[Template:Pp-move-indef](/wiki/Template:Pp-move-indef" \o "Template:Pp-move-indef) [Template:Infobox Physical quantity](/wiki/Template:Infobox_Physical_quantity) The **viscosity** of a [fluid](/wiki/Fluid) is a measure of its [resistance](/wiki/Drag_(physics)) to gradual deformation by [shear stress](/wiki/Shear_stress) or [tensile stress](/wiki/Tensile_stress).[[1]](#cite_note-1) However, other authors dispute this hypothesis, claiming instead that there is some threshold for the stress, below which most solids will not flow at all,[[9]](#cite_note-9) and that alleged instances of glass flow in window panes of old buildings are due to the crude manufacturing process of older eras rather than to the viscosity of glass.[[10]](#cite_note-10) Viscoelastic solids may exhibit both shear viscosity and bulk viscosity. The [extensional viscosity](/wiki/Extensional_viscosity) is a [linear combination](/wiki/Linear_combination) of the shear and bulk viscosities that describes the reaction of a solid elastic material to elongation. It is widely used for characterizing polymers.

In [geology](/wiki/Geology), earth materials that exhibit viscous deformation at least three orders of magnitude greater than their elastic deformation are sometimes called [rheids](/wiki/Rheid).[[11]](#cite_note-11)

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## Viscosity measurement[[edit](/index.php?title=(none)&action=edit&section=9)]

[Template:Main](/wiki/Template:Main) Viscosity is measured with various types of [viscometers](/wiki/Viscometer) and [rheometers](/wiki/Rheometer). A rheometer is used for those fluids that cannot be defined by a single value of viscosity and therefore require more parameters to be set and measured than is the case for a viscometer. Close temperature control of the fluid is essential to acquire accurate measurements, particularly in materials like lubricants,[[12]](#cite_note-12) whose viscosity can double with a change of only 5 °C.

For some fluids, viscosity is a constant over a wide range of shear rates ([Newtonian fluids](/wiki/Newtonian_fluids)). The fluids without a constant viscosity ([non-Newtonian fluids](/wiki/Non-Newtonian_fluid)) cannot be described by a single number. Non-Newtonian fluids exhibit a variety of different correlations between shear stress and shear rate.

One of the most common instruments for measuring kinematic viscosity is the glass capillary viscometer.

In [coating](/wiki/Coating) industries, viscosity may be measured with a cup in which the [efflux time](/wiki/Efflux_time) is measured. There are several sorts of cup- e.g. [Zahn cup](/wiki/Zahn_cup), [Ford viscosity cup](/wiki/Ford_viscosity_cup)- with usage of each type varying mainly according to the industry. The efflux time can also be converted to kinematic viscosities (centistokes, cSt) through the conversion equations.[[13]](#cite_note-13) Also used in coatings, a Stormer viscometer uses load-based rotation in order to determine viscosity. The viscosity is reported in Krebs units (KU), which are unique to Stormer viscometers.

Vibrating viscometers can also be used to measure viscosity. These models such as the *Dynatrol* use vibration rather than rotation to measure viscosity.

*Extensional viscosity* can be measured with various [rheometers](/wiki/Rheometer) that apply [extensional stress](/wiki/Extensional_stress).

[Volume viscosity](/wiki/Volume_viscosity) can be measured with an [acoustic rheometer](/wiki/Acoustic_rheometer).

[Apparent viscosity](/wiki/Apparent_viscosity) is a calculation derived from tests performed on [drilling fluid](/wiki/Drilling_fluid) used in oil or gas well development. These calculations and tests help engineers develop and maintain the properties of the drilling fluid to the specifications required.

## Units[[edit](/index.php?title=(none)&action=edit&section=10)]

### Dynamic viscosity ''μ''[[edit](/index.php?title=(none)&action=edit&section=11)]

Both the [physical unit](/wiki/Physical_unit) of dynamic viscosity in [SI](/wiki/SI) Poiseuille (Pl) and the cgs units Poise (P) come from [Jean Léonard Marie Poiseuille](/wiki/Jean_Léonard_Marie_Poiseuille). The [poiseuille](/wiki/Poiseuille), which is rarely used, is equivalent to the [pascal](/wiki/Pascal_(unit))-[second](/wiki/Second) (Pa·s), or (N·s)/m2, or kg/(m·s). If a [fluid](/wiki/Fluid) is placed between two plates with distance one [meter](/wiki/Meter), and one plate is pushed sideways with a [shear stress](/wiki/Shear_stress) of one [pascal](/wiki/Pascal_(unit)), and it moves at x meter per [second](/wiki/Second), then it has viscosity of 1/x Pascal second. For example, water at 20 °C has a viscosity of 1.002 mPa·s, while a typical motor oil could have a viscosity of about 250  mPa·s.[[14]](#cite_note-14) The units used in practice are either Pa·s and its submultiples or the cgs Poise referred to below, and its submultiples.

