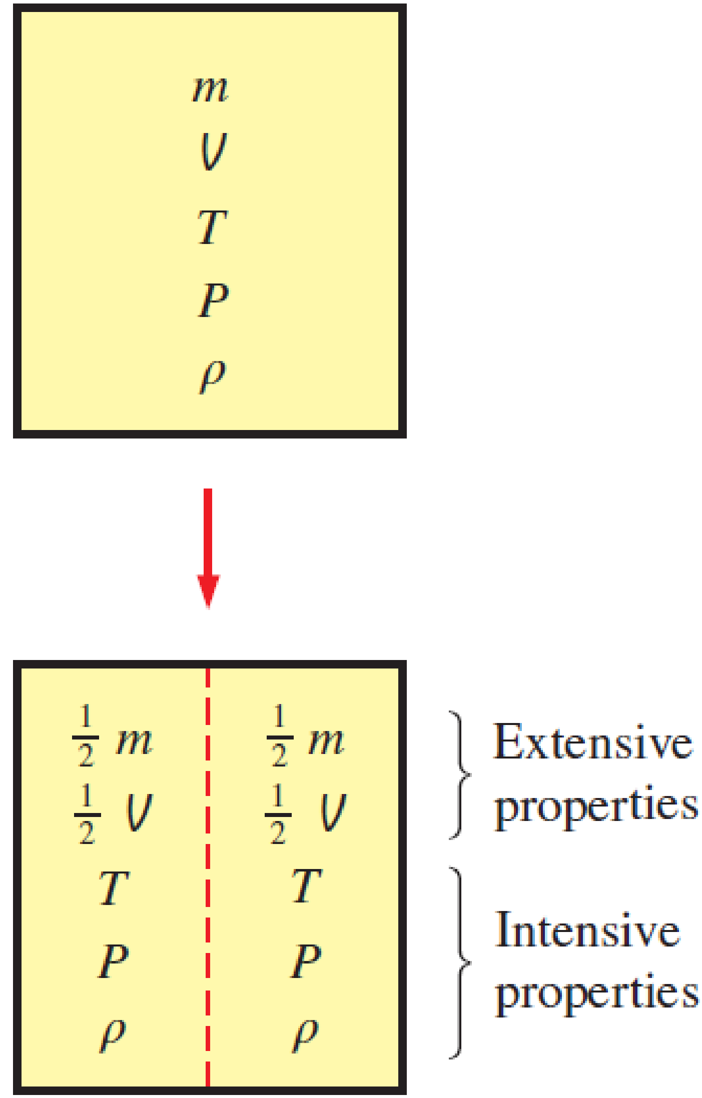
Properties are considered to be either *intensive* or *extensive*.

Intensive properties (内在性质): Those that are *independent* of the *mass* (质量无关) of a system, such as temperature, pressure, and density.

Extensive properties (外延性质): Those whose values *depend on* the *size (尺寸有关)*—or *extent—of the system*.

Specific properties (比性质): Extensive properties per unit mass.

如 specific volume **(比容)** $v = V/m$ 等



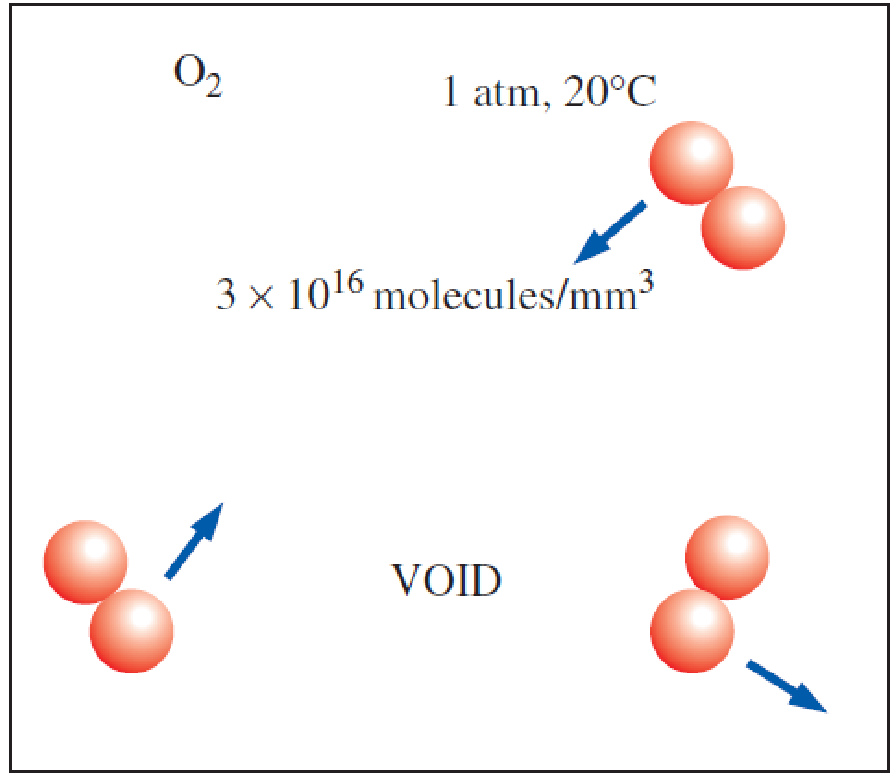
Criterion to differentiate intensive and extensive properties.

引言

Continuum (连续介质)

Matter is made up of atoms that are widely spaced in the gas phase. Yet it is very convenient to disregard the atomic nature of a substance and view it as a continuous, homogeneous matter with no holes (连续均匀的无孔介质), that is, a **continuum**.

This idealization is valid as long as *<u>the size of the system we deal with is large relative to the space between the molecules</u>*. This is the case in practically all problems.



Despite the relatively large gaps between molecules, a substance can be treated as a continuum because of the very large number of molecules even in an extremely small volume.

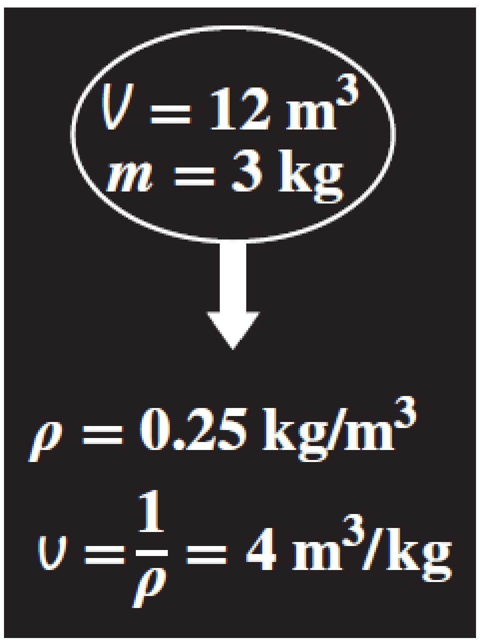
2–2 密度与比重

Density (密度)

$$\rho = \frac{m}{V} \quad \left(\mathrm{kg/m^3}\right)$$

Specific volume (比容)

$$v = V/m = 1/\rho$$



Density is mass per unit volume; specific volume is volume per unit mass.

Specific gravity (比重): The ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C).

$$\mathrm{SG} = \frac{\rho}{\rho_{\mathrm{H_2O}}}$$

Specific weight (重度，容重): The weight of a unit volume of a substance.

$$\gamma_s = \rho g \quad \left(\mathrm{N/m^3}\right)$$

2–2 密度与比重

TABLE 2–1

The specific gravity of some substances at 20°C and 1 atm unless stated otherwise

Substance	SG
Water	1.0
Blood (at 37°C)	1.06
Seawater	1.025
Gasoline	0.68
Ethyl alcohol	0.790
Mercury	13.6
Balsa wood	0.17
Dense oak wood	0.93
Gold	19.3
Bones	1.7–2.0
Ice (at 0°C)	0.916
Air	0.001204

2–2 密度与比重

Density of Ideal Gases

Equation of state (状态方程): Any equation that relates the *pressure, temperature, and density* (or specific volume) of a substance.

Ideal-gas equation of state (理想气体状态方程): The simplest and best-known equation of state for substances in the gas phase.

比容

$$Pv = RT \quad \text{or} \quad P = \rho RT$$

$$R = R_u / M \qquad R_u = 8.314 \ \text{kj/kmol} \cdot \text{K}$$

The universal gas constant (通用气体常数)

$$P_1 V_1 / T_1 = P_2 V_2 / T_2$$

For a fixed mass

2–2 密度与比重

Temperature Scales (温标)

Kelvin scale (开氏温度): The thermodynamic temperature scale in the SI system.

Rankine scale (兰氏温度): The thermodynamic temperature scale in English system.

$$T(\mathrm{K}) = T(^\circ\mathrm{C}) + 273.15 = T(\mathrm{R})/1.8$$

$$T(\mathrm{R}) = T(^\circ\mathrm{F}) + 459.67 = 1.8\, T(\mathrm{K})$$

2–2 密度与比重

An ideal gas **(理想气体)** is a hypothetical substance that obeys the relation $Pv = RT$.

The ideal-gas relation closely approximates the *P-v-T* behavior of real gases at *low densities (低密度).*

At *low pressures and high temperatures (低压高温下)*, the density of a gas decreases and the gas behaves like an ideal gas.

In the range of practical interest, many familiar gases such as air, nitrogen, oxygen, hydrogen, helium, argon, neon, and carbon dioxide can be treated as ideal gases with negligible error.

Dense gases (稠密气体) such as water vapor (水蒸气) in steam power plants and refrigerant vapor (制冷剂) in refrigerators, however, should not be treated as ideal gases since they usually exist at a state *near saturation*.

