CIVIL ENGINEERING ORIENTATION 2020/2021

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- 2 Test (definitions + calculations)
- Homeworks – calculations
- Max 50 points

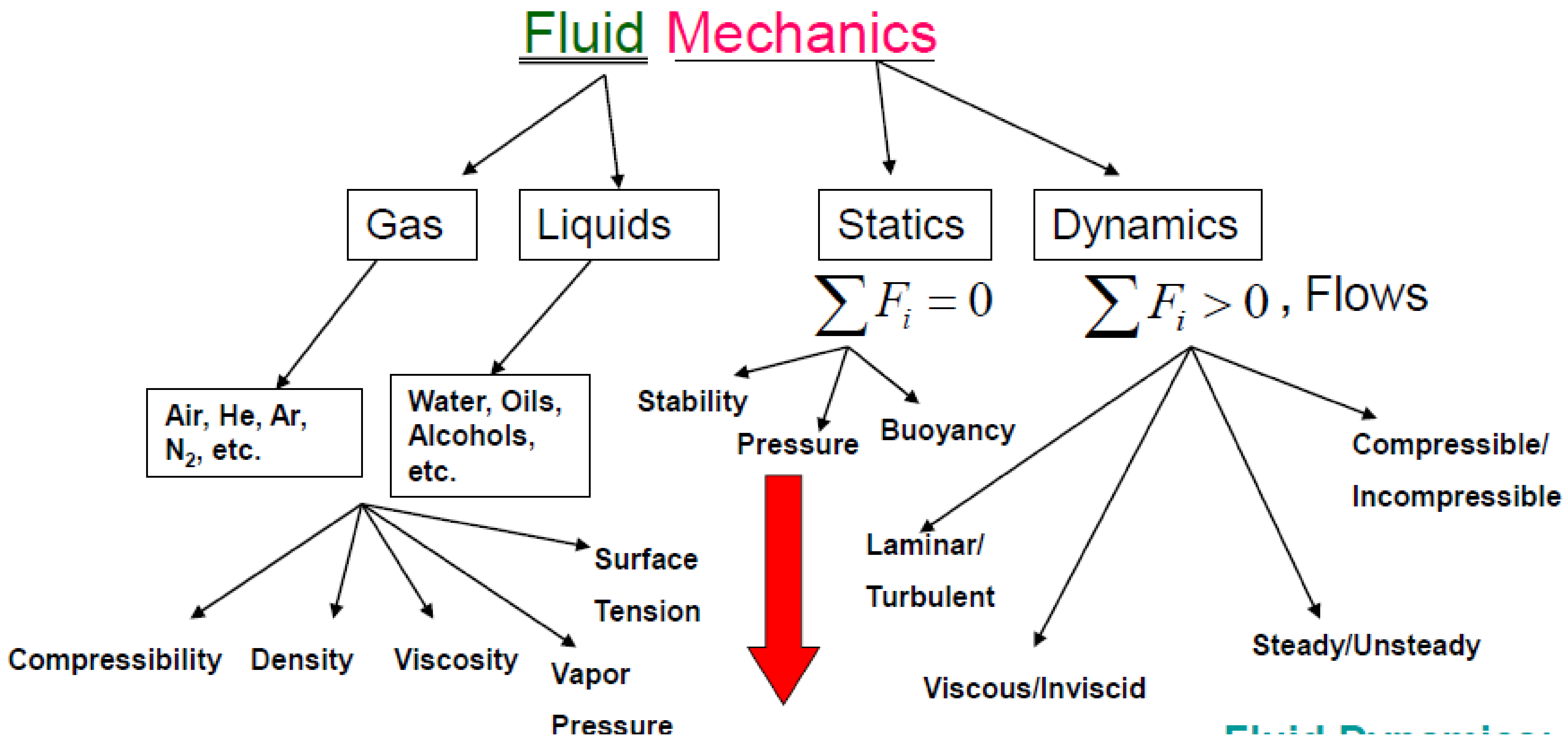
FUNDAMENTALS OF Fluid Mechanics

seventh edition

Fluid Mechanics in Civil/Structural Engineering

Every civil/structural engineering graduate needs to have a thorough understanding of fluids!!!

- Drainage for developments
- Attenuation of surface water for city centre sites
- Sea and river (flood) defences
- Water distribution/sewerage (sanitation) networks
- Hydraulic design of water/sewage treatment works
- Dams
- Irrigation
- Pumps and Turbines
- Water retaining structures
- Flow of air in / around buildings
- Bridge piers in rivers
- Ground-water flow

