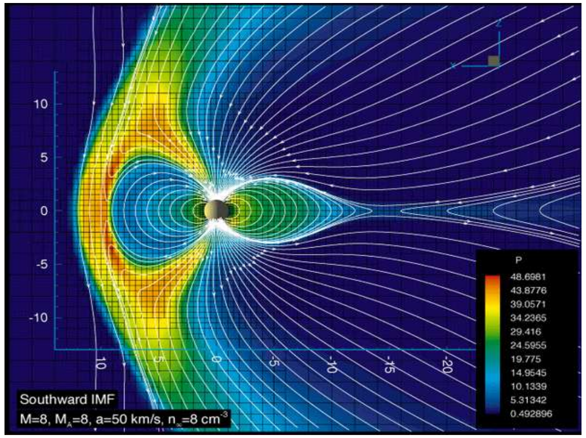
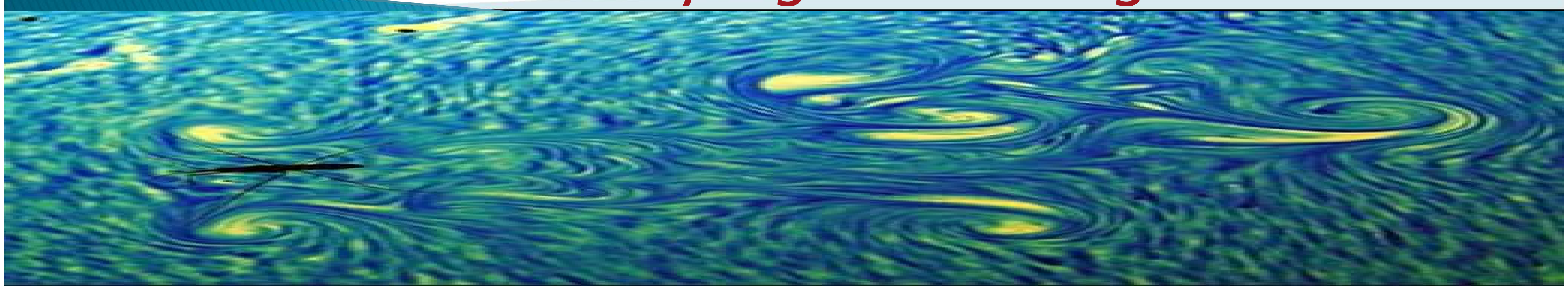


ME 251 Introduction to Fluid Mechanics

Introduction

Dr. Yesuenyeagbe A.K. Fiagbe



Course Objectives

- Understand the Characteristics/Properties of fluid
- Have good knowledge of fluid static
  - Static Pressure in Fluid
  - Manometers
  - Hydrostatic forces
  - Buoyancy and flotation
- Appreciate the importance of dimensions and dimensional analysis in problem solving.

Areas to Cover

- Characteristics/Properties of Fluid
  - Properties of fluid (Density, mass density, viscosity).
  - Thermodynamic properties (compressibility, surface tension and capillarity).
- Fluid Statics
  - Pressure variation in a fluid at rest
  - Absolute, gauge, atmospheric and vacuum pressures
  - Measurement of pressure: Manometers, mechanical gauges
  - Hydrostatic forces on submerged surfaces
  - Buoyancy and flotation
  - Fluids in rigid-body motion

Areas to Cover

- Introduction to Dimensional Analysis
  - Secondary or derived quantities,
  - Dimensional homogeneity,
  - Methods of dimensional analysis:
  - Buckingham's pie theorem,
  - method of selecting repeating variables,
  - procedure for solving problems by Buckingham's pie theorem

Instruction Format

Lecture

Mechanical	Thursday	PB014 8.00 – 10.00 a.m.
Aerospace	Monday	Room B 3.00 – 5.00 p.m.
Agricultural	Tuesday	PB020 5.00 – 7.00 p.m.

Laboratory session will be taken in ME 295

Schedule

Week	Date	Subject Category	What to cover (Topic)	Remark
1		**Introduction**		
2		Characteristics of Fluid	Properties of fluid (Density, mass density, viscosity).	
3			Thermodynamic properties (compressibility, surface tension and capillarity).	
4				
5				
6		Fluid Statics	Pressure variation in a fluid at rest Absolute, gauge, atmospheric and vacuum pressures	
7			Measurement of pressure: Manometers, mechanical gauges	**Mid Sem Exam**
8			Hydrostatic forces on submerged surfaces Buoyancy and flotation	
9			Fluids in rigid-body motion	
10		Introduction to Dimensional Analysis	Secondary or derived quantities, Dimensional homogeneity, Methods of dimensional analysis:	
11			Buckingham's pie theorem, method of selecting repeating variables,	
12			procedure for solving problems by Buckingham's pie theorem	
13		Review		
14		End of Semester Exam		
15				

Assessment

- Random and Unannounced Quizzes
- Assignments
- Attendance
- Mid Semester Examination
- End of Semester Examination

Class Regulations

- No lateness beyond 10 minutes: Student will be turned out.
- No mobile phone use in class: the phone will be confiscated for one week on first offence and for the semester on second offence.
- Decent conduct (both in dressing and demeanour).