The [cgs](/wiki/Cgs) [physical unit](/wiki/Physical_unit) for dynamic viscosity, the [*poise*](/wiki/Poise)[[15]](#cite_note-15) (P), is also named after Jean Poiseuille. It is more commonly expressed, particularly in [ASTM](/wiki/ASTM) standards, as *centipoise* (cP) since the latter is equal to the SI multiple milliPascal seconds (mPa·s). For example, water at 20 °C has a viscosity of 1.002 mPa·s = 1.0020 cP.

1Pl = 1Pa·s

1 P = 0.1 Pa·s= 0.1 kg·m−1·s−1

1 cP = 1 mPa·s = 0.001 Pa·s = 0.001 N·s·m−2 = 0.001 kg·m−1·s−1.

### {{anchor|Stokes (unit)}}Kinematic viscosity <math>\nu</math>[[edit](/index.php?title=(none)&action=edit&section=12)]

The SI unit of kinematic viscosity is m2/s.

The cgs physical unit for kinematic viscosity is the *stokes* (St), named after [George Gabriel Stokes](/wiki/George_Gabriel_Stokes). It is sometimes expressed in terms of *centistokes* (cSt). In U.S. usage, *stoke* is sometimes used as the singular form.

1 St = 1 cm2·s−1 = 10−4 m2·s−1.

1 cSt = 1 mm2·s−1 = 10−6 m2·s−1.

Water at 20 °C has a kinematic viscosity of about 10−6 m2·s−1 or 1 cSt.

The kinematic viscosity is sometimes referred to as *diffusivity of momentum*, because it is analogous to [diffusivity of heat](/wiki/Thermal_diffusivity) and [diffusivity of mass](/wiki/Diffusion_coefficient). It is therefore used in [dimensionless numbers](/wiki/Dimensionless_number) which compare the ratio of the diffusivities.

### Fluidity[[edit](/index.php?title=(none)&action=edit&section=13)]

The [reciprocal](/wiki/Multiplicative_inverse) of viscosity is *fluidity*, usually symbolized by *φ* = 1 / *μ* or *F* = 1 / *μ*, depending on the convention used, measured in *reciprocal poise* ([cm](/wiki/Centimetre)·[s](/wiki/Second)·[g](/wiki/Gram)−1), sometimes called the *rhe*. *Fluidity* is seldom used in [engineering](/wiki/Engineering) practice.

The concept of fluidity can be used to determine the viscosity of an [ideal solution](/wiki/Ideal_solution). For two components <math>a</math> and <math>b</math>, the fluidity when *a* and *b* are mixed is

<math>F \approx \chi\_a F\_a + \chi\_b F\_b,</math>,

which is only slightly simpler than the equivalent equation in terms of viscosity:

<math>\mu \approx \frac{1}{\chi\_a /\mu\_a + \chi\_b/\mu\_b},</math>

where *χa* and *χb* is the mole fraction of component *a* and *b* respectively, and *μa* and *μb* are the components' pure viscosities.

### Non-standard units[[edit](/index.php?title=(none)&action=edit&section=14)]

The [Reyn](/wiki/Reyn) is a British unit of dynamic viscosity.

[Viscosity index](/wiki/Viscosity_index) is a measure for the change of [kinematic viscosity](/wiki/Kinematic_viscosity) with temperature. It is used to characterise lubricating oil in the automotive industry.

At one time the petroleum industry relied on measuring [kinematic viscosity](/wiki/Kinematic_viscosity) by means of the Saybolt viscometer, and expressing kinematic viscosity in units of [*Saybolt Universal Seconds*](/wiki/Saybolt_Universal_Second) (SUS).[[16]](#cite_note-16) Other abbreviations such as SSU (*Saybolt Seconds Universal*) or SUV (*Saybolt Universal Viscosity*) are sometimes used. Kinematic viscosity in centistoke can be converted from SUS according to the arithmetic and the reference table provided in [ASTM](/wiki/ASTM) D 2161.[[17]](#cite_note-17)