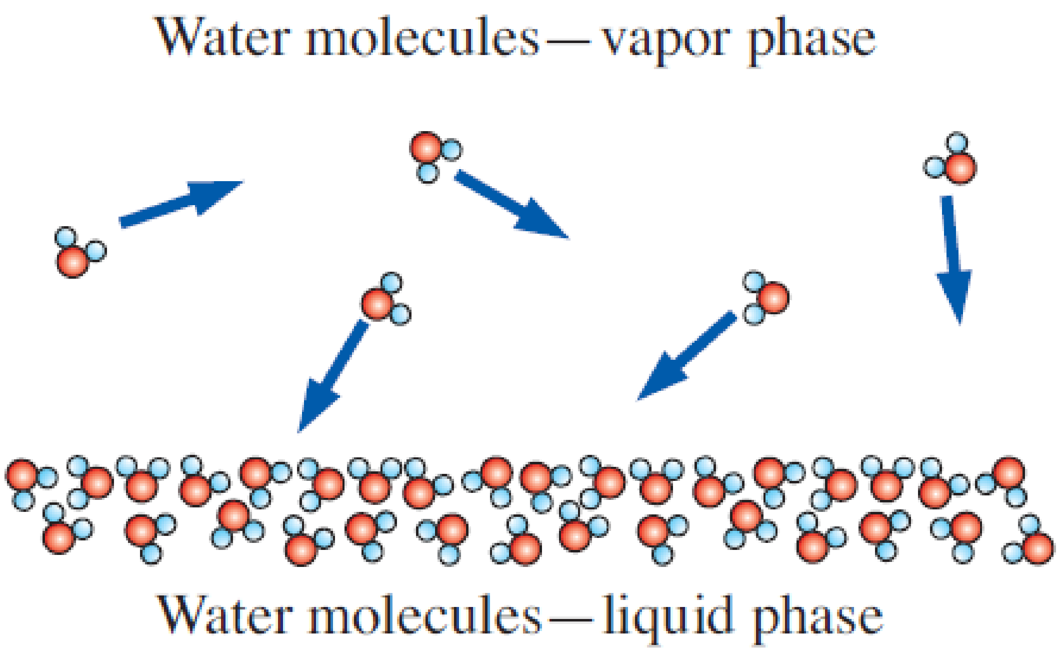
2–3 蒸气压与空化

Saturation temperature (饱和温度) T_{sat}: The temperature at which a pure substance changes phase (相变) at a given pressure.

Saturation pressure (饱和压强) P_{sat}: The pressure at which a pure substance (纯净物质) changes phase at a given temperature.

Vapor pressure (蒸气压) P_v: The pressure exerted by its vapor in phase equilibrium (相平衡) with its liquid at *a given temperature* (pure substance). It is identical to the saturation pressure P_{sat} of the liquid ($P_v = P_{sat}$).

Partial pressure (分压) : The pressure of ***a gas or vapor*** *in a mixture* with other gases. For example, atmospheric air is a mixture of dry air and water vapor, and atmospheric pressure is the sum of the partial pressure of dry air and the partial pressure of water vapor.



The vapor pressure (saturation pressure, **饱和压强**) of a <u>*pure substance*</u> (e.g., water) is the pressure exerted by its vapor molecules when the system is <u>in phase equilibrium</u> with its liquid molecules at <u>a given temperature</u>.

*** 纯净物质的蒸气压和饱和压强相同**

TABLE 2–2

水在不同温度下的饱和压强（蒸气压）

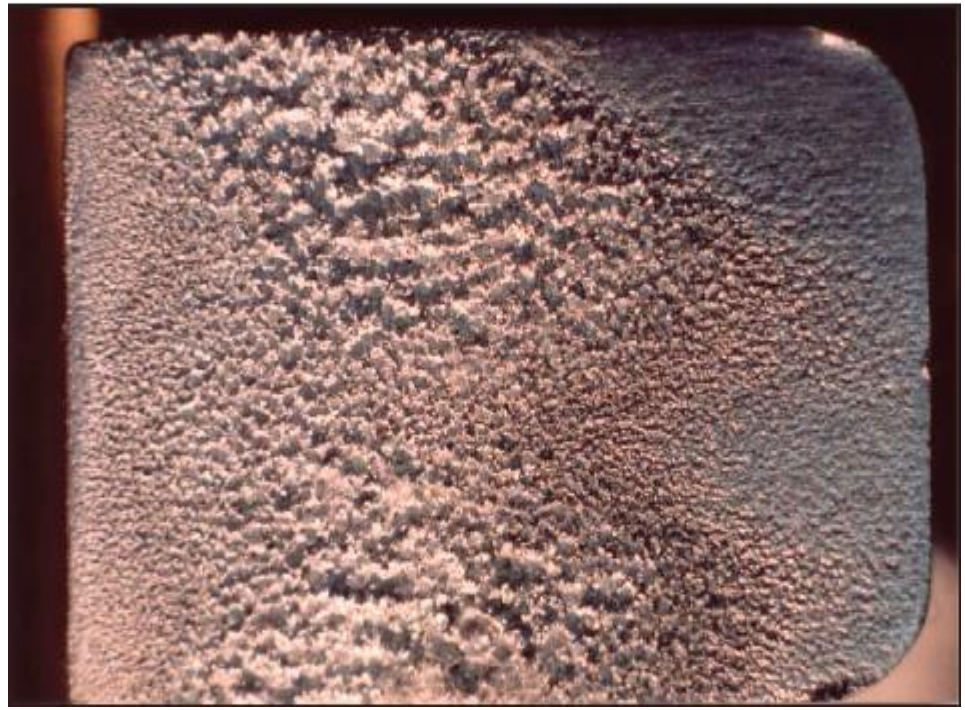
Temperature T, °C	Saturation Pressure P_{sat}, kPa
−10	0.260
−5	0.403
0	0.611
5	0.872
10	1.23
15	1.71
20	2.34
25	3.17
30	4.25
40	7.38
50	12.35
100	101.3 (1 atm)
150	475.8
200	1554
250	3973
300	8581

2–3 蒸气压与空化

There is a possibility of the liquid pressure in liquid-flow systems <u>dropping below the vapor pressure</u> at some locations, and the resulting unplanned vaporization (汽化现象).

The vapor bubbles (called **cavitation bubbles (空化气泡)** since they form "cavities" in the liquid) <u>collapse</u> as they are swept away from the <u>low-pressure regions</u>, generating highly destructive, extremely high-pressure waves.

This phenomenon, which is a common cause for drop in performance and even the erosion of impeller blades, is called **cavitation (空化)**, and it is an important consideration in the design of hydraulic turbines and pumps.



Photograph by David Stinebring, ARL/ Pennsylvania State University. Used by permission.

铝制样品在60m/s流速下测试2.5h形成的空化损坏

2–4 能量与比热

Energy (能量) can exist in numerous forms such as *thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear,* and their sum constitutes the **total energy, *E*** of a system (系统的总能量).

Macroscopic forms of energy (宏观能量): Those a system *possesses as a whole* (作为一个整体) with respect to some *outside reference frame* (外部参照体系所具有的), such as kinetic (动能) and potential (势能) energies.

Microscopic forms of energy (微观能量): Those related to *the molecular structure* (分子结构) of a system and the degree of the *molecular activity* (分子活动程度).

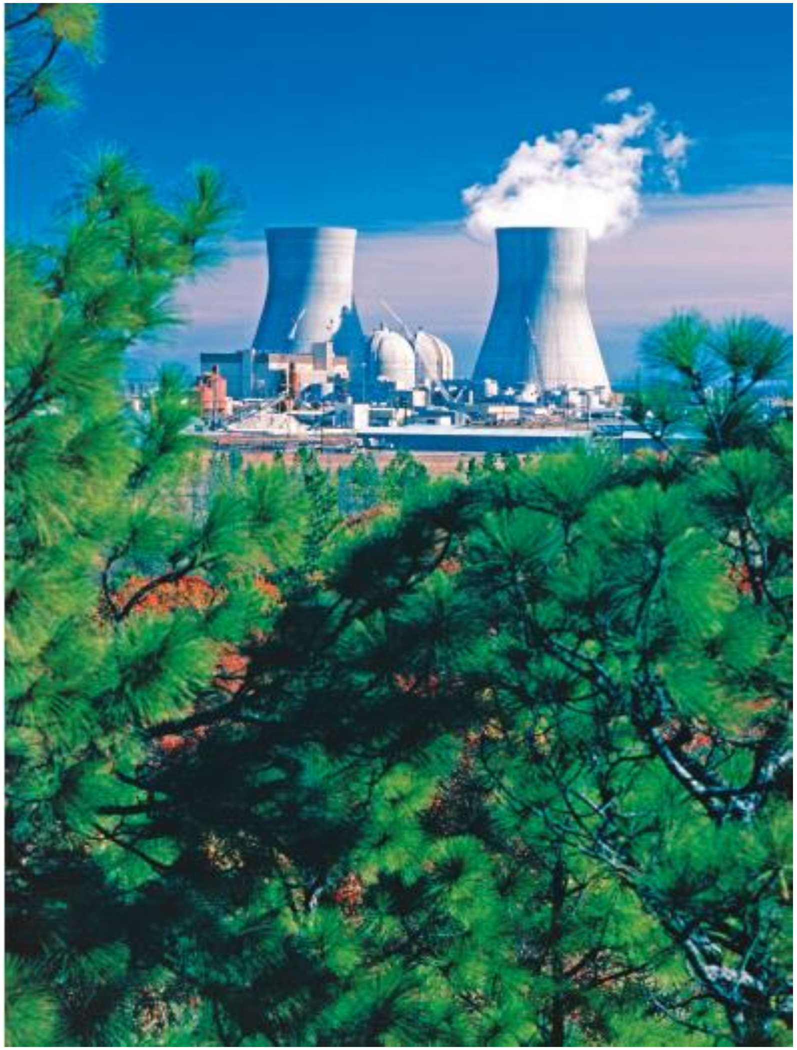
Internal energy (内能), *U*: The sum of all the microscopic forms of energy.