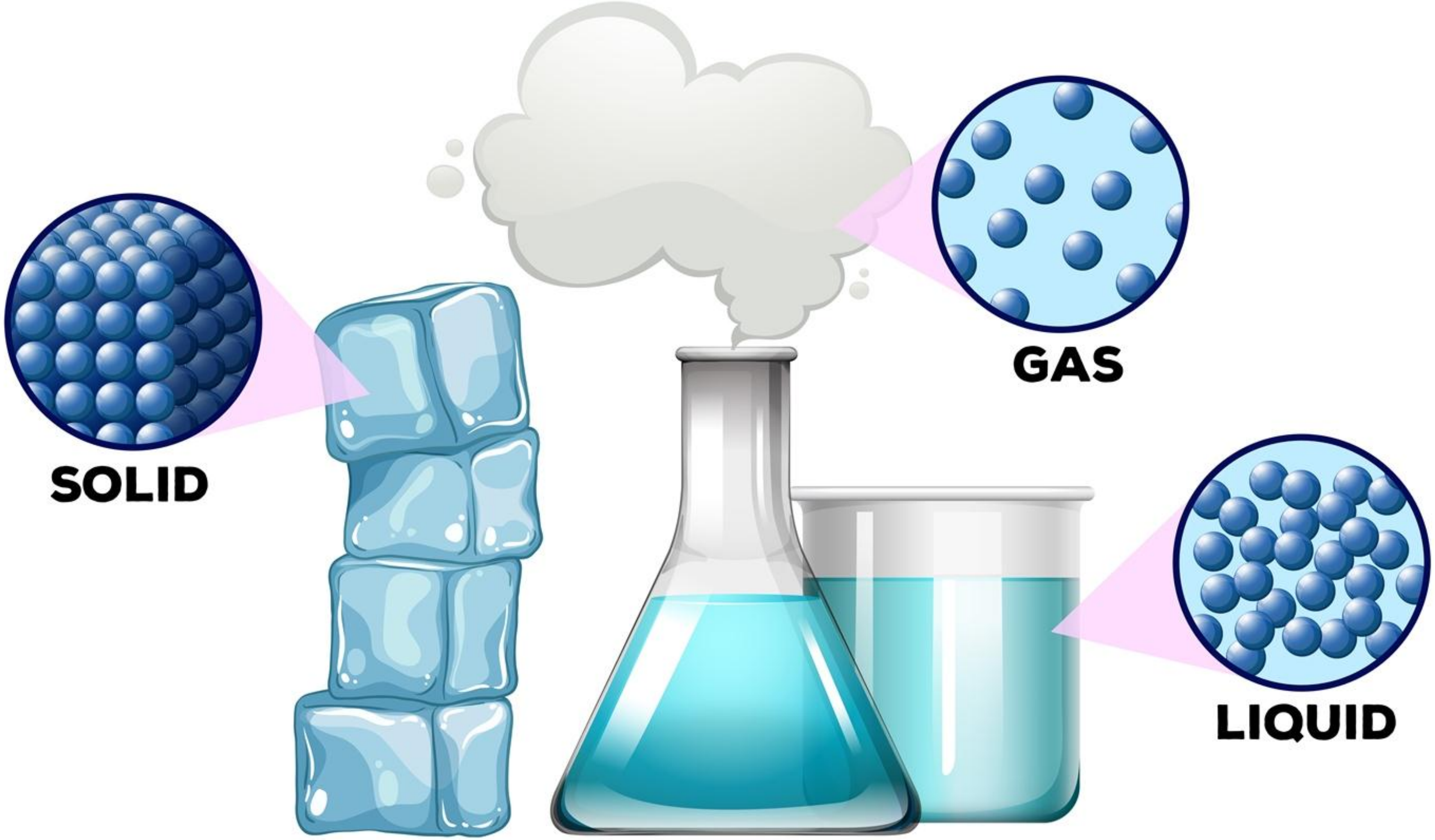


Fluid Mechanics
Gas
Liquids
Statics
Dynamics
Air, He, Ar, N_2, etc.
Water, Oils, Alcohols, etc.
$\sum F_i = 0$
$\sum F_i > 0$, Flows
Stability
Pressure
Buoyancy
Compressible/ Incompressible
Laminar/ Turbulent
Steady/Unsteady
Viscous/Inviscid
Compressibility
Density
Viscosity
Vapor Pressure
Surface Tension

- One of the first questions we need to explore is – what is a fluid?
- What is the difference between a solid and a fluid?

BOTH LIQUIDS AND GASES ARE FLUIDS

STATES OF MATTER



https://www.ase.org.uk/resources/solids-liquids-and-gases

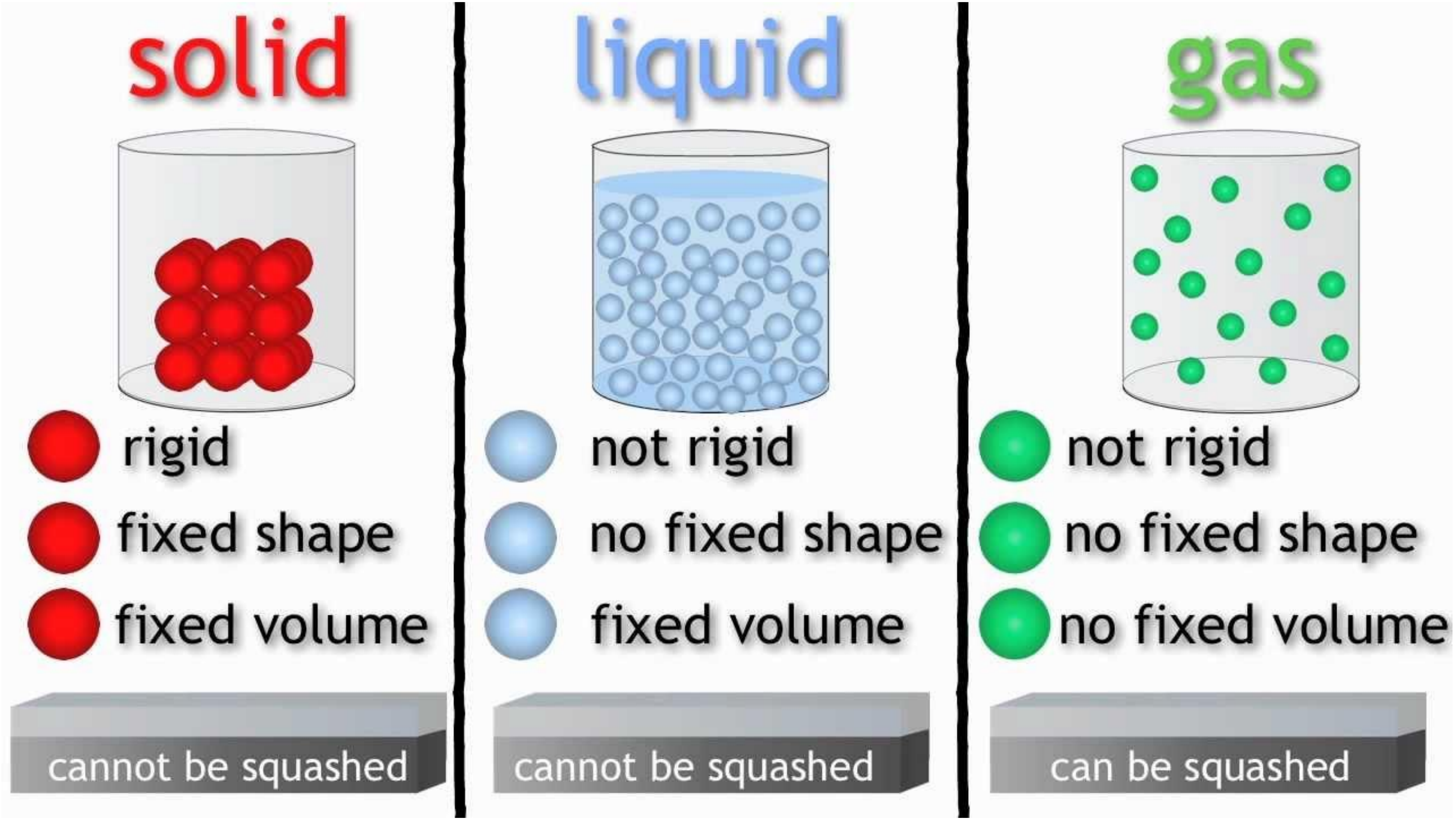
What is the difference between a solid and a fluid?