## Molecular origins[[edit](/index.php?title=(none)&action=edit&section=15)]

[thumb|right|](/wiki/File:University_of_Queensland_Pitch_drop_experiment-white_bg.jpg)[Pitch](/wiki/Pitch_drop_experiment) has a viscosity approximately 230 billion (2.3[Template:E](/wiki/Template:E)) times that of water.[[18]](#cite_note-18) The viscosity of a system is determined by how molecules constituting the system interact. There are no simple but correct expressions for the viscosity of a fluid. The simplest exact expressions are the [Green–Kubo relations](/wiki/Green–Kubo_relations) for the linear shear viscosity or the [Transient Time Correlation Function](/wiki/Transient_Time_Correlation_Function) expressions derived by Evans and Morriss in 1985.[[19]](#cite_note-19) Although these expressions are each exact, in order to calculate the viscosity of a dense fluid using these relations currently requires the use of [molecular dynamics](/wiki/Molecular_dynamics) computer simulations.

### Gases[[edit](/index.php?title=(none)&action=edit&section=16)]

Viscosity in gases arises principally from the molecular diffusion that transports momentum between layers of flow. The kinetic theory of gases allows accurate prediction of the behavior of gaseous viscosity.

Within the regime where the theory is applicable:

* Viscosity is independent of pressure and
* Viscosity increases as temperature increases.<ref name=physicsinfo>[Template:Cite web](/wiki/Template:Cite_web)</ref>

[James Clerk Maxwell](/wiki/James_Clerk_Maxwell) published a famous paper in 1866 using the kinetic theory of gases to study gaseous viscosity.<ref name=Maxwell1866>[Template:Cite journal](/wiki/Template:Cite_journal)</ref> To understand why the viscosity is independent of pressure, consider two adjacent boundary layers (A and B) moving with respect to each other. The internal friction (the viscosity) of the gas is determined by the probability a particle of layer A enters layer B with a corresponding transfer of momentum. Maxwell's calculations show that the viscosity coefficient is proportional to the density, the mean free path, and the mean velocity of the atoms. On the other hand, the *mean free path* is inversely proportional to the density. So an increase in density due to an increase in pressure doesn't result in any change in viscosity.

#### Relation to mean free path of diffusing particles[[edit](/index.php?title=(none)&action=edit&section=17)]

In relation to diffusion, the kinematic viscosity provides a better understanding of the behavior of mass transport of a dilute species. Viscosity is related to shear stress and the rate of shear in a fluid, which illustrates its dependence on the mean free path, *λ*, of the diffusing particles.

From [fluid mechanics](/wiki/Fluid_mechanics), for a [Newtonian fluid](/wiki/Newtonian_fluid), the [shear stress](/wiki/Shear_stress), *τ*, on a unit area moving parallel to itself, is found to be proportional to the rate of change of velocity with distance perpendicular to the unit area:

<math>\tau = \mu \frac{\mathrm{d}u\_x}{\mathrm{d}y}</math>

for a unit area parallel to the x-z plane, moving along the x axis. We will derive this formula and show how *μ* is related to *λ*.

Interpreting shear stress as the time rate of change of [momentum](/wiki/Momentum), *p*, per unit area *A* (rate of momentum flux) of an arbitrary control surface gives

<math>\tau = \frac{\dot{p}}{A} = \frac{\dot{m} \langle u\_x \rangle}{A}.</math>

where <math>\langle u\_x \rangle</math> is the average velocity, along the x axis, of fluid molecules hitting the unit area, with respect to the unit area and <math>\dot{m}</math> is the rate of fluid mass hitting the surface.

By making simplified assumption that the velocity of the molecules depends linearly on the distance they are coming from, the mean velocity depends linearly on the mean distance:

<math>\langle u\_x \rangle = \lambda\frac{\mathrm{d}u\_x}{\mathrm{d}y}</math>.

Further manipulation will show,[[20]](#cite_note-20)

<math>\dot{m} = \rho \bar{u} A </math>

<math>\tau = \underbrace{\rho \bar{u} \lambda}\_{\mu} \cdot \frac{\mathrm{d}u\_x}{\mathrm{d}y} \; \; \Rightarrow \; \; \nu = \frac{\mu}{\rho} = \bar{u} \lambda,</math>

where

*ρ* is the density of the fluid,

*ū* is the average molecular speed (<math>\bar{u} = \sqrt{\langle u^2 \rangle}</math>),

*μ* is the dynamic viscosity.

Note, that the mean free path itself typically depends (inversely) on the density.