In daily life, we frequently refer to the sensible and latent forms (可感知和潜在的) of internal energy as heat (热). In engineering, however, those forms of energy are usually referred to as thermal energy (热能).

Kinetic energy (动能), KE: The energy that a system possesses as a result of its motion relative to some reference frame.

Potential energy (势能), PE: The energy that a system possesses as a result of its *elevation in a gravitational field* (重力场中的高度).

2–4 能量与比热



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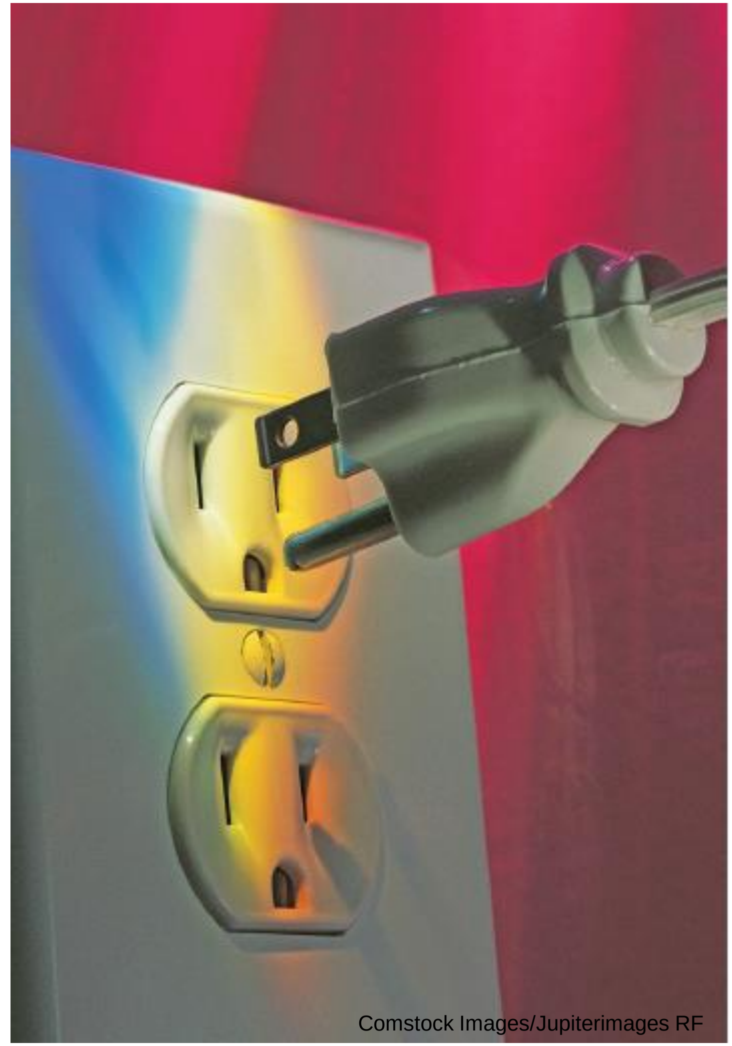

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At *least six different forms of energy* are encountered in bringing power from a nuclear plant to your home, nuclear, thermal, mechanical, kinetic, magnetic, and electrical.

2–4 能量与比热容

$$h = u + Pv = u + \frac{P}{\rho}$$

Enthalpy **(焓)**

$du = c_v\ dT$ and $dh = c_p\ dT$ 理想气体时

$\Delta u \cong c_{v,\mathrm{avg}}\ \Delta T$ and $\Delta h \cong c_{p,\mathrm{avg}}\ \Delta T$

$\Delta h = \Delta u + \Delta P/\rho \cong c_{\mathrm{avg}}\ \Delta T + \Delta P/\rho$

$\Delta h \cong \Delta u \cong c_{\mathrm{avg}}\ \Delta T$ for a P = const. process

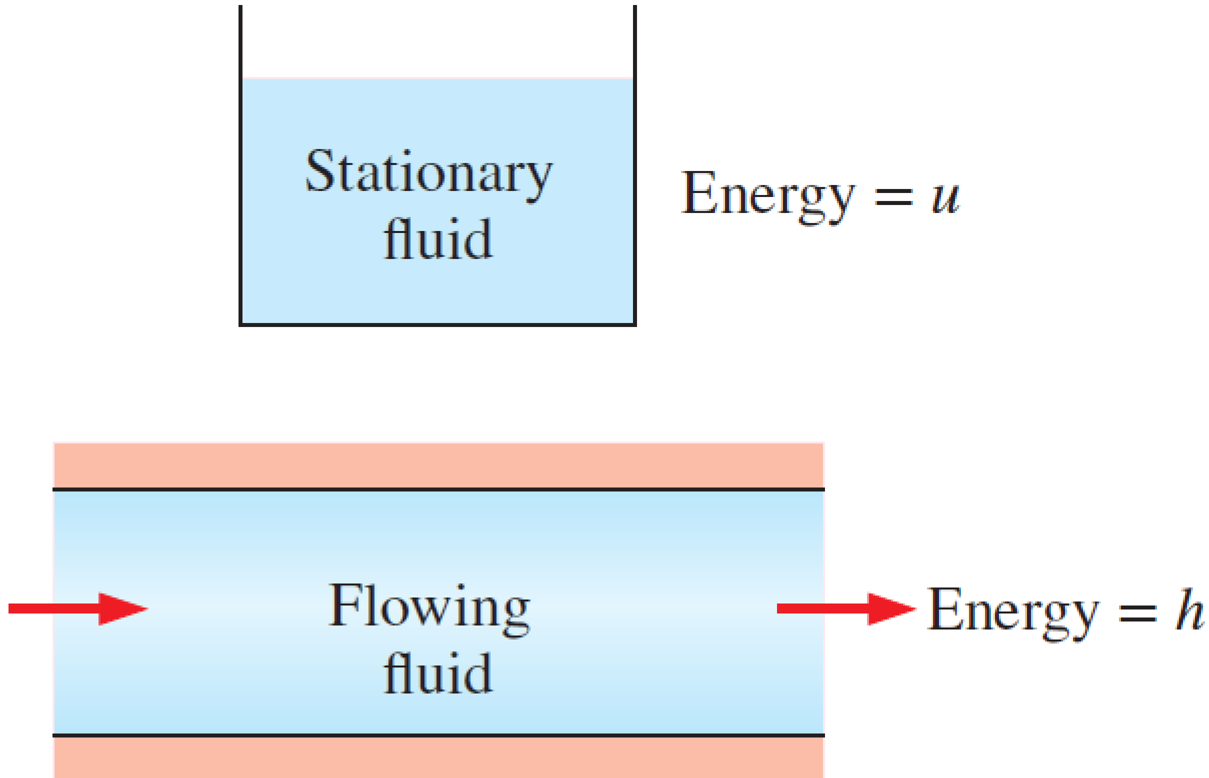
$\Delta h = \Delta p/\rho$ For a T = const. process

P/ρ is the *flow energy* (流动能), also called the *flow work*, which is the energy per unit mass needed to move the fluid and maintain flow.

Specific heat at constant volume **(定容比热), c_v:** The energy required to raise the temperature of the unit mass of a substance by one degree as the volume is maintained constant.

Specific heat at constant pressure **(定压比热), c_p:** The energy required to raise the temperature of the unit mass of a substance by one degree as the pressure is maintained constant.

2–4 能量与比热容



The *internal energy u (内能)* represents the microscopic energy of a *nonflowing fluid* per unit mass, whereas *enthalpy h (焓)* represents the microscopic energy of a *flowing fluid* per unit mass.

2–5 可压缩性

Coefficient of Compressibility
压缩系数

The volume (or density) of a fluid changes with a *change in its temperature or pressure.*

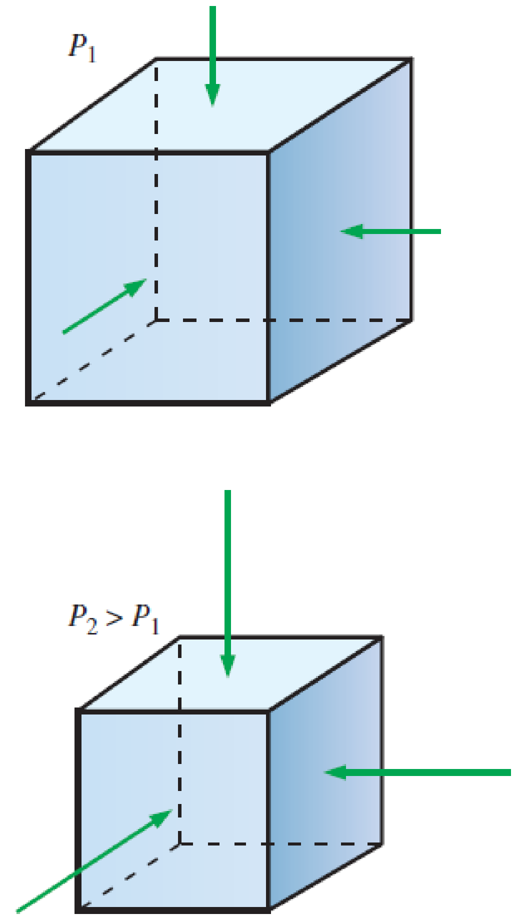
Fluids usually *expand* (膨胀) as they are heated or depressurized and *contract* (收缩) as they are cooled or pressurized.

But the amount of volume change is different for different fluids, and we need to define properties that relate volume changes to the changes in pressure and temperature.