SOLID

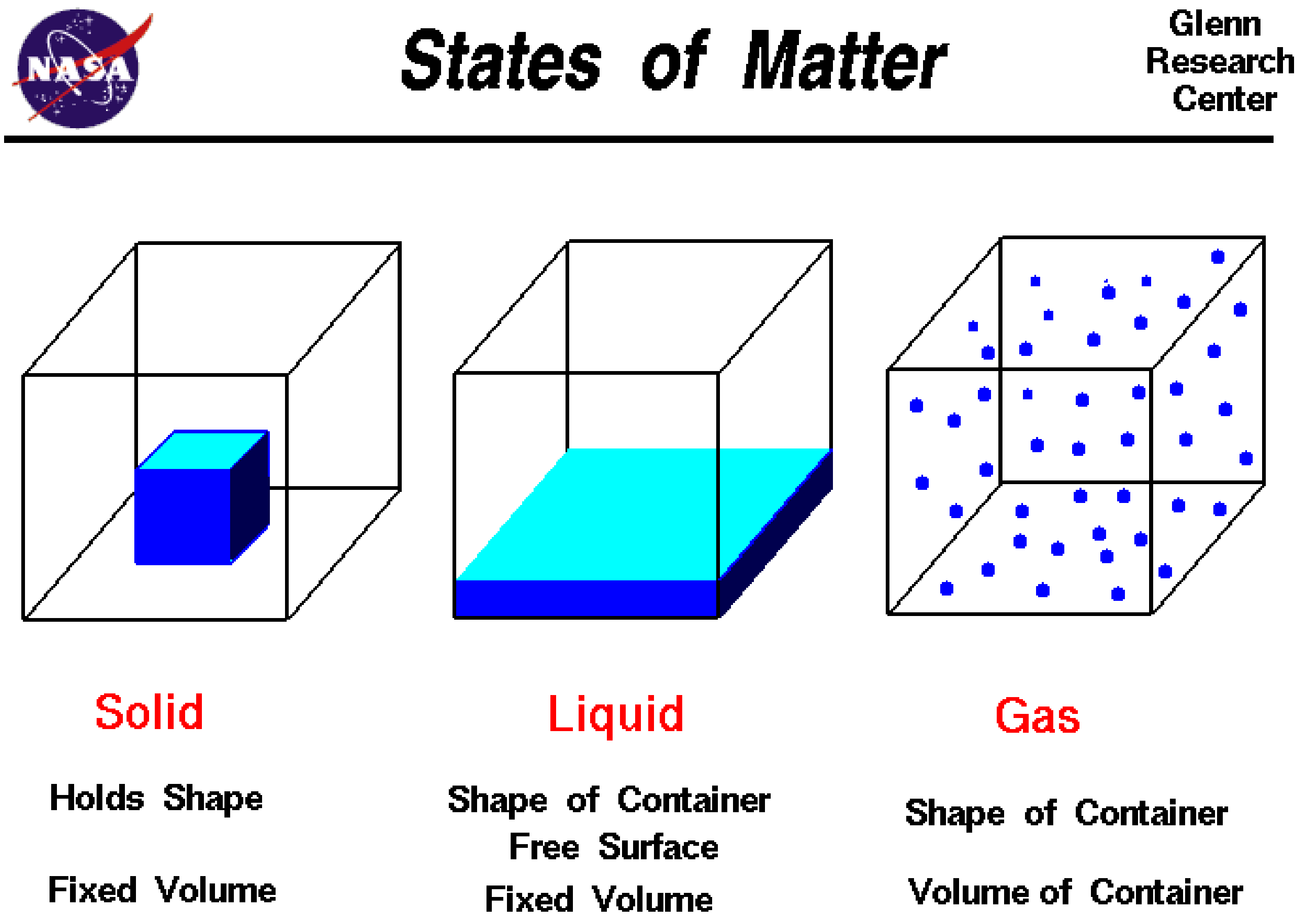
- „hard” and not to easily deformed
- densely spaced molecules with large intermolecular cohesive forces (steel, concrete, etc.)
- SHAPE
- not to be easily deformed

FLUID

- „soft” and easily deformed
- **Liquids**: molecules are spaced farther apart, the intermolecular forces are smaller than for solids; the molecules have more freedom of movement; can be easily deformed, but not easily compressed!!!
- **Gases:** greater molecular spacing and freedom of motion with negligible cohesive intermolecular forces; easily deformed and compressed; completely fill the volume of any container in which they are placed



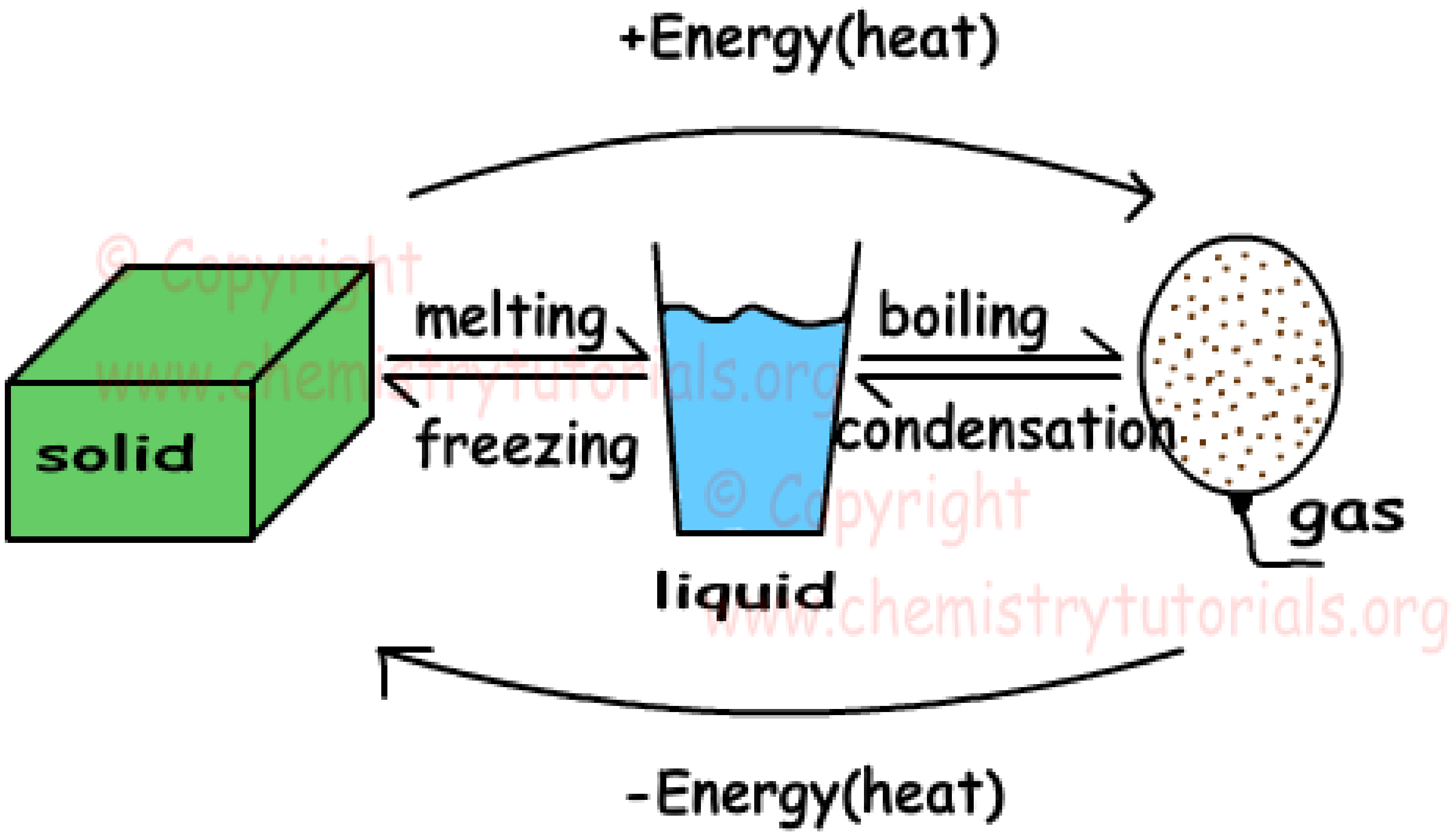
https://www.schoolsofkingedwardvi.co.uk/ks2-science-year-4-3-states-matter-solids-liquids-gases/



https://www.grc.nasa.gov/WWW/K-12/BGP/state.html

	Solids	Liquids	Gases
has particular shape	yes	no	no
has particular volume	yes	yes	no
spaces between molecules	no	yes	yes
Compressibility	a little bit	a little bit	yes

https://www.chemistrytutorials.org/content/matters-and-properties-of-matters/matters-and-properties-of-matters-cheat-sheet/7-phases-states-of-matter



https://www.chemistrytutorials.org/content/matters-and-properties-of-matters/matters-and-properties-of-matters-cheat-sheet/7-phases-states-of-matter

Some Characteristics of Gases, Liquids and Solids and the Microscopic Explanation for the Behavior

gas	liquid	solid
assumes the shape and volume of its container particles can move past one another	assumes the shape of the part of the container which it occupies particles can move/slide past one another	retains a fixed volume and shape rigid - particles locked into place
compressible lots of free space between particles	not easily compressible little free space between particles	not easily compressible little free space between particles
flows easily particles can move past one another	flows easily particles can move/slide past one another	does not flow easily rigid - particles cannot move/slide past one another