#### Effect of temperature on the viscosity of a gas[[edit](/index.php?title=(none)&action=edit&section=18)]

*Sutherland's formula* can be used to derive the dynamic viscosity of an [ideal gas](/wiki/Ideal_gas) as a function of the temperature:[[21]](#cite_note-21)

<math> {\mu} = {\mu}\_0 \frac {T\_0+C} {T + C} \left (\frac {T} {T\_0} \right )^{3/2}.</math>

This in turn is equal to

<math>\lambda\,\frac{T^{3/2}}{T+C}\,,</math>  where  <math>\lambda = \frac{\mu\_0(T\_0+C)}{T\_0^{3/2}}\,</math>  is a constant for the gas.

in Sutherland's formula:

* *μ* = dynamic viscosity (Pa·s or μPa·s) at input temperature *T*,
* *μ0* = reference viscosity (in the same units as μ) at reference temperature *T0*,
* *T* = input temperature (kelvin),
* *T0* = reference temperature (kelvin),
* *C* = Sutherland's constant for the gaseous material in question.

Valid for temperatures between 0 < *T* < 555 K with an error due to pressure less than 10% below 3.45 MPa.

According to Sutherland's formula, if the absolute temperature is less than C, the relative change in viscosity for a small change in temperature is greater than the relative change in the absolute temperature, but it is smaller when T is above C. The kinematic viscosity though always increases faster than the temperature (that is, d log(ν)/d log(T) is greater than 1).

Sutherland's constant, reference values and λ values for some gases:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Gas** | ***C* [K]** | ***T0* [K]** | ***μ0* [μPa s]** | ***λ* [μPa s K−1/2]** |
| [air](/wiki/Air) | 120 | 291.15 | 18.27 | 1.512041288 |
| [nitrogen](/wiki/Nitrogen) | 111 | 300.55 | 17.81 | 1.406732195 |
| [oxygen](/wiki/Oxygen) | 127 | 292.25 | 20.18 | 1.693411300 |
| [carbon dioxide](/wiki/Carbon_dioxide) | 240 | 293.15 | 14.8 | 1.572085931 |
| [carbon monoxide](/wiki/Carbon_monoxide) | 118 | 288.15 | 17.2 | 1.428193225 |
| [hydrogen](/wiki/Hydrogen) | 72 | 293.85 | 8.76 | 0.636236562 |
| [ammonia](/wiki/Ammonia) | 370 | 293.15 | 9.82 | 1.297443379 |
| [sulfur dioxide](/wiki/Sulfur_dioxide) | 416 | 293.65 | 12.54 | 1.768466086 |
| [helium](/wiki/Helium) | 79.4[[22]](#cite_note-22) | 273 | 19<ref name=hyper>[Viscosity of liquids and gases](http://hyperphysics.phy-astr.gsu.edu/Hbase/tables/viscosity.html). hyperphysics.phy-astr.gsu.edu</ref> | 1.484381490 |

#### Viscosity of a dilute gas[[edit](/index.php?title=(none)&action=edit&section=19)]

The [Chapman-Enskog equation](/wiki/Chapman-Enskog_theory)[[23]](#cite_note-23) may be used to estimate viscosity for a dilute gas. This equation is based on a semi-theoretical assumption by Chapman and Enskog. The equation requires three empirically determined parameters: the collision diameter (*σ*), the maximum energy of attraction divided by the [Boltzmann constant](/wiki/Boltzmann_constant) (*є*/*к*) and the collision integral (*ω*(*T\**)).

<math> {\mu}\_0 \times 10^6 = {2.6693}\frac {(MT)^{1/2}} {\sigma^{2}\omega(T^\*)},</math>

with

* *T\** = *κT/ε* — reduced temperature (dimensionless),
* *μ0* = viscosity for dilute gas (μPa.s),
* *M* = molecular mass (g/mol),
* *T* = temperature (K),
* *σ* = the collision diameter (Å),
* *ε* / *κ* = the maximum energy of attraction divided by the Boltzmann constant (K),
* *ωμ* = the collision integral.

### Liquids[[edit](/index.php?title=(none)&action=edit&section=20)]

[thumb|right|Video showing three liquids with different viscosities](/wiki/File:Viscosity_video_science_museum.ogv) In liquids, the additional forces between molecules become important. This leads to an additional contribution to the shear stress though the exact mechanics of this are still controversial.[Template:Citation needed](/wiki/Template:Citation_needed) Thus, in liquids:

* Viscosity is independent of pressure (except at very high pressure); and
* Viscosity tends to fall as temperature increases (for example, water viscosity goes from 1.79 cP to 0.28 cP in the temperature range from 0 °C to 100 °C); see [temperature dependence of liquid viscosity](/wiki/Temperature_dependence_of_liquid_viscosity) for more details.

The dynamic viscosities of liquids are typically several orders of magnitude higher than dynamic viscosities of gases.