Two such properties are:

the bulk modulus of elasticity (压缩系数) κ

the coefficient of volume expansion (体积膨胀系数) β



Fluids, like solids, compress when the applied pressure is increased from P_1 to P_2.

2–5 可压缩性

$$\kappa = -\mathrm{v}\left(\frac{\partial P}{\partial \mathrm{v}}\right)_T = \rho\left(\frac{\partial P}{\partial \rho}\right)_T \qquad (\mathrm{Pa})$$

Coefficient of compressibility (压缩系数) for fluids

$$\kappa \cong -\frac{\Delta P}{\Delta \mathrm{v}/\mathrm{v}} \cong \frac{\Delta P}{\Delta \rho/\rho} \qquad (T = \text{constant})$$

The coefficient of compressibility represents *the change in pressure* corresponding to a fractional *change in volume or density* of the fluid while the *temperature remains constant*.

A large value of κ indicates that a large change in pressure is needed to cause a small fractional change in volume, and thus a fluid with a large κ is essentially incompressible.

* *标准大气条件下，压强提高到 210atm，才使水体积压缩1%，对应的压缩系数约 21000atm*

2–5 可压缩性

For an ideal gas, κ_{ig}?

$P = \rho RT$ and $(\partial P/\partial \rho)_T = RT = P/\rho$, and thus

$$\kappa_{ig} = P \quad \text{(Pa)}$$

The coefficient of compressibility of an ideal gas is equal to its absolute pressure (绝对压强), and the coefficient of compressibility of the gas increases with increasing pressure.

$$\textit{Ideal gas:} \qquad \frac{\Delta\rho}{\rho} = \frac{\Delta P}{P} \qquad (T = \text{constant})$$

The percent increase of density of an *ideal gas* during isothermal compression is equal to the percent increase in pressure.

Isothermal compressibility (等温压缩系数): The inverse of the coefficient of compressibility.

The isothermal compressibility of a fluid represents the fractional change in volume or density corresponding to a unit change in pressure.

$$\alpha = \frac{1}{\kappa} = -\frac{1}{\text{v}}\left(\frac{\partial \text{v}}{\partial P}\right)_T = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial P}\right)_T \qquad (1/\text{Pa})$$

2–5 可压缩性

Coefficient of Volume Expansion
体积膨胀系数

The **density of a fluid** depends more strongly on *temperature* than it does on pressure.

we need a property that represents the *variation of the density of a fluid with temperature* *at constant pressure* (表示恒定压强下，流体密度随温度的变化)

2–5 可压缩性

The **coefficient of volume expansion**

The variation of the density (volume) of a fluid with temperature at constant pressure.

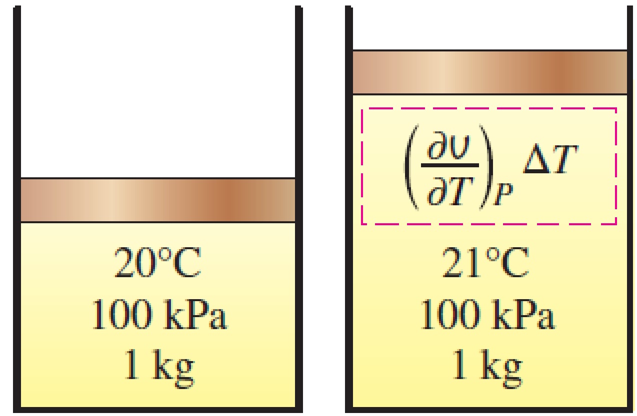
$$\beta = \frac{1}{v}\left(\frac{\partial v}{\partial T}\right)_P = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P \qquad (1/K)$$

$$\beta \approx \frac{\Delta v/v}{\Delta T} = -\frac{\Delta \rho/\rho}{\Delta T} \qquad (\text{at constant } P)$$

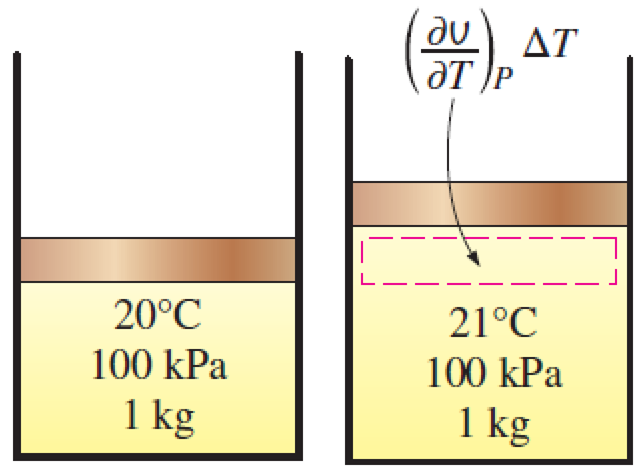
A large value of β for a fluid means *a large change in density* with temperature (体积膨胀系数大，表示密度或体积随着温度变化也大)

The volume expansion coefficient of an *ideal gas* ($P = \rho RT$) at a temperature T is equivalent to the inverse of the temperature:

$$\beta_{\text{ideal gas}} = \frac{1}{T} \qquad (1/K)$$



(a) A substance with a large β



(b) A substance with a small β

The coefficient of volume expansion is a measure of the change in volume of a substance with temperature *at constant pressure.*

2–5 可压缩性

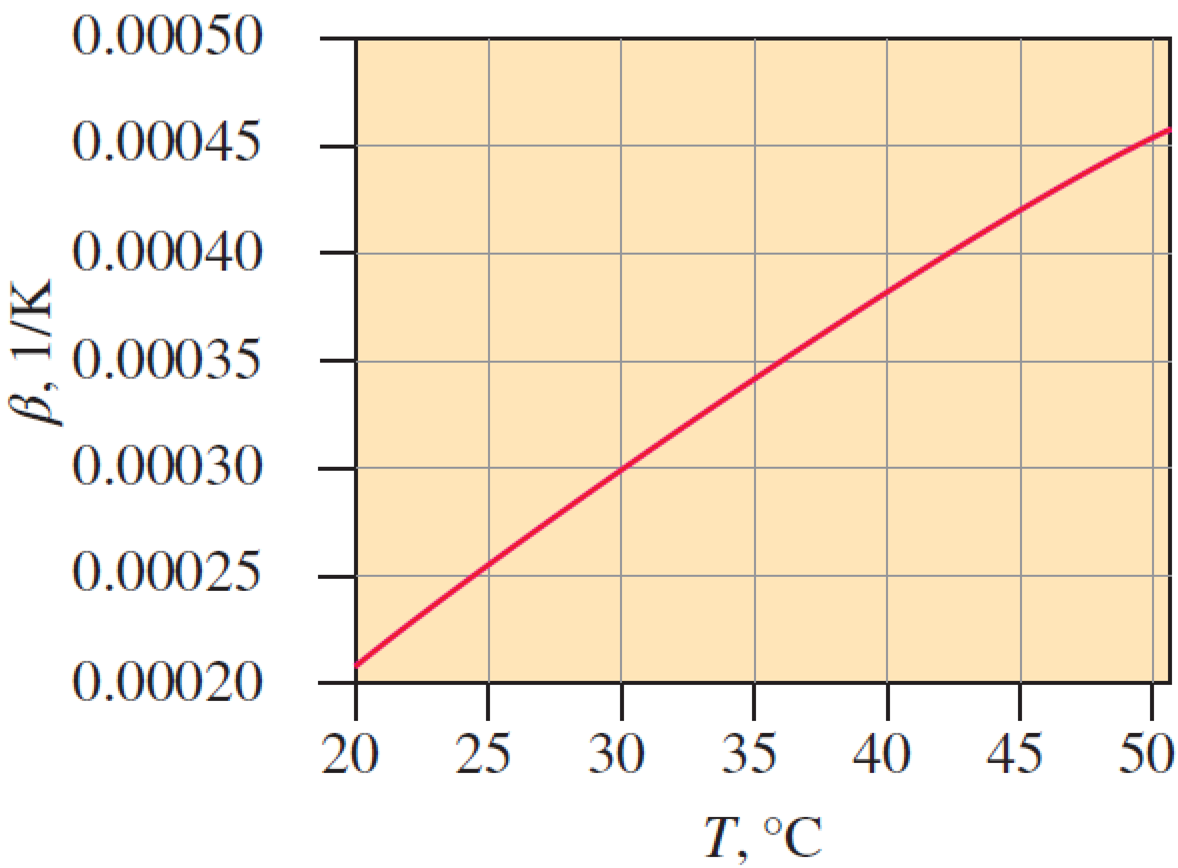
The combined effects of P, T changes on the *volume change* of a fluid can be determined by taking the specific volume to be a function of *T* and *P*.

$$d\mathrm{v} = \left(\frac{\partial \mathrm{v}}{\partial T}\right)_P dT + \left(\frac{\partial \mathrm{v}}{\partial P}\right)_T dP = (\beta\, dT - \alpha\, dP)\mathrm{v}$$

The fractional change in volume (or density) due to changes in pressure and temperature can be *expressed approximately* as

$$\frac{\Delta \mathrm{v}}{\mathrm{v}} = -\frac{\Delta\rho}{\rho} \cong \beta\,\Delta T - \alpha\,\Delta P \qquad (2\text{-}23)$$

2–5 可压缩性



The variation of the coefficient of volume expansion (体积膨胀系数) of water with temperature in the range of 20°C to 50°C.