Properties of Gases

- A collection of widely separated molecules
- The kinetic energy of the molecules is greater than any attractive forces between the molecules
- The lack of any significant attractive force between molecules allows a gas to expand to fill its container
- If attractive forces become large enough, then the gases exhibit non-ideal behavior

Properties of Liquids

- The intermolecular attractive forces are strong enough to hold molecules close together

- Liquids are more dense and less compressible than gasses

- Liquids have a definite volume, independent of the size and shape of their container

- The attractive forces are not strong enough, however, to keep neighboring molecules in a fixed position and molecules are free to move past or slide over one another

Properties of Solids

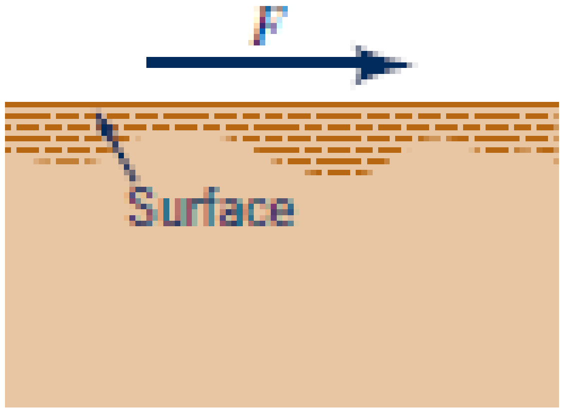
- The intermolecular forces between neighboring molecules are strong enough to keep them locked in position

- Solids (like liquids) are not very compressible due to the lack of space between molecules

- If the molecules in a solid adopt a highly ordered packing arrangement, the structures are said to be crystalline

Fluid is defined as a…..

- ***Fluid is defined as a substance that deforms continuously when acted on by a shearing stress of any magnitude***
- A shearing stress (force per unit area) is created whenever a tangential force acts on a surface



System of Units – INTERNATIONAL SYSTEM (SI)

- SI as the accepted standard
- widely adopted worldwide and widely used in the United States
- in SI the unit of length is the meter (m); the time unit is the second (s); the mass unit is the kilogram (kg); and the temperature unit is kelvin (K)
- The kelvin temperature scale is an absolute scale and is related to the Celcius scale (°C) through the relationship

$$K = {}^{\circ}C + 273.15$$

UNITS

- The **force** unit, called the Newton (N), is defined from Newton's second law [F=m x a] → 1 N = (1 kg) x (1 m/s^2)
- Unit of **work** is the joule → 1 J = 1 N x m
- Unit of **power** is the watt → 1 W = 1 J/s = 1 N x m/s [P = W / t]

Prefixes for forming multiples and fractions of SI units are given in Table 1.2.

Table 1.2

Prefixes for SI Units

Factor by Which Unit Is Multiplied	Prefix	Symbol	Factor by Which Unit Is Multiplied	Prefix	Symbol
10^{15}	peta	P	10^{-2}	centi	c
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	μ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p
10^{2}	hecto	h	10^{-15}	femto	f
10	deka	da	10^{-18}	atto	a
10^{-1}	deci	d			

Converting Quantities

27 000 cm = ...dm

30 000 m^2 = ……………………………………………........cm^2

2750 s = …………………… min = …………………………h

4.7 km = ……………………………………………………m

3.2 h = ………………………min = …………………………s

304 km/h = …………………………………………………m/s

370 K = …………………………………………………… °C

12.5 m/s = ……………………………………………… km/h

3 L = …………………….. dm^3 = …………………………... m^3

1570 mL = ………………… dL = …………………………... L

0.25 g / cm^3 = ………………………………………….. kg/m^3

5 mol = ……………………………………………….. number of particles

6300 kJ = ………………………………………………………… J

150 dm^2= ………………………………………………………… m^2

94 °C = …………………………………………………………… K

35600 m = ………………………………………………………..…km

15 cm^3 = ……………………………………………………….....dm^3

35 N/cm^2= ……………………………………………………….Pa

15800 Pa = …………………………………………………….. kPa

740 N/m^2 = …………………………………………………. …Pa

4,3 t = …………………………kg =………………………..…dkg

5200 mg = ……………………………………………………… g

3,745 kJ = ……………………………………………………….J

35500 kW = ……………………………………………………W

4.55 m^3= ………………………………………………………dm^3

13600 kg/m^3 = ……………………………………………….. g/cm^3

30 x 1023 particles = ……………………………………… mol

5 N/m^3 = ……………………………………………….. …N/dm^3

2 m^3/s = ………………………………………………………m^3/h

12770 N = ……………………………………………………. kN

15.67 kN/m^3 = ……………………………………………...N/m^3

457.43 m^3= ……………………………………………………cm^3

3 MN/m^2 = ……………………………………………………Pa

10000 cm^2 = …………………………………………………..m^2

23970 mm^3 = ……………………………………………….…cm^3

2.43 GPa = ……………………………………………………Pa

2.2. What is the definition of the fluid?
A) a substance that doesn’t permanently resist distortion
B) has shear stress
C) a substance that does permanently resist distortion
D) shear stress magnitudes depend on the volume of the fluid

2.3. True or false?
1. The principal difference between liquids and gases is in the compressibility
2. Fluids have a preferred shape
3. Gases can fill the container fully
4. Macroscopic properties of gases: pressure, temperature, viscosity, thermal conductivity, volume
5. Gases can be dissolved in the liquid
6. The most obvious property of fluids, their ability to flow and change their volume
7. The most obvious property of gases, their ability to flow and change their shape
8. Gases have a preferred shape
9. The interface forms between the liquid and the surrounding gas called a free surface
10. Gases are compressible

11. The pressure of a gas depends on its temperature
12. The pressure of a gas depends on its volume
13. Incompressible Flow – the volume of the fluid has a constant value throughout the fluid
14. Gas molecules are monatomic, diatomic and polyatomic molecules
15. Gases have mass
16. Fluids have mass
17. Gases diffuse through each other very rapidly
18. The kinetic energy of the gas molecules decreases with added temperature
19. Particles in a liquid are attracted to each other
20. Gases are highly sensitive to changes in temperature and pressure
21. Macroscopic properties of gases: volume, pressure, temperature, mass
22. The density of the fluid can change under pressure
23. In real fluids: shear forces oppose motion of one particle past another
24. An ideal fluid is incompressible, the density is constant