#### Viscosity of blends of liquids[[edit](/index.php?title=(none)&action=edit&section=21)]

The viscosity of the blend of two or more liquids can be estimated using the Refutas equation.[[24]](#cite_note-24) The calculation is carried out in three steps.

The first step is to calculate the Viscosity Blending Number (VBN) (also called the Viscosity Blending Index) of each component of the blend:

(1) [Template:Pad](/wiki/Template:Pad) <math>\mbox{VBN} = 14.534 \times \ln\left[ \ln(\nu + 0.8) \right] + 10.975\,</math>

where *ν* is the kinematic viscosity in centistokes (cSt). It is important that the kinematic viscosity of each component of the blend be obtained at the same temperature.

The next step is to calculate the VBN of the blend, using this equation:

(2) [Template:Pad](/wiki/Template:Pad) <math>\mbox{VBN}\_\text{Blend} = \left[ x\_A \times \mbox{VBN}\_A \right] + \left[x\_B \times \mbox{VBN}\_B\right] + \cdots + \left[x\_N \times \mbox{VBN}\_N\right]\,</math>

where *xX* is the [mass fraction](/wiki/Mass_fraction_(chemistry)) of each component of the blend.

Once the viscosity blending number of a blend has been calculated using equation (2), the final step is to determine the kinematic viscosity of the blend by solving equation (1) for *ν*:

(3) [Template:Pad](/wiki/Template:Pad) <math>\nu = \exp\left( \exp\left( \frac{\text{VBN}\_\text{Blend} - 10.975}{14.534} \right) \right) - 0.8,</math>

where *VBNBlend* is the viscosity blending number of the blend.

## Viscosity of selected substances[[edit](/index.php?title=(none)&action=edit&section=22)]

### Air[[edit](/index.php?title=(none)&action=edit&section=23)]

[thumb|right|Pressure dependence of the dynamic viscosity of dry air at the temperatures of 300, 400 and 500 K](/wiki/File:Air_dry_dynamic_visocity_on_pressure_temperature.svg) The viscosity of air depends mostly on the temperature. At 15 °C, the viscosity of air is 1.81[Template:E](/wiki/Template:E) kg/(m·s), 18.1 μPa.s or 1.81[Template:E](/wiki/Template:E) Pa.s. The kinematic viscosity at 15 °C is 1.48[Template:E](/wiki/Template:E) m2/s or 14.8 cSt. At 25 °C, the viscosity is 18.6 μPa.s and the kinematic viscosity 15.7 cSt.

### Water[[edit](/index.php?title=(none)&action=edit&section=24)]

[thumb|Dynamic viscosity of water](/wiki/File:Dynamic_Viscosity_of_Water.png) The [dynamic](/wiki/Dynamics_(mechanics)) viscosity of [water](/wiki/Water) is 8.90 × 10−4 [Pa](/wiki/Pascal_(unit))·[s](/wiki/Second) or 8.90 × 10−3 dyn·s/cm2 or 0.890 cP at about 25 °C.  
Water has a viscosity of 0.0091 poise at 25 °C, or 1 centipoise at 20 °C.  
As a function of temperature *T* (K): (Pa·s) = *A* × 10*B*/(*T*−*C*)  
where *A*=2.414 × 10−5 Pa·s ; *B* = 247.8 K ; and *C* = 140 K.[Template:Citation needed](/wiki/Template:Citation_needed)

Viscosity of liquid water at different temperatures up to the normal boiling point is listed below.

|  |  |
| --- | --- |
| **Temperature [°C]** | **Viscosity [mPa·s]** |
| 10 | 1.308 |
| 20 | 1.002 |
| 30 | 0.7978 |
| 40 | 0.6531 |
| 50 | 0.5471 |
| 60 | 0.4658 |
| 70 | 0.4044 |
| 80 | 0.3550 |
| 90 | 0.3150 |
| 100 | 0.2822 |

### Other substances[[edit](/index.php?title=(none)&action=edit&section=25)]

[thumb|right|Example of the viscosity of milk and water. Liquids with higher viscosities make smaller splashes when poured at the same velocity.](/wiki/File:Drop_0.jpg)

[thumb|](/wiki/File:Runny_hunny.jpg)[Honey](/wiki/Honey) being drizzled. [thumb|](/wiki/File:PeanutButter.jpg)[Peanut butter](/wiki/Peanut_butter) is a [semi-solid](/wiki/Semi-solid) and can therefore hold peaks.