练习2-1

温度和压强变化引起的密度变化

假设水的初始状态为20°C、1 atm，求以下两种情况下水的最终密度:(a)如果它在1atm 的恒定压强下被加热到50°C，(b)如果在20°C的恒定温度下被压缩到 100atm 的压强。已知水的等温压缩系数α=4.80x10^{-5}atm^{-1}。

【解】：假设: 1-在给定温度范围内，水的体积膨胀系数和等温压缩系数恒定; 2-用增量代替微分量来进行近似分析。

在20°C和1 atm 下，水的密度为$\rho 1$=998.0kg/m^3。在平均温度(20+50)°C/2=35°C下，体积膨胀系数为β=0.337x10^{-3}K^{-1}。微分量由增量来代替，且α和β视为常数，则密度随压强和温度变化的变化[式 (2-23)]可近似表示为

$$\Delta\rho = \alpha\rho\Delta P - \beta\rho\Delta T$$

(a)恒压下，温度由20°C 上升至50°C引起的密度变化为

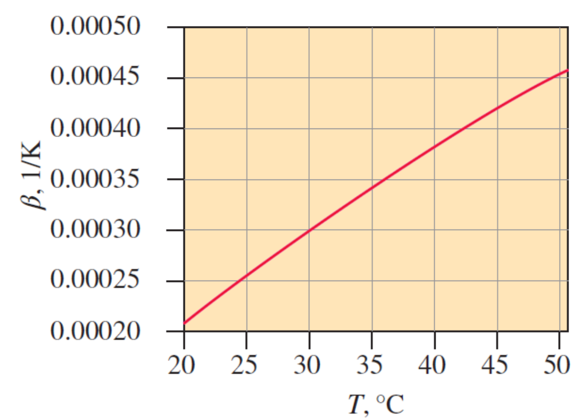
$$\Delta\rho = -\beta\rho\Delta T = -10.0kg/m^3$$

$$\rho2 = \rho1 + \Delta\rho = 988.0\ kg/m^3$$

(b)恒温下，压强由 latm 上升至 100atm 引起的密度变化为

$$\Delta\rho = \alpha\rho\Delta P = 4.7kg/m^3$$

$$\rho2 = \rho1 + \Delta\rho = 1002.7\ kg/m^3$$



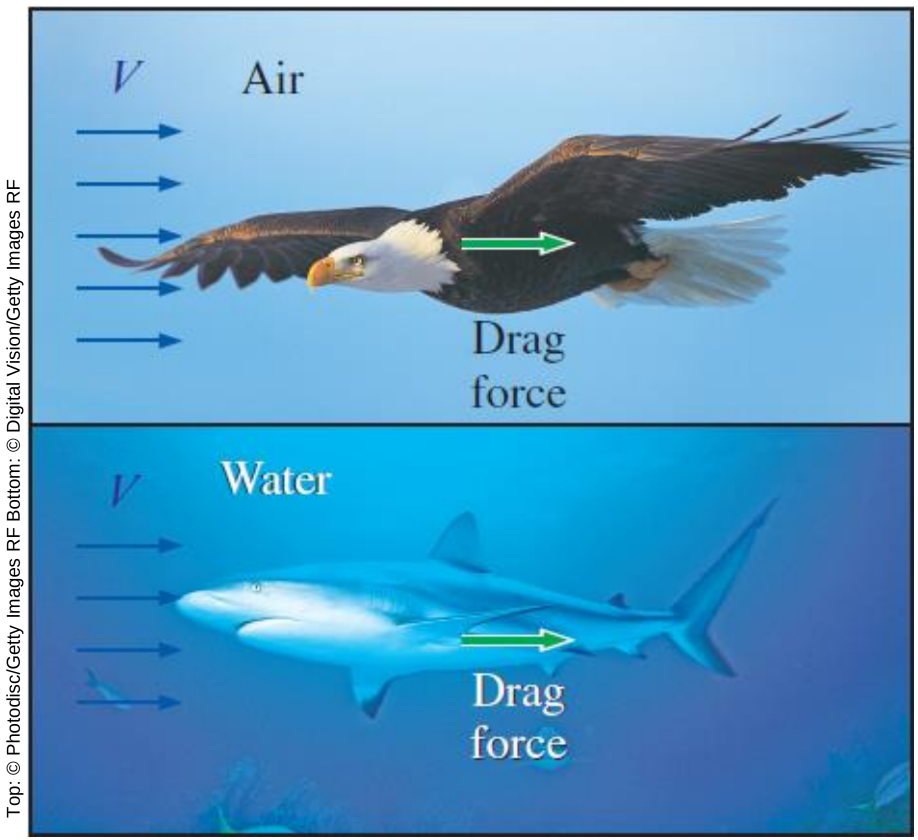
【讨论】如预想一样，当水加热时密度降低，而压缩时密度增加。

2–6 黏度

Viscosity (黏度): A property that represents the internal resistance of a fluid to motion or the “fluidity” (表示流体对运动或流动性内部阻力的一个性质).

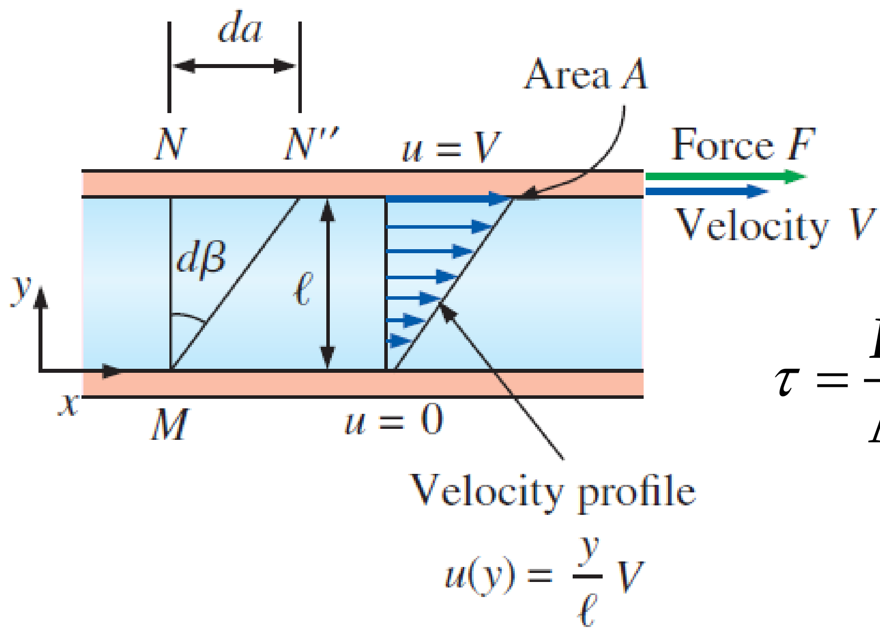
Drag force (阻力): The force a flowing fluid exerts on a body in the flow direction (流动流体在流动方向上作用于物体的力).

The magnitude of drag force depends, *in part, on viscosity*.



A fluid moving relative to a body exerts a drag force on the body, *partly because of friction caused by viscosity*.

2–6 黏度



$$\tau = \frac{F}{A}$$

The behavior of a fluid *in laminar flow (层流流动)* between two parallel plates when the upper plate moves with a constant velocity.

$$u(y) = \frac{y}{\ell}V \quad \text{and} \quad \frac{du}{dy} = \frac{V}{\ell}$$

$$d\beta \approx \tan d\beta = \frac{da}{\ell} = \frac{Vdt}{\ell} = \frac{du}{dy}dt \qquad \frac{d\beta}{dt} = \frac{du}{dy}$$

Newtonian fluids (牛顿流体): Fluids for which the rate of deformation is proportional to the shear stress.

$$\tau \propto \frac{d\beta}{dt} \quad \text{or} \quad \tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy} \qquad \left(\mathrm{N/m^2}\right)$$

Shear stress (切应力)

Shear force (剪切力)

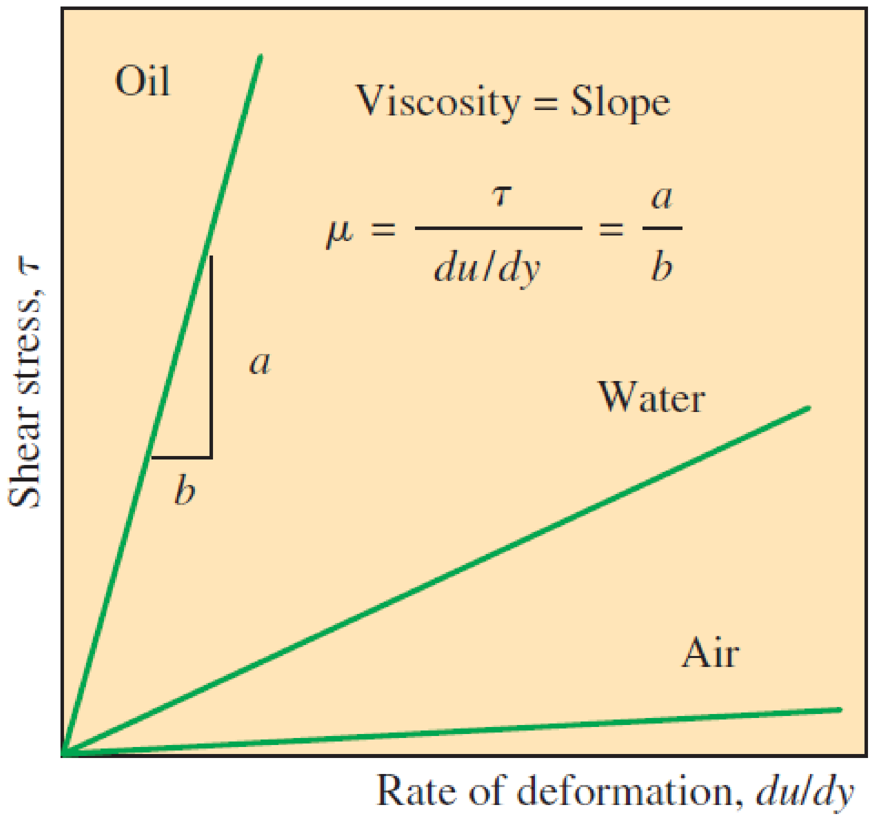
$$F = \tau A = \mu A \frac{du}{dy} \qquad (\mathrm{N})$$