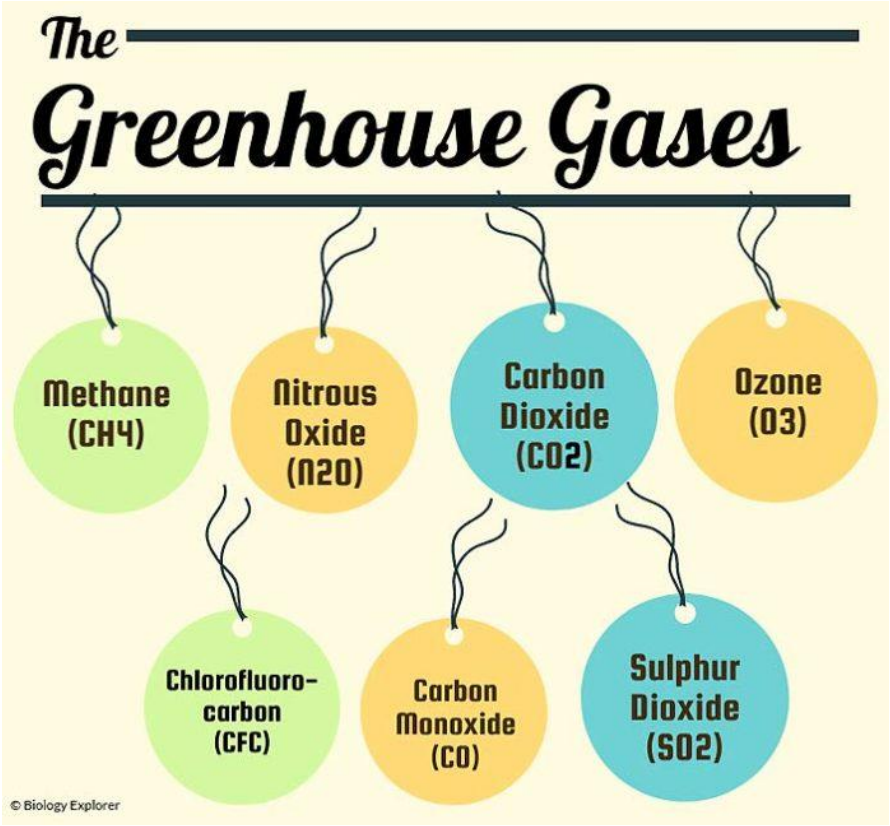
Comparison liquids and gases - Fill up the missing spots in the table below!

	LIQUID	GAS
TYPES		
PARTICLES		
SHAPE		
EFFECT OF CHANGE OF PRESSURE ON THE VOLUME		
FREE SPACE BETWEEN PARTICLES		
PARTICLES CAN MOVE		
COMPRESSIBILITY		
DISTANCE BETWEEN MOLECULES		
ROLE OF INTERACTIONS OF MOLECULES		
CAUSE OF VISCOSITY		

1) plant oils
2) attraction among molecules
3) large
4) Solutions
5) vibrate, move about, and slide past each other
6) small
7) assumes the shape of the part of the container which it occupies
8) lots of free space between particles
9) significant
10) vibrate and move freely at high speeds
11) compressible
12) small, fill the available space
13) little free space between particles
14) particles can move past one another
15) acetone
16) well separated with no regular arrangement
17) small
18) Sulfur dioxide
19) Suspensions
20) assumes the shape and volume of its container
21) not easily compressible
22) Green House gases
23) Emulsions
24) close together with no regular arrangement
25) particles can move/slide past one another
26) large
27) momentum exchange among molecules
28) Solvents
29) Sea water
30) oxygen

2.6. True or false?

1. If the concentration of the Green House gases increases, it can lead to global warming.
2. Greenhouse gases are from human activities
3. Greenhouse gases aren't Climate Change Indicators
4. Carbon dioxide has a significant impact on global warming partly
5. methane is about 11 times more efficient at absorbing radiation than CO_2



https://climate.nasa.gov/faq/

https://www.bioexplorer.net/greenhouse-gases.html/

Measures of Fluid Mass and Weight: Density

The density of a fluid is defined as mass per unit volume.

$$\rho = \frac{m}{v}$$

m = mass, and v = volume.

- Different fluids can vary greatly in density
- Liquids densities do not vary much with pressure and temperature
- Gas densities can vary quite a bit with pressure and temperature
- Density of water at 4° C : 1000 kg/m^3
- Density of Air at 4° C : 1.20 kg/m^3

Alternatively, **Specific Volume**: $$\upsilon = \frac{1}{\rho}$$

Measures of Fluid Mass and Weight: Specific Weight

The specific weight of fluid is its weight per unit volume.

$$\gamma = \rho g$$

g = local acceleration of gravity, 9.807 m/s^2

- Specific weight characterizes the weight of the fluid system
- Specific weight of water at 4° C : 9.80 kN/m^3

Measures of Fluid Mass and Weight: Specific Gravity

The specific gravity of fluid is the ratio of the density of the fluid to the density of water @ 4° C.

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

- Gases have low specific gravities
- A liquid such as Mercury has a high specific gravity, 13.2
- The ratio is unitless.
- Density of water at 4° C : 1000 kg/m^3

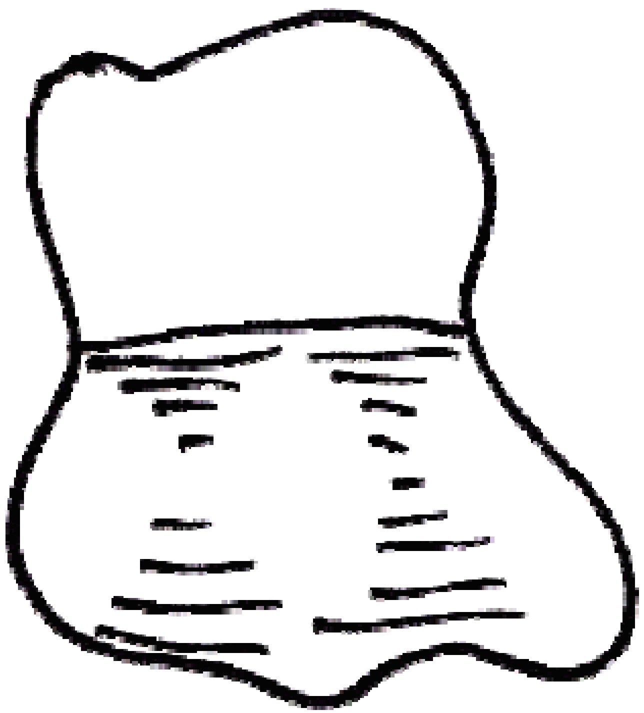
Relative Density (Specific Gravity)

A dimensionless measure of the density of a substance with reference to the density of some standard substance, usually water at 4°C:

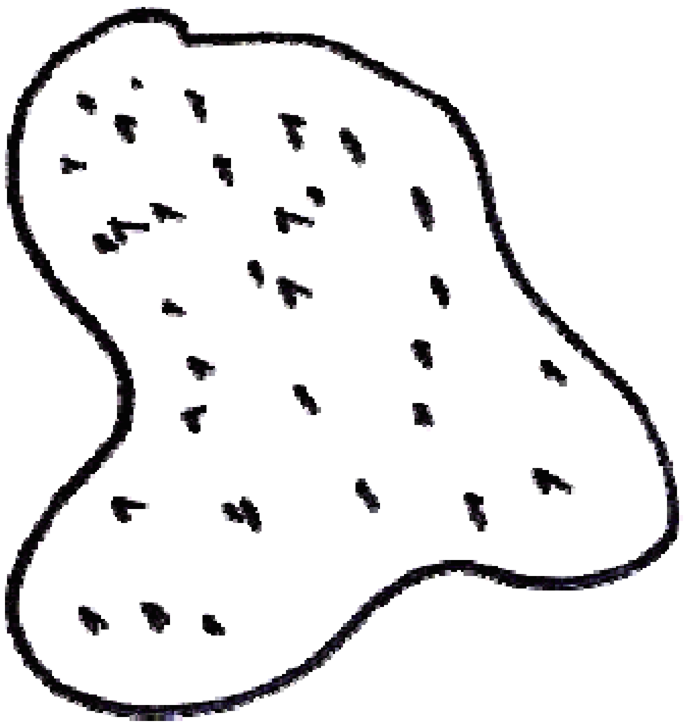
$$\text{relative density} = \frac{\text{density of substance}}{\text{density of water}}$$