Some dynamic viscosities of Newtonian fluids are listed below:

|  |  |  |
| --- | --- | --- |
| Viscosity of selected gases at 100 kPa, [μPa·s] | | |
| [**Gas**](/wiki/Gas) | **at 0 °**[**C**](/wiki/Celsius) **(273 K)** | **at 27 °C (300 K)**[**[25]**](#cite_note-25) |
| [air](/wiki/Earth's_atmosphere) | 17.4 | 18.6 |
| [hydrogen](/wiki/Hydrogen) | 8.4 | 9.0 |
| [helium](/wiki/Helium) |  | 20.0 |
| [argon](/wiki/Argon) |  | 22.9 |
| [xenon](/wiki/Xenon) | 21.2 | 23.2 |
| [carbon dioxide](/wiki/Carbon_dioxide) |  | 15.0 |
| [methane](/wiki/Methane) |  | 11.2 |
| [ethane](/wiki/Ethane) |  | 9.5 |

|  |  |  |  |
| --- | --- | --- | --- |
| +Viscosity of [fluids](/wiki/Fluid) with variable compositions | **Fluid** | **Viscosity [Pa·s]** | **Viscosity [cP]** |
| [blood](/wiki/Blood) (37 °C)<ref name=r1/> | (3–4)[Template:E](/wiki/Template:E) | 3–4 |  |
| [honey](/wiki/Honey) | 2–10[[26]](#cite_note-26) | 2,000–10,000 |  |
| [molasses](/wiki/Molasses) | 5–10 | 5,000–10,000 |  |
| molten [glass](/wiki/Glass) | 10–1,000 | 10,000–1,000,000 |  |
| [chocolate syrup](/wiki/Chocolate_syrup) | 10–25 | 10,000–25,000 |  |
| molten [chocolate](/wiki/Chocolate)\* | 45–130[[27]](#cite_note-27) | 45,000–130,000 |  |
| [ketchup](/wiki/Ketchup)\* | 50–100 | 50,000–100,000 |  |
| [lard](/wiki/Lard) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |  |
| [peanut butter](/wiki/Peanut_butter)\* | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |  |
| [shortening](/wiki/Shortening)\* | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |  |

|  |  |  |
| --- | --- | --- |
| Viscosity of [liquids](/wiki/Liquid)  (at 25 °[C](/wiki/Celsius) unless otherwise specified) | | |
| **Liquid** | **Viscosity [Pa·s]** | **Viscosity [cP=mPa·s]** |
| [acetone](/wiki/Acetone)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [benzene](/wiki/Benzene)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [castor oil](/wiki/Castor_oil)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [corn syrup](/wiki/Corn_syrup)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [ethanol](/wiki/Ethanol)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [ethylene glycol](/wiki/Ethylene_glycol) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [glycerol](/wiki/Glycerol) (at 20 °[C](/wiki/Celsius))<ref name=hyper/> | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [HFO-380](/wiki/Fuel_oil) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [mercury](/wiki/Mercury_(element))[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [methanol](/wiki/Methanol)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [motor oil](/wiki/Motor_oil) SAE 10 (20 °C)<ref name=physicsinfo/> | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [motor oil](/wiki/Motor_oil) SAE 40 (20 °C)<ref name=physicsinfo/> | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [nitrobenzene](/wiki/Nitrobenzene)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [liquid nitrogen](/wiki/Liquid_nitrogen) @ 77K | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [propanol](/wiki/Propan-1-ol)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [olive oil](/wiki/Olive_oil) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [pitch](/wiki/Pitch_(resin)) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [sulfuric acid](/wiki/Sulfuric_acid)[[25]](#cite_note-25) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |
| [water](/wiki/Water) | [Template:Nts](/wiki/Template:Nts) | [Template:Nts](/wiki/Template:Nts) |

|  |  |  |  |
| --- | --- | --- | --- |
| +Viscosity of [solids](/wiki/Solid) | **Solid** | **Viscosity [Pa·s]** | **Temperature [K]** |
| [asthenosphere](/wiki/Asthenosphere)<ref name=asthenosphere>[Template:Cite journal](/wiki/Template:Cite_journal)</ref> | [Template:Nts](/wiki/Template:Nts) | 900 °C |  |
| [upper mantle](/wiki/Upper_mantle)<ref name=asthenosphere/> | (0.7-1.0)[Template:E](/wiki/Template:E) | 1300-3000 °C |  |
| [lower mantle](/wiki/Lower_mantle) | (1.0-2.0)[Template:E](/wiki/Template:E) | 3000-4000 °C |  |

\* These materials are highly [non-Newtonian](/wiki/Non-Newtonian_fluid).