μ coefficient of (dynamic) viscosity (黏性系数或动力黏度)

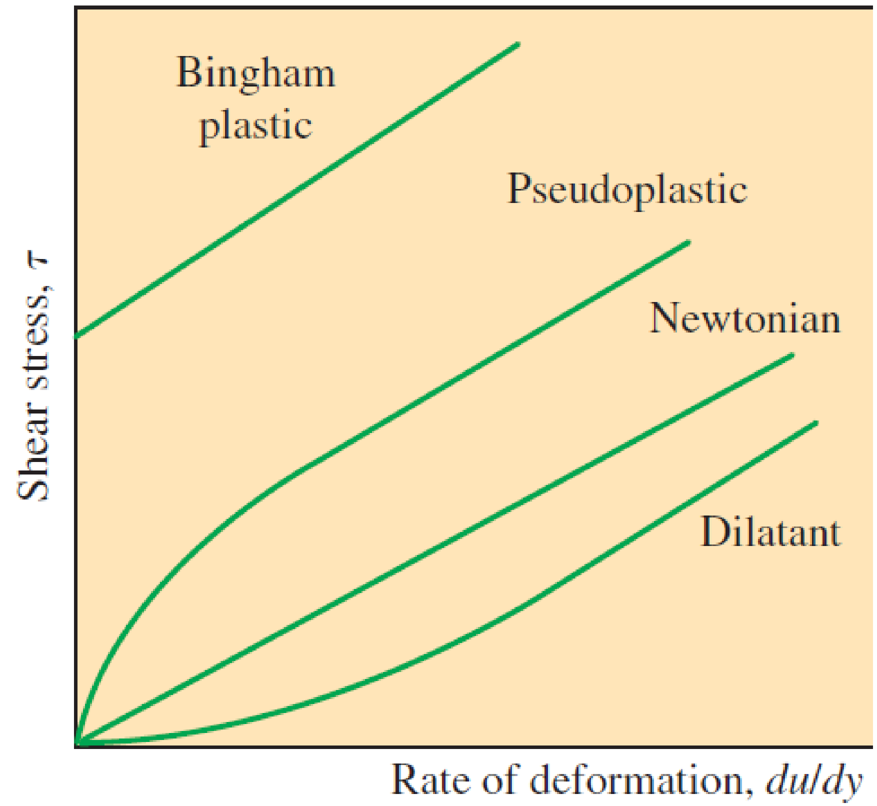
kg/m·s or N·s/m^2 or Pa·s

1 poise = 0.1 Pa·s

2–6 黏度



The rate of deformation (velocity gradient) of a Newtonian fluid (牛顿流体) is proportional to shear stress (切应力), and the constant of proportionality is the viscosity.



Variation of shear stress with the rate of deformation for Newtonian and non-Newtonian fluids (the slope of a curve at a point is the apparent viscosity **(动力黏度)** of the fluid at that point).

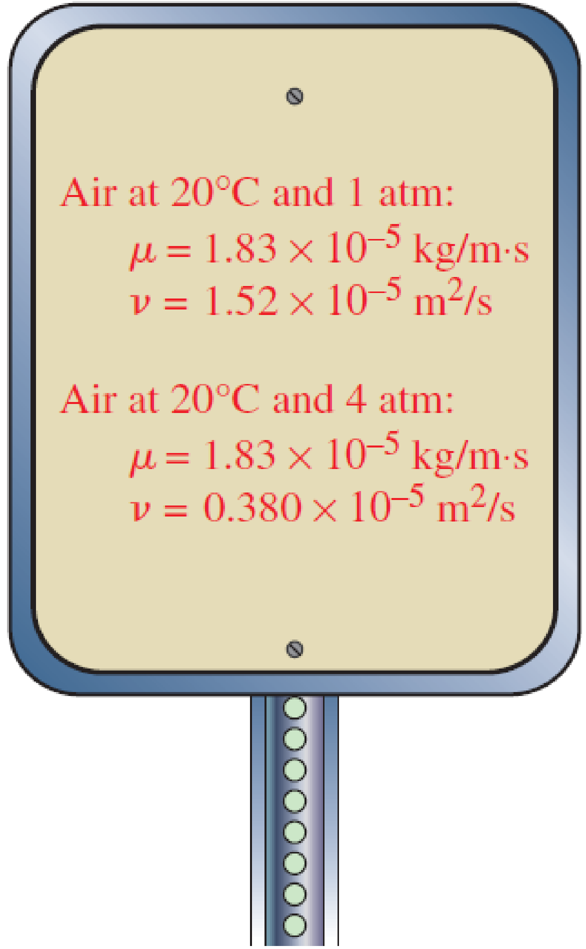
2–6 黏度

Kinematic viscosity (运动粘度)

$$\nu = \mu/\rho \qquad \mathrm{m^2/s}$$

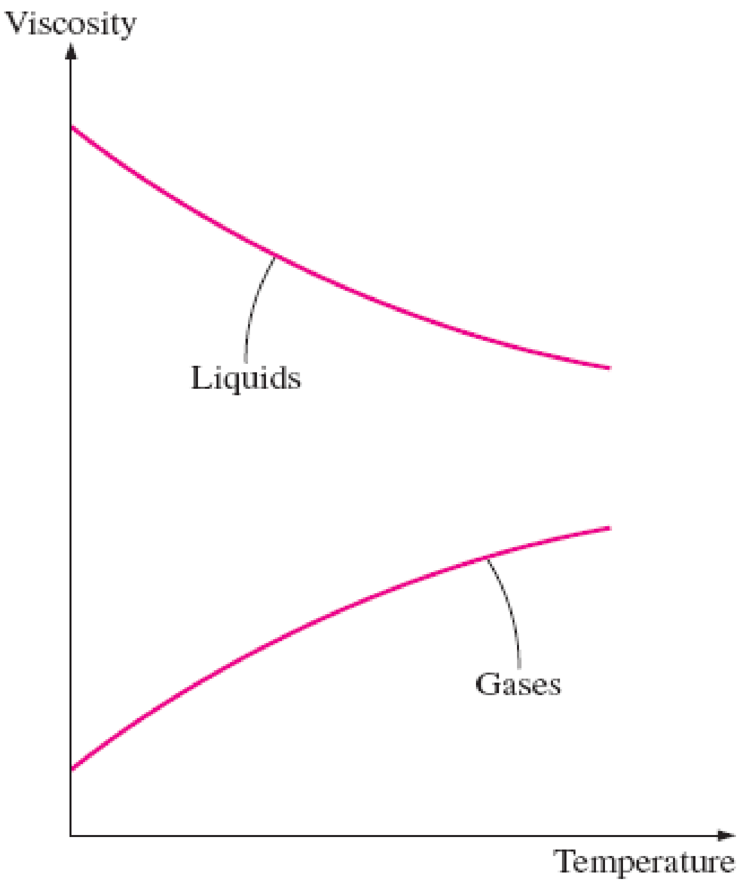
For *liquids*, both the dynamic and kinematic viscosities are practically *independent of pressure*, and any small variation with pressure is usually disregarded, except at extremely high pressures.

For *gases*, this is also the case for dynamic viscosity (at low to moderate pressures), but not for kinematic viscosity since the density of a gas is proportional to its pressure.



Dynamic viscosity (动力黏度), in general, does not *depend on pressure*, but kinematic viscosity does.

2–6 黏度



The viscosity of liquids decreases and the viscosity of gases increases with temperature.

The viscosity of a fluid is directly related to the pumping power needed to transport a fluid in a pipe or to move a body through a fluid.

Viscosity (黏度) is caused by the cohesive forces (内聚力) between the molecules in liquids and by the molecular collisions (分子碰撞) in gases, and it *varies greatly with temperature.*

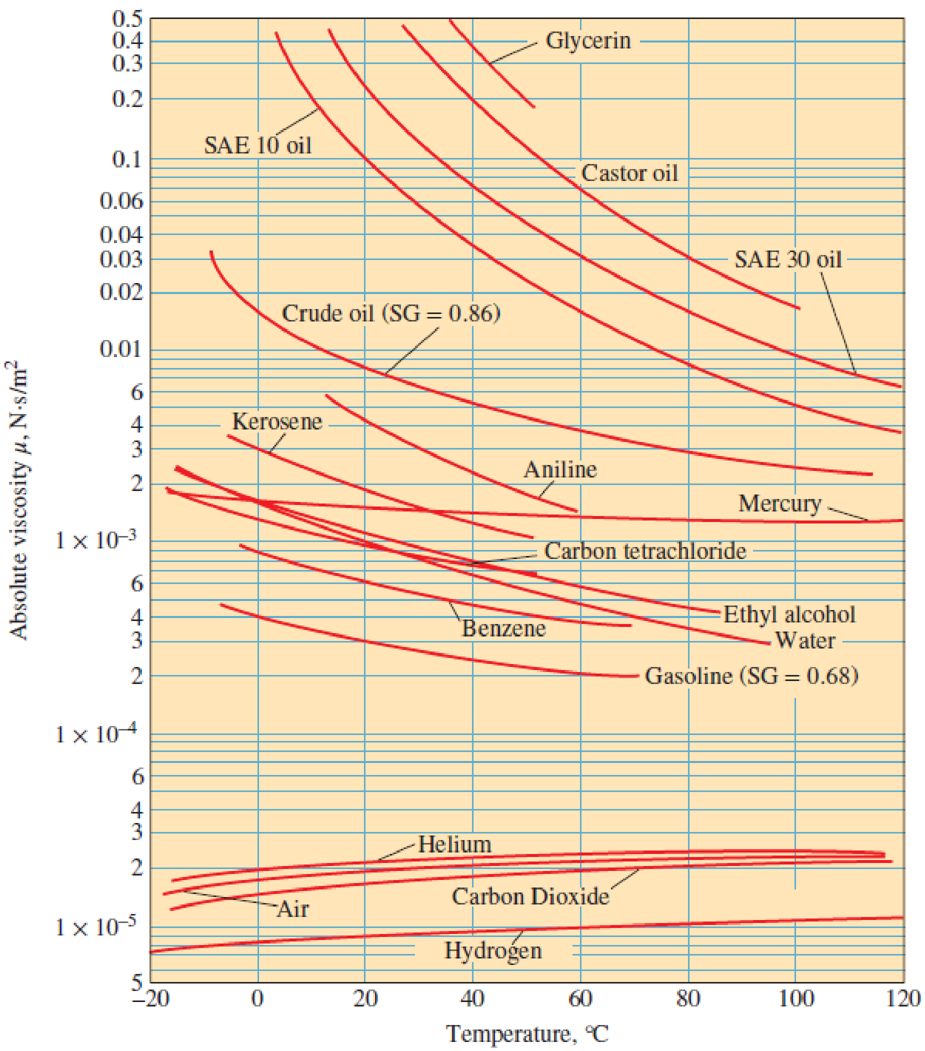
$$\mu = \frac{aT^{1/2}}{1+b/T} \qquad \textit{For gases}$$