$$= \frac{\text{specific weight of substance}}{\text{specific weight of water}}$$

$$= \frac{\rho_s}{\rho_w} = \frac{\gamma_s}{\gamma_w}$$



Liquid showing free surface



Gas filling volume

Behaviour of fluids in containers

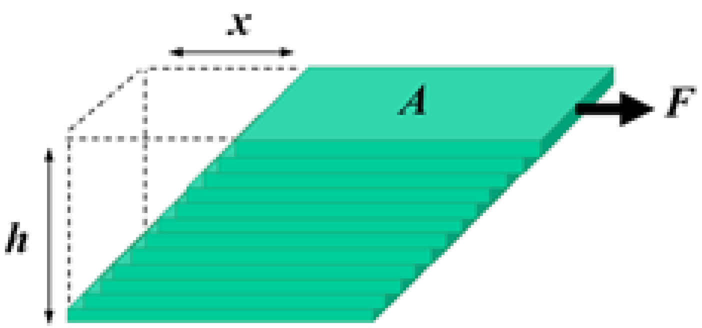
- There are three states of matter: solids, liquids and gases.
- Both liquids and gases are classified as fluids.
- Fluids do not resist a change in shape. Therefore fluids assume the shape of the container they occupy.
- Liquids may be considered to have a fixed volume and therefore can have a free surface. Liquids are almost incompressible.
- Conversely, gases are easily compressed and will expand to fill a container they occupy.
- We will usually be interested in liquids, either at rest or in motion.

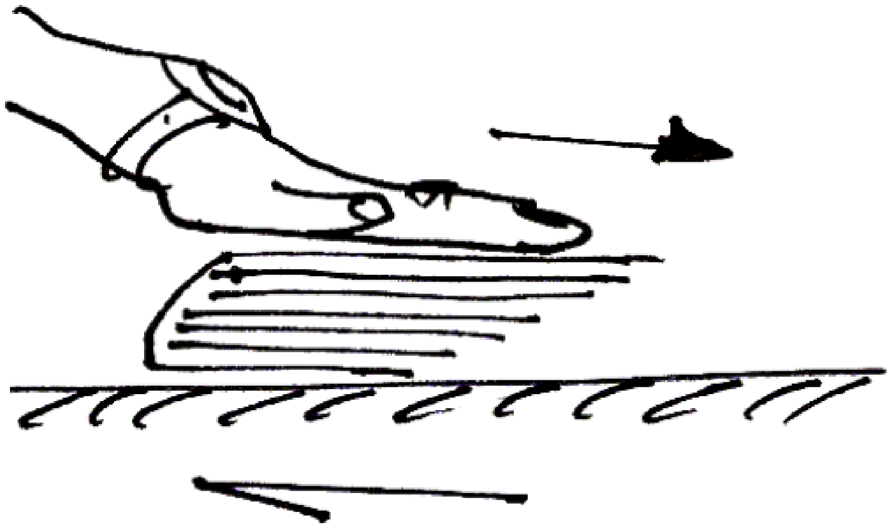
The strict definition of a fluid is:

A fluid is a substance which conforms continuously under the action of shearing forces.

To understand this, remind ourselves of what a shear force is:

Shear Stress	$\sigma = F / A$	(Pa)
Shear strain	$\gamma = x / h$	
Shear rate	$\dot{\gamma} = d\gamma / dt$	(s^{-1})
Shear viscosity	$\eta = \sigma / \dot{\gamma}$	(Pa.s)





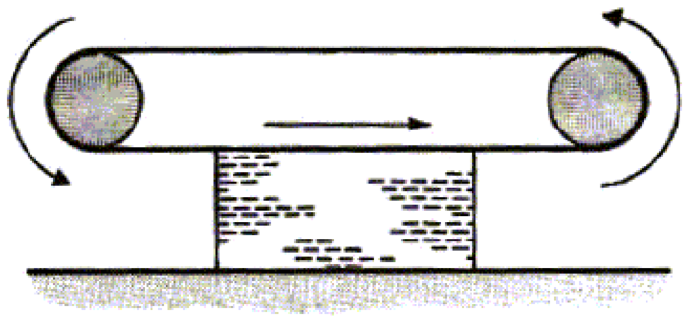
Application and effect of shear force on a book

Definition Applied to Static Fluids

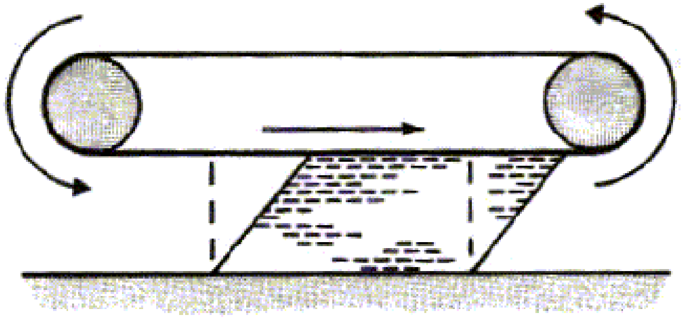
If a fluid is at rest there can be no shearing forces acting and therefore all forces in the fluid must be perpendicular to the planes in which they act.

Note here that we specify that the fluid must be at rest. This is because, it is found experimentally that fluids in motion can have slight resistance to shear force. This is the source of *viscosity*.

If one layer of is moving faster than another layer of fluid, there must be shear forces acting between them. For example, if we have fluid in contact with a conveyor belt that is moving we will get the behaviour shown:



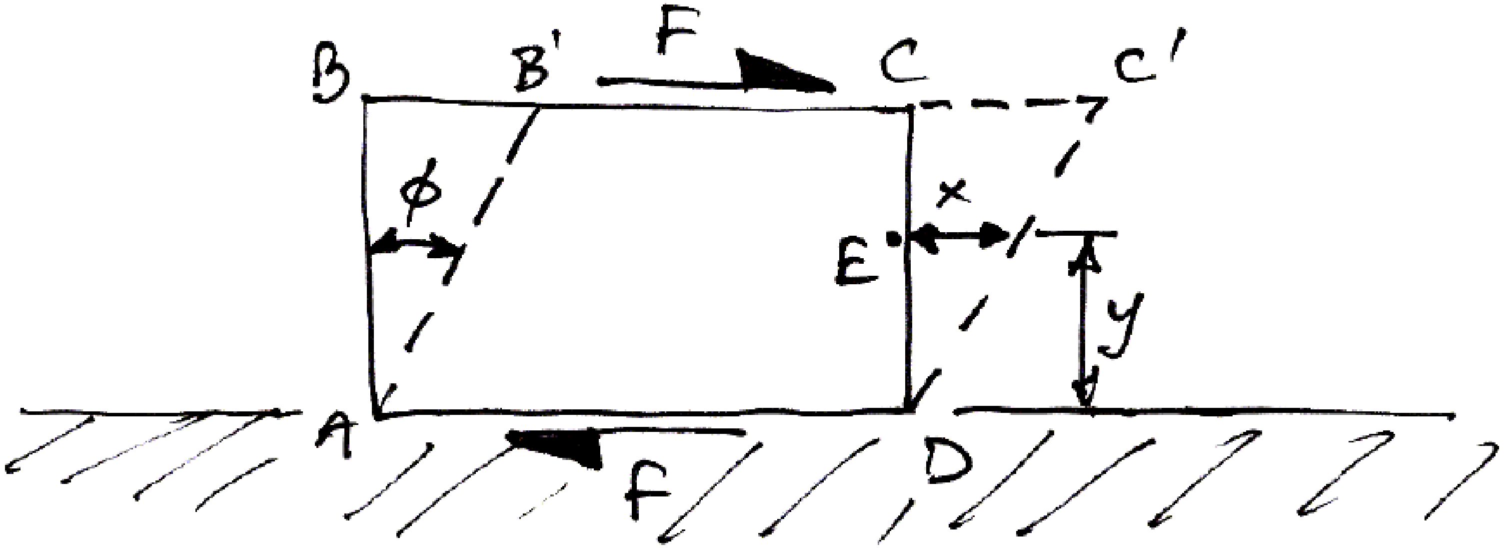
Ideal fluid



Real (Viscous) Fluid

When fluid is in motion, any difference in velocity between adjacent layers has the same effect as the conveyor belt does.