Note: Higher viscosity means thicker substance

## Viscosity of slurry[[edit](/index.php?title=(none)&action=edit&section=26)]

[300px|thumb|Plot of slurry relative viscosity *μr* as calculated by empirical correlations from Einstein,](/wiki/File:Slurry_Viscosity_Plot.png)[[28]](#cite_note-28) Guth and Simha,[[29]](#cite_note-29) Thomas,[[30]](#cite_note-30) and Kitano *et al.*.[[31]](#cite_note-31) The term [slurry](/wiki/Slurry) describes mixtures of a liquid and solid particles that retain some fluidity. The viscosity of slurry can be described as relative to the viscosity of the liquid phase:

<math>\mu\_s = \mu\_r \cdot \mu\_l,</math>

where *μs* and *μl* are respectively the dynamic viscosity of the slurry and liquid (Pa·s), and *μr* is the relative viscosity (dimensionless).

Depending on the size and concentration of the solid particles, several models exist that describe the relative viscosity as a function of [volume fraction](/wiki/Slurry#Volumetric_fraction_from_mass_fraction) *ɸ* of solid particles.

In the case of extremely low concentrations of fine particles, Einstein's equation<ref name=Einstein>[Template:Cite journal](/wiki/Template:Cite_journal)</ref> may be used:

<math>\mu\_r = 1 + 2.5 \cdot \phi</math>

In the case of higher concentrations, a modified equation was proposed by Guth and Simha,<ref name=GuthAndSimha>[Template:Cite journal](/wiki/Template:Cite_journal)</ref> which takes into account interaction between the solid particles:

<math>\mu\_r = 1 + 2.5 \cdot \phi + 14.1 \cdot \phi^2</math>

Further modification of this equation was proposed by Thomas<ref name=Thomas>[Template:Cite journal](/wiki/Template:Cite_journal)</ref> from the fitting of empirical data:

<math>\mu\_r = 1 + 2.5 \cdot \phi + 10.05 \cdot \phi^2 + A \cdot e^{B \cdot \phi},</math>

where *A = 0.00273* and *B = 16.6*.

In the case of high shear stress (above 1 kPa), another empirical equation was proposed by Kitano *et al.* for polymer melts:<ref name=KitanoEtAl>[Template:Cite journal](/wiki/Template:Cite_journal)</ref>

<math>\mu\_r = (1 - \frac{\phi}{A})^{-2},</math>

where *A = 0.68* for smooth spherical particles.

## Viscosity of amorphous materials[[edit](/index.php?title=(none)&action=edit&section=27)]

[300px|thumb|Common](/wiki/File:Glassviscosityexamples.png) [glass](/wiki/Glass) viscosity curves.[[32]](#cite_note-32)

Viscous flow in [amorphous materials](/wiki/Amorphous_solid) (e.g. in [glasses](/wiki/Glass) and melts)[[33]](#cite_note-33)[[34]](#cite_note-34)[[35]](#cite_note-35) is a thermally activated process:

<math>\mu = A \cdot e^{Q/RT},</math>

where *Q* is activation energy, *T* is temperature, *R* is the molar gas constant and *A* is approximately a constant.

The viscous flow in amorphous materials is characterized by a deviation from the [Arrhenius-type](/wiki/Arrhenius_equation) behavior: *Q* changes from a high value *QH* at low temperatures (in the glassy state) to a low value *QL* at high temperatures (in the liquid state). Depending on this change, amorphous materials are classified as either

* strong when: *QH* − *QL* < *QL* or
* fragile when: *QH* − *QL* ≥ *QL*.

The fragility of amorphous materials is numerically characterized by the Doremus’ fragility ratio:

<math>R\_D = \frac{Q\_H}{Q\_L}</math>

and strong material have *RD* < 2 whereas fragile materials have *RD* ≥ 2.

[thumb|Common log of viscosity vs. temperature for B2O3, showing two regimes](/wiki/Image:B2O3_viscosoty.jpg)

The viscosity of amorphous materials is quite exactly described by a two-exponential equation:

<math>\mu = A\_1 \cdot T \cdot \left[1 + A\_2 \cdot e^{B/RT}] \cdot [1 + C \cdot e^{D/RT} \right],</math>

with constants *A1*, *A2*, *B*, *C* and *D* related to thermodynamic parameters of joining bonds of an amorphous material.

Not very far from the [glass transition temperature](/wiki/Glass_transition_temperature), *Tg*, this equation can be approximated by a [Vogel-Fulcher-Tammann](/wiki/Vogel-Fulcher-Tammann_equation) (VFT) equation.