$$\mu = a10^{b/(T-c)} \qquad \textit{For liquids}$$

In a liquid, the molecules possess more energy at higher temperatures, and they can oppose the large cohesive intermolecular forces more strongly. As a result, the energized liquid molecules can move more freely.

In a gas, the intermolecular forces are negligible, and *the gas molecules at high temperatures move randomly at higher velocities*. This results in more molecular collisions per unit volume per unit time and therefore in greater resistance to flow.

2–6 黏度



The variation of dynamic viscosity (动力黏度) of common fluids with temperature at 1 atm

(1 N·s/m^2 = 1 kg/m·s = 0.020886 lbf·s/ft^2)

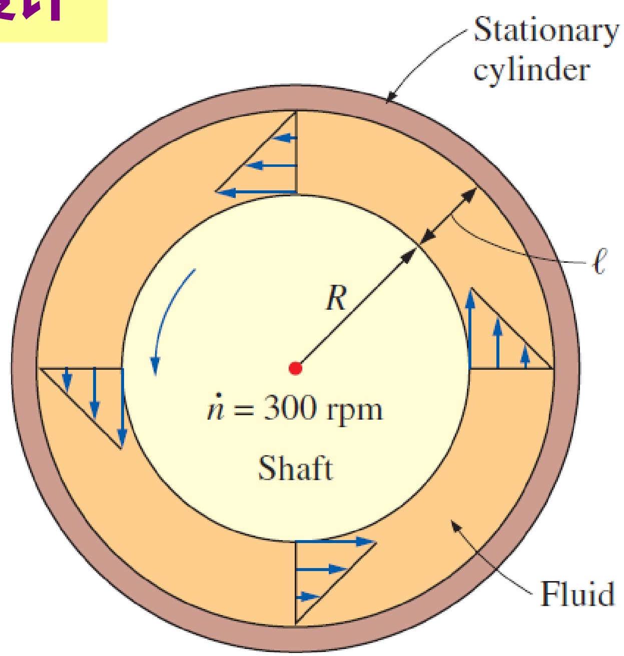
TABLE 2–3

Dynamic viscosity of some fluids at 1 atm and 20°C (unless otherwise stated)

Fluid	Dynamic Viscosity μ, kg/m·s
Glycerin:	
-20°C	134.0
0°C	10.5
20°C	1.52
40°C	0.31
Engine oil:	
SAE 10W	0.10
SAE 10W30	0.17
SAE 30	0.29
SAE 50	0.86
Mercury	0.0015
Ethyl alcohol	0.0012
Water:	
0°C	0.0018
20°C	0.0010
100°C (liquid)	0.00028
100°C (vapor)	0.000012
Blood, 37°C	0.00040
Gasoline	0.00029
Ammonia	0.00015
Air	0.000018
Hydrogen, 0°C	0.0000088

2–6 黏度

黏度计



L length of the cylinder

$\dot{n}$ number of revolutions per unit time

$$\mathrm{T}=FR=\mu\frac{2\pi R^3\omega L}{\ell}=\mu\frac{4\pi^2R^3\dot{n}L}{\ell}$$

$$\omega=2\pi\dot{n}$$ Rad/min

This equation can be used to calculate the viscosity of a fluid by measuring torque (转矩) at a specified angular velocity.

Therefore, two concentric cylinders can be used as a ***viscometer*** (黏度计), a device that measures viscosity.

练习2-2

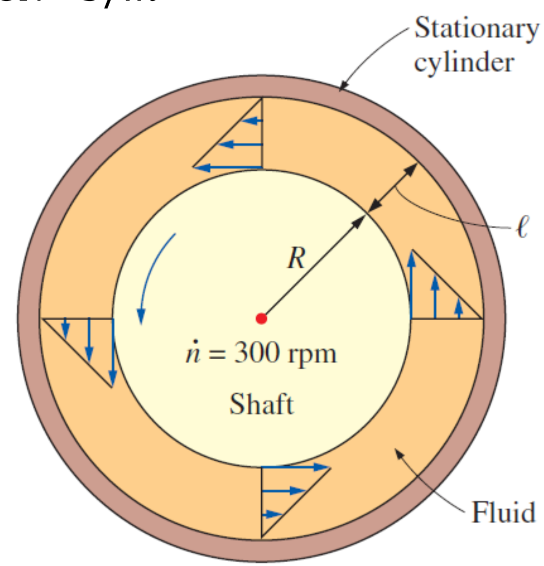
求流体黏度

流体黏度是由两个40cm 长的同心圆构成的黏度计测量的（图）。内圆筒的外径为 12cm，两个圆筒之间的间隙为0.15cm。内筒的转速为300rpm，测量到的转矩为 1.8N·m。求流体黏度。

【解】： 已知双圆筒黏度计的转矩和转速，求流体黏度。(假设: 1. D内圆筒完全浸入流体中，2. 内圆筒两端的黏滞效应忽略不计)

$$\mu = \frac{Tl}{4\pi^2 R^3 \dot{n} L} = \frac{(1.8\ N\cdot m)(0.0015m)}{4\pi^2(0.06m)^3\left(300\,\frac{1}{min}\right)\left(\frac{1min}{60s}\right)(0.4m)} = 0.158N\cdot s/m^2$$

【注意】黏度受温度影响较大，不给出对应温度的黏度数据毫无意义。因此，实验过程中应该测量流体温度，并在计算中给出。



2–7 表面张力与毛细现象

Liquid droplets behave like small balloons filled with the liquid on a solid surface, and the surface of the liquid acts like a stretched elastic membrane under tension.

The pulling force (拉力) that causes this tension acts parallel to the surface and is due to the *attractive forces* (引力) between the molecules of the liquid.

The magnitude of this force per unit length is called **surface tension, σ_s (表面张力)** and is usually expressed in the unit N/m.

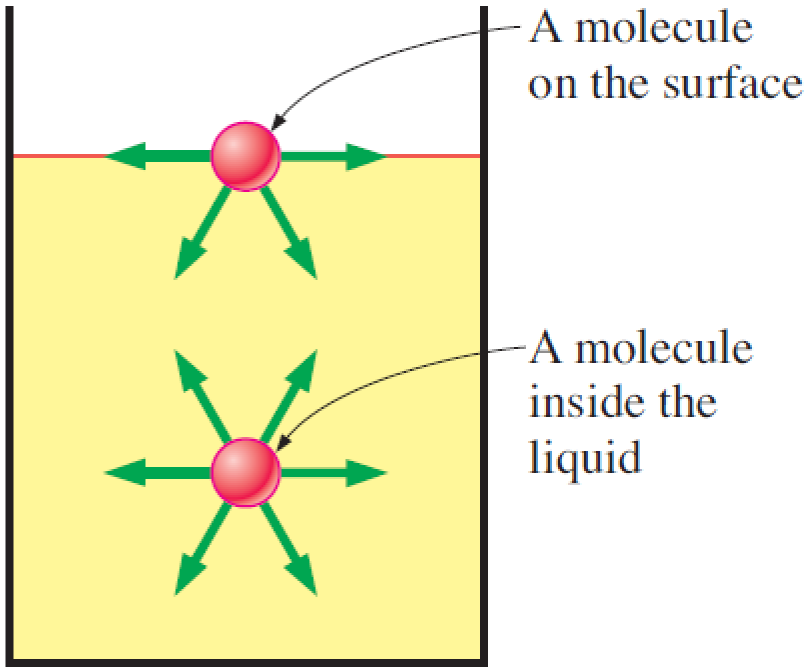
This effect is also called *surface energy (表面能)* [per unit area] and is expressed in the equivalent unit of N·m/m^2 (J /m^2).