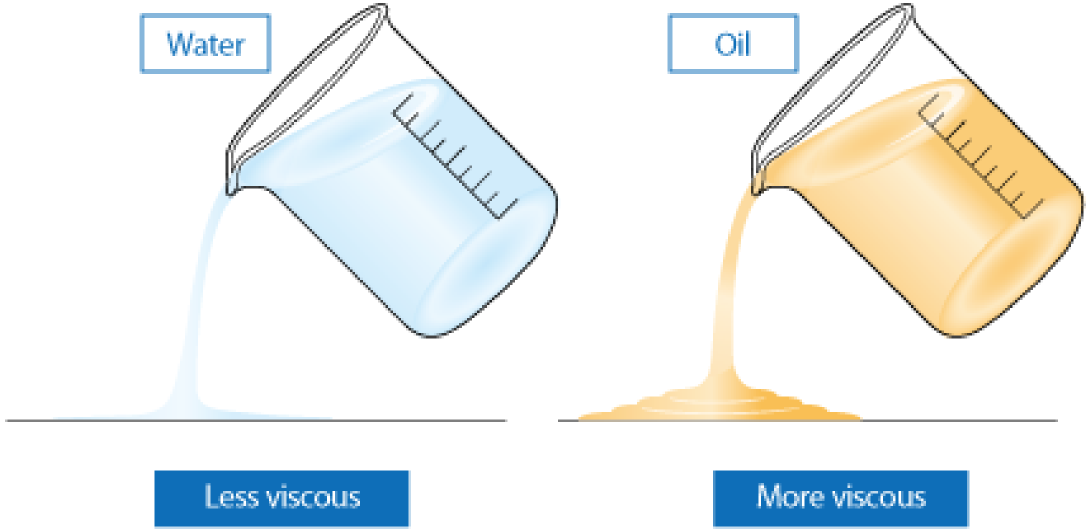
Therefore, to represent real fluids in motion we must consider the action of shear forces.



Consider the small element of fluid shown, which is subject to shear force and has a dimension s into the page. The force F acts over an area A = BC×s. Hence we have a *shear stress* applied:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

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



The viscosity is measure of the "fluidity" of the fluid which is not captured simply by density or specific weight. A fluid can not resist a shear and under shear begins to flow. The shearing stress and shearing strain can be related with a relationship of the following form for common fluids such as water, air, oil, and gasoline:

$$\tau = \mu \frac{du}{dy}$$

Lastly, we also consider the *ideal fluid*. This is a fluid which is assumed to have no viscosity and is very useful for developing theoretical solutions. It helps achieve some practically useful solutions.

Ideal fluid	Real fluid
Ideal fluids have zero viscosity.	Viscosity exists.
Incompressible.	Can be compressible.
Infinite bulk modulus	Finite bulk modulus
No surface tension	Surface tension exists
Imaginary and do not exists in nature	Exists in nature

Viscosity

The viscosity of a fluid determines the amount of resistance to shear force. Viscosities of liquids decrease as temperature increases and are usually not affected by pressure changes. From Newton's Law of Viscosity:

Shear stress (N/m^2)

Coefficient of dynamic or absolute viscosity ($N\ s/m^2$)

$$\mu = \frac{\tau}{du/dy} = \frac{\text{shear stress}}{\text{rate of shear strain}}$$

Velocity gradient or the rate of deformation (rad/s)

- **Kinematic viscosity** (ν) is the ratio of dynamic viscosity to mass density expressed in metres squared per second

Kinematic Viscosity, $\nu = \mu / \rho$

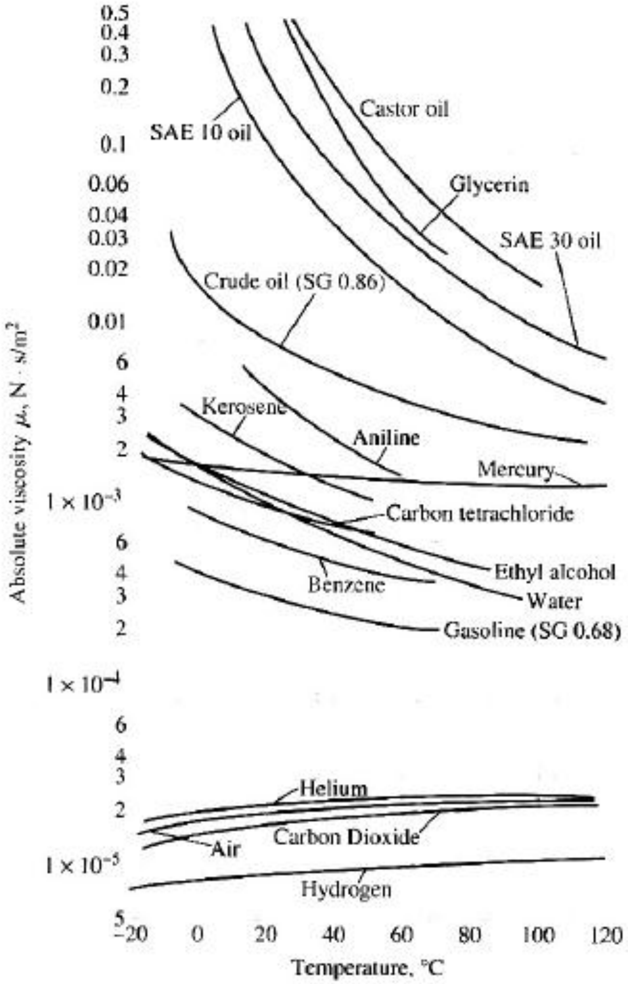
Where,.

ν = Kinematic viscosity

μ = Dynamic viscosity

ρ = Density of the fluid

Hence the units of viscosity are $\mathrm{Pa \cdot s}$ or $\mathrm{N \cdot s/m^2}$. This measure of viscosity is known as *dynamic viscosity* and some typical values are given:



Surface Tension

At the interface between a liquid and a gas or two immiscible liquids, forces develop forming an analogous "skin" or "membrane" stretched over the fluid mass which can support weight.

This "skin" is due to an imbalance of cohesive forces. The interior of the fluid is in balance as molecules of the like fluid are attracting each other while on the interface there is a net inward pulling force.

Surface tension is the intensity of the molecular attraction per unit length along any line in the surface.