If the temperature is significantly lower than the glass transition temperature, *T* ≪ *Tg*, then the two-exponential equation simplifies to an Arrhenius type equation:

<math>\mu = A\_LT \cdot e^{Q\_H/RT}</math>

with:

<math>Q\_H = H\_d + H\_m,\,</math>

where *Hd* is the [enthalpy of formation](/wiki/Enthalpy_of_formation) of broken bonds (termed [configuron](http://www.wikidoc.org/index.php/Configuron) s) and *Hm* is the [enthalpy](/wiki/Enthalpy) of their motion. When the temperature is less than the glass transition temperature, *T* < *Tg*, the activation energy of viscosity is high because the amorphous materials are in the glassy state and most of their joining bonds are intact.

If the temperature is highly above the glass transition temperature, *T* ≫ *Tg*, the two-exponential equation also simplifies to an Arrhenius type equation:

<math>\mu = A\_HT\cdot e^{Q\_L/RT},</math>

with:

<math>Q\_L = H\_m.\,</math>

When the temperature is higher than the glass transition temperature, *T* > *Tg*, the activation energy of viscosity is low because amorphous materials are melted and have most of their joining bonds broken, which facilitates flow.

## Eddy viscosity[[edit](/index.php?title=(none)&action=edit&section=28)]

In the study of [turbulence](/wiki/Turbulence) in [fluids](/wiki/Fluid), a common practical strategy for calculation is to ignore the small-scale *vortices* (or *eddies*) in the motion and to calculate a large-scale motion with an *eddy viscosity* that characterizes the transport and dissipation of [energy](/wiki/Energy) in the smaller-scale flow (see [*large eddy simulation*](/wiki/Large_eddy_simulation)). Values of eddy viscosity used in modeling [ocean](/wiki/Ocean) circulation may be from 5×104 to 106 Pa·s depending upon the resolution of the numerical grid.

## See also[[edit](/index.php?title=(none)&action=edit&section=29)]

[Template:Columns-list](/wiki/Template:Columns-list)

## References[[edit](/index.php?title=(none)&action=edit&section=30)]

[Template:Reflist](/wiki/Template:Reflist)

## Further reading[[edit](/index.php?title=(none)&action=edit&section=31)]

* Hatschek, Emil (1928). *The Viscosity of Liquids*. New York: [Van Nostrand](/wiki/Van_Nostrand). [Template:Oclc](/wiki/Template:Oclc).
* [Template:Cite book](/wiki/Template:Cite_book)

## External links[[edit](/index.php?title=(none)&action=edit&section=32)]

[Template:Wiktionary](/wiki/Template:Wiktionary) [Template:NSRW Poster](/wiki/Template:NSRW_Poster)

* [Fluid properties](http://webbook.nist.gov/chemistry/fluid/) High accuracy calculation of viscosity and other physical properties of frequent used pure liquids and gases.
* [Gas viscosity calculator as function of temperature](http://www.enggcyclopedia.com/calculators/physical-properties/gas-viscosity/)
* [Air viscosity calculator as function of temperature and pressure](http://www.enggcyclopedia.com/calculators/physical-properties/air-viscosity-calculator/)
* [Fluid Characteristics Chart](http://www.engineersedge.com/fluid_flow/fluid_data.htm) A table of viscosities and vapor pressures for various fluids
* [Gas Dynamics Toolbox](http://web.ics.purdue.edu/~alexeenk/GDT/index.html) Calculate coefficient of viscosity for mixtures of gases
* [Glass Viscosity Measurement](http://glassproperties.com/viscosity/ViscosityMeasurement.htm) Viscosity measurement, viscosity units and fixpoints, glass viscosity calculation
* [Kinematic Viscosity](http://www.diracdelta.co.uk/science/source/k/i/kinematic%20viscosity/source.html) conversion between kinematic and dynamic viscosity.
* [Physical Characteristics of Water](http://www.thermexcel.com/english/tables/eau_atm.htm) A table of water viscosity as a function of temperature
* [Vogel–Tammann–Fulcher Equation Parameters](http://www.iop.org/EJ/abstract/0953-8984/12/46/305)
* [Calculation of temperature-dependent dynamic viscosities for some common components](http://ddbonline.ddbst.de/VogelCalculation/VogelCalculationCGI.exe)
* ["Test Procedures for Testing Highway and Nonroad Engines and Omnibus Technical Amendments"](http://www.epa.gov/EPA-AIR/2005/July/Day-13/a11534d.htm). [United States Environmental Protection Agency](/wiki/United_States_Environmental_Protection_Agency)
* [Artificial viscosity](http://www.astro.uu.se/~bf/course/numhd_course/2_5_2Artificial_viscosity.html)

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