2–7 表面张力与毛细现象

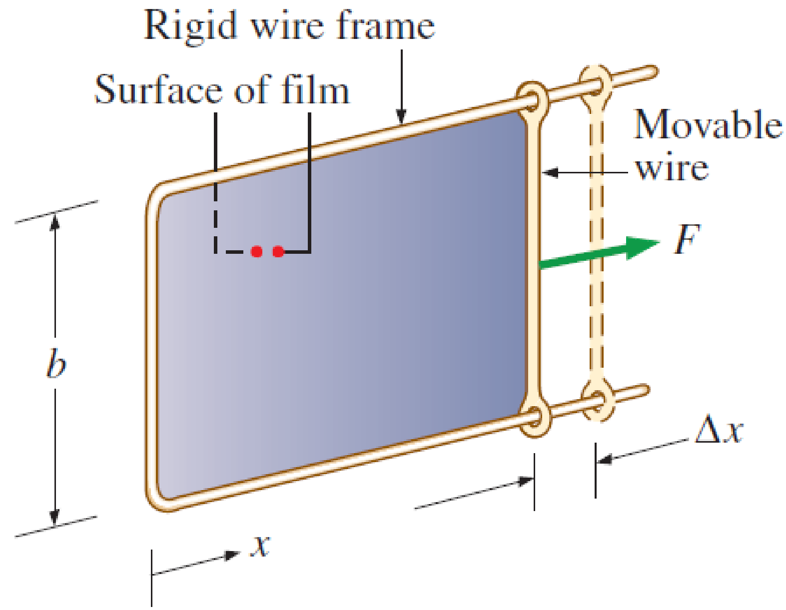
(*a*)

(*b*)

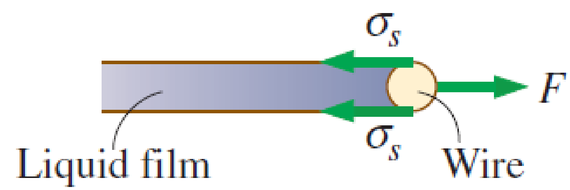
Some consequences of surface tension: (*a) drops of water beading up on a leaf,* (*b) a water strider sitting on top of the* surface of water).



Attractive forces acting on a liquid molecule at the surface and deep inside the liquid.



$$\sigma_s = \frac{F}{2b}$$



Stretching a liquid film with a U-shaped wire, and the forces acting on the movable wire of length *b*.

$$W = \text{Force} \times \text{Distance} = F\Delta x = 2b\sigma_s \Delta x = \sigma_s \Delta A$$

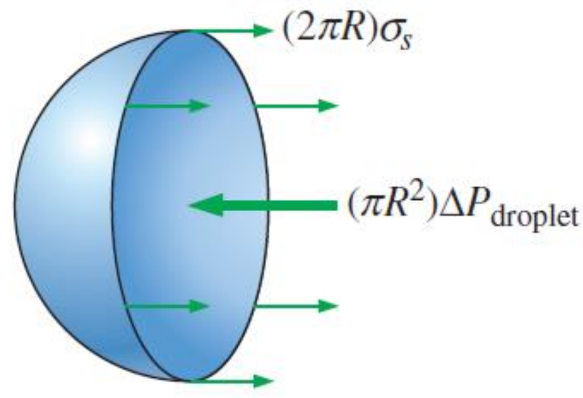
Surface tension (表面张力):

- magnitude of the pulling force per unit length. (N/m)
- The work done per unit increase in the surface area of the liquid. (J /m^2)

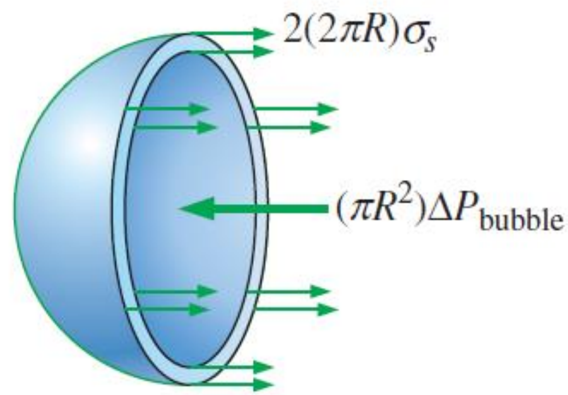
TABLE 2–4

Surface tension of some fluids in air at 1 atm and 20°C (unless otherwise stated)

Fluid	Surface Tension σ_s, N/m
Water:	
0°C	0.076
20°C	0.073
100°C	0.059
300°C	0.014
Glycerin	0.063
SAE 30 oil	0.035
Mercury	0.440
Ethyl alcohol	0.023
Blood, 37°C	0.058
Gasoline	0.022
Ammonia	0.021
Soap solution	0.025
Kerosene	0.028



(a) Half of a droplet or air bubble



(b) Half of a soap bubble

The free-body diagram of half a droplet or air bubble and half a soap bubble.

$$\textit{Droplet or air bubble:} \quad (2\pi R)\sigma_s = (\pi R^2)\Delta P_{\text{droplet}} \rightarrow \Delta P_{\text{droplet}} = P_i - P_o = \frac{2\sigma_s}{R}$$

$$\textit{Soap bubble:} \quad 2(2\pi R)\sigma_s = (\pi R^2)\Delta P_{\text{bubble}} \rightarrow \Delta P_{\text{bubble}} = P_i - P_o = \frac{4\sigma_s}{R}$$

2–7 表面张力与毛细现象

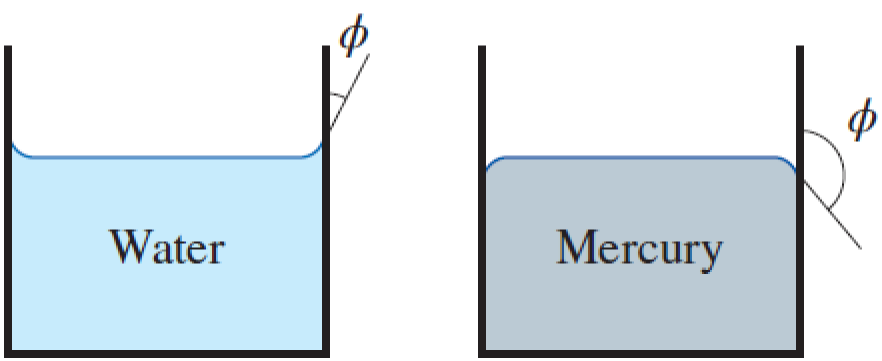
Capillary Effect

Capillary effect (毛细现象): The rise or fall of a liquid in a small-diameter tube inserted into the liquid.

Capillaries (毛细管): Such narrow tubes or confined flow channels.

Meniscus (弯月面): The curved free surface of a liquid in a capillary tube.

The strength of the capillary effect is quantified by the **contact** (or *wetting*) **angle** (接触角), defined as *the angle that the tangent to the liquid surface makes with the solid surface at the point of contact*.

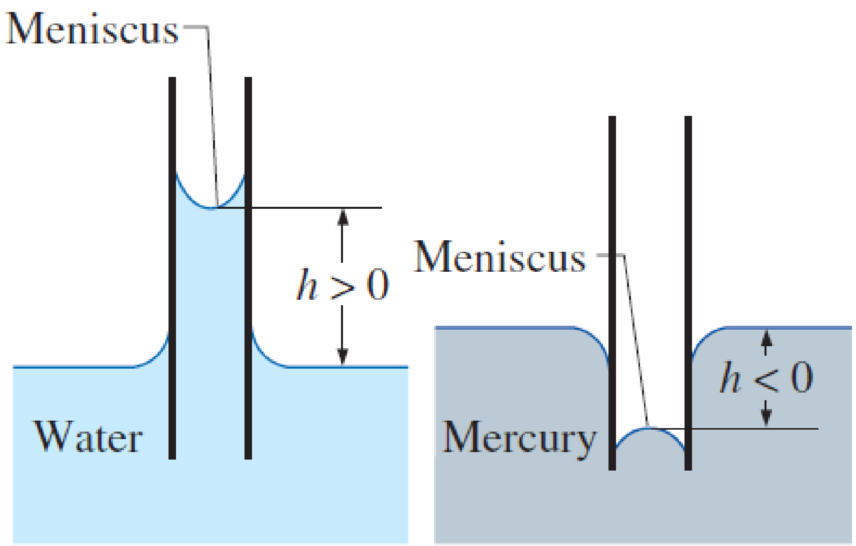


(*a*) Wetting fluid

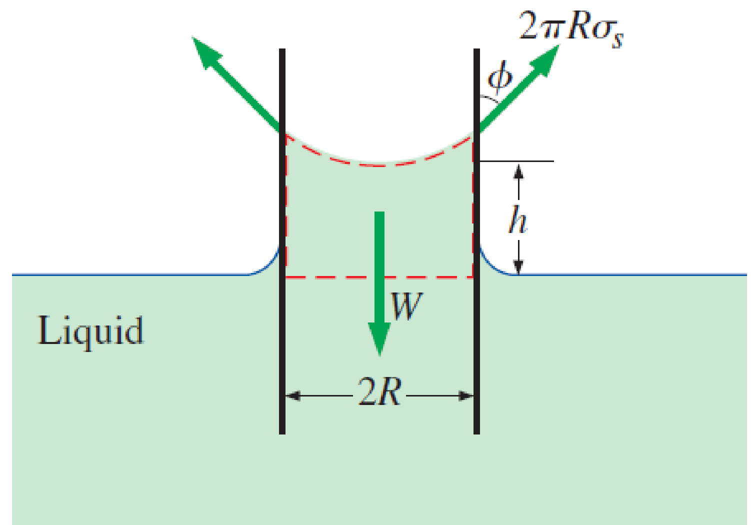
(*b*) Nonwetting fluid

The contact angle for wetting and nonwetting fluids.

2–7 表面张力与毛细现象



The capillary rise of water and the capillary fall of mercury in a small-diameter glass tube.



The forces acting on a liquid column that has risen in a tube due to the capillary effect.

$$\textit{Capillary rise}: \quad h = \frac{2\sigma_s}{\rho g R}\cos\phi \quad (R = \text{constant})$$

Capillary rise is inversely proportional to the *radius of the tube* and *density of the liquid*.