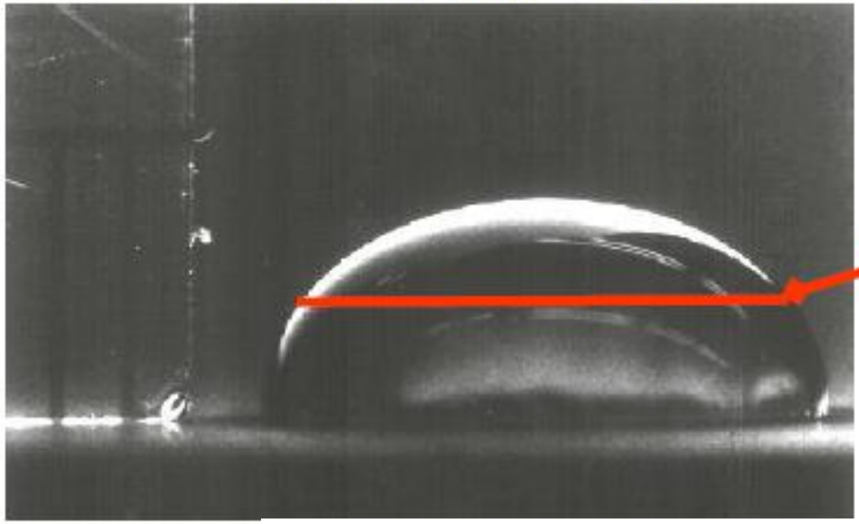
Surface tension is a property of the liquid type, the temperature, and the other fluid at the interface.

This membrane can be "broken" with a surfactant which reduces the surface tension.

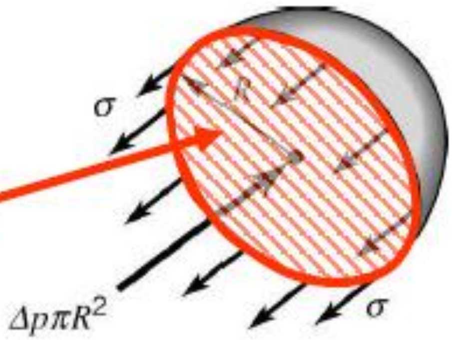
Surface Tension: Liquid Drop

The pressure inside a drop of fluid can be calculated using a free-body diagram:

Real Fluid Drops



Mathematical Model



R is the radius of the droplet, σ is the surface tension, Δp is the pressure difference between the inside and outside pressure.

The force developed around the edge due to surface tension along the line:

$$F_{surface} = 2\pi R\sigma$$

Applied to Circumference

This force is balanced by the pressure difference Δp:

$$F_{pressure} = \Delta p \pi R^2$$

Applied to Area

Surface Tension: Liquid Drop

Now, equating the Surface Tension Force to the Pressure Force, we can estimate $\Delta p = p_i - p_e$:

$$\Delta p = \frac{2\sigma}{R}$$

This indicates that the internal pressure in the droplet is greater that the external pressure since the right hand side is entirely positive.

Is the pressure inside a bubble of water greater or less than that of a droplet of water?

Prove to yourself the following result: $\Delta p = \frac{4\sigma}{R}$

2.7. Ideal Fluid or Real Fluid?

1. Incompressible
2. Viscous in nature
3. Conceptual model of a fluid
4. Compressible
5. Non-Viscous
6. friction between the layers
7. surface tension
8. laminar flow
9. a fluid with no friction
10. Shear forces oppose motion of one particle past another
11. internal molecular activity
12. unable to resist
13. only an imaginary fluid
14. zero viscosity
15. Tangential or shearing forces
16. have a steady – flow
17. turbulent flow
18. no surface tension
19. viscosity
20. constant density

3.1. What is the symbol for density?
A) β
B) ρ
C) η
D) σ

3.2. What are units of density?
A) g/cm^3
B) N/m^3
C) kg/m^2
D) kg/m^3

3.3. What is the formula for mass density?
A) density = volume/ mass
B) density = the mass of the substance / unit volume
C) density = the mass of the substance x unit volume
D) density = the mass of the substance + unit volume

3.4. What is the unit of the relative density?

A) g/cm^3
B) N/m^3
C) dimensionless
D) kg/m^3

3.6. Convert the density from gram/cubic decimeter [g/dm^3] to kilogram/cubic meter [kg/m^3]!

3.2 g/dm^3 = ... kg/m^3

A) 3.2
B) 3200
C) 320 000
D) 0.0032

3.7. Convert the density from kilogram/liter [kg/L] to gram/cubic centimeter [g/cm^3]!

11.22 kg/L = ……………. g/cm^3

A) 0.01122
B) 11.22
C) 11220
D) 11220000

3.8. Convert the density from gram/cubic centimeter [g/cm^3] to kilogram/cubic meter [kg/m^3]!

2.9 g/cm^3 = ……………. kg/m^3

A) 2.9
B) 0.0029
C) 2900
D) 2900000

3.11. Alcohol is less dense than water. If you measured the mass of the same volume of alcohol and water

a) The mass of the alcohol and water would cancel each other
b) The mass of the alcohol and water would be the same
c) The water would have a lower mass
d) The water would have a greater mass out

3.12. Density of water is maximum at

A) - 4 °C
B) 4 °C
C) 100 °C
D) 0 °C

3.13. The calculation of the specific weight

A) $\gamma=\rho/g$

B) $\gamma=\rho\eta$

C) $\gamma=\rho\nu$

D) $\gamma=\rho g$

3.14. True or falls?

A) Specific gravity usually means relative density with respect to water.

B) The symbol of the relative density is R

C) Relative density is dimensionless

D) Relative density = $\rho_{substance} / \rho_{reference}$

E) Relative density is the specific weight

3.29. Viscosity is very ……………… dependent.

A) pressure
B) volume
C) mass
D) temperature

3.30. Viscosity of a liquid ………………………………..

A) decreases with increasing temperature
B) decreases with increasing pressure
C) increases with decreasing temperature
D) increases with decreasing pressure

3.31. Viscosity of a gas ....

A) increases with increasing pressure
B) increases with increasing volume
C) increases with increasing density
D) increases with increasing temperature

3.32. The symbol of the shear stress

A) σ
B) τ
C) Δ
D) s

3.33. The unit of the shear stress

A) N/m
B) Nm
D) N/m^2
D) Nm^2

3.38. The value of specific weight for water in SI units

A) 9.81 x 1000 x 1000 N/m^3
B) 9.81 x 1000 N/m^3
C) 9810 x 1000 N/m^3
D) 9810 x 1000 x 1000 N/m^3

3.39. What is Specific volume?

A) $1 / \rho$
B) $1 / V$
C) γ / g
D) η / g

3.41. When the specific gravity of mercury is 13.6, the density of mercury

A) 13600 x 1000 kg/m^3
B) 13.6 x 1000 x 1000 kg/m^3
C) 13.6 x 1000 kg/m^3
D) 13.6 ÷1000 kg/m^3

3.43. Calculate the density, when the specific gravity is 0.7138!

A) 1.4 kg/m^3
B) 713.8 kg/m^3
C) 71.38 kg/m^3
D) 7.138 kg/m^3

3.44. In SI the unit of viscosity

A) Ns/m
B) Pa·s^2
C) Pa·s
D) Nm^2/s

3.45. The Greek symbol of the kinematic viscosity
A) σ
B) η
C) χ
D) ν

3.46. In SI the unit of kinematic viscosity

A) m^2/s

B) m/s^2

C) m/s

D) m^2/s^2

3.49. The density of the water is 1000 kg/m^3, the kinematic viscosity is 10^{-6} m^2/s. What is the dynamic viscosity of the water?

A) 10^{-3} Pa·s

B) 10^{-6} Pa·s

C) 10^{-9} Pa·s

D) 10 Pa·s