Useful Reference Books

1. Cengel Y.A. and Cimbala J.M (2006) Fluid Mechaics: Fundamentals and Application, McGraw-Hill Companies Inc
2. Cengel, Y. A., & Turner, R. A. (2001). *Fundamentals of Thermal-Fluid Sciences.* New York: McGraw-Hill Companies Inc.
3. Crowe, C., & Elger, D. (2009). *Engineering Fluid Mechanics.* John Wiley & Sons, Inc.
4. Fox, R. W., McDonald, A. T., & Pritchard, P. J. (2004). *Introduction to Fluid Mechanics* (Sixth Edition ed.). Bogota: John Wiley & Sons, Inc.
5. NAKAYAMA, Y. (2000). *Introduction to Fluid Mechanics.* Tokyo: Yokendo Co. Ltd.

What is Fluid Mechanics?

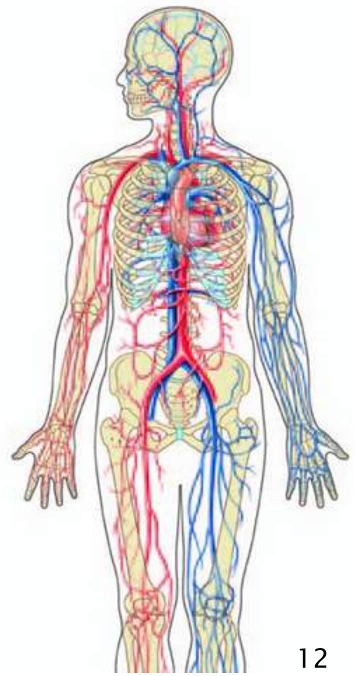
- The science that deals with the behavior of
  - Fluids at rest (fluid statics) or
  - Fluid in motion (fluid dynamics), and
  - Interaction of fluids with solids or other fluids at the boundaries.
- Fluid mechanics = fluid dynamics (fluids at rest as a special case of motion with zero velocity).

Areas of Fluid Mechanics

- Hydrodynamics – Study of the motion of fluids that are practically incompressible (such as liquids, especially water, and gases at low speeds).
  - The study that deals with liquid flows in pipes and open channels is referred to as hydraulics
- Aerodynamics deals with the flow of gases (especially air) over bodies such as aircraft, rockets, and automobiles at high or low speeds.
- Gas dynamics deals with the flow of fluids that undergo significant density changes, such as the flow of gases through nozzles at high speeds.
- Meteorology, Oceanography, and Hydrology deal with naturally occurring flows.

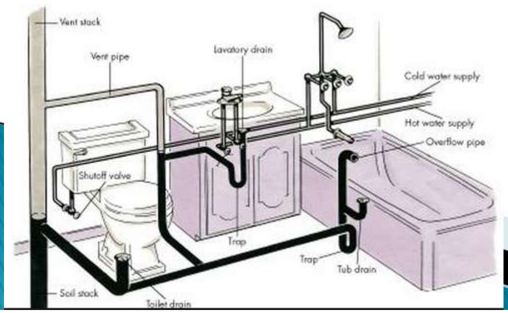
Application Areas of Fluid Mechanics

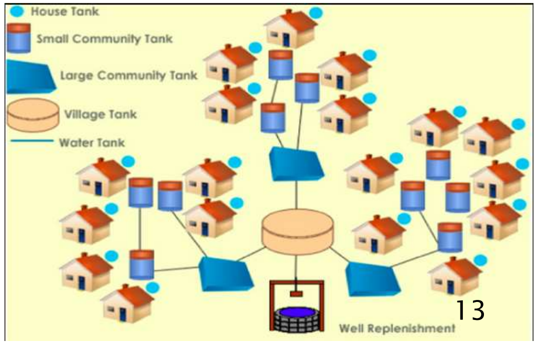
- Widely used both in everyday activities and in the design of modern engineering systems.
- Fluid mechanics plays a vital role in the human body. The heart is constantly pumping blood to all parts of the human body through the arteries and veins, and the lungs are the sites of airflow in alternating directions.
  - All artificial hearts, breathing machines, and dialysis systems are designed using fluid dynamics.



Application Areas of Fluid Mechanics

- Homes/house and its fittings (water and sewage networks) and appliances.
- The piping systems for cold water, natural gas, and sewage for an individual house and the entire city.
- Piping and ducting network of heating and air-conditioning systems.
- Refrigerators use in homes.
- Operation of ordinary faucets.
- Fluid mechanics plays a major role in the design of all these components.





Application Areas of Fluid Mechanics

- Transportation: Cars, Train, airplanes, etc.
- All components associated with the transportation of the fuel from the fuel tank to the cylinders—the fuel line, fuel pump, fuel injectors, or carburetors—as well as the mixing of the fuel and the air in the cylinders and the purging of combustion gases in exhaust pipes are analyzed using fluid mechanics.
- Fluid mechanics is also used in the design of the heating and air-conditioning system, the hydraulic brakes, the power steering, automatic transmission, and lubrication systems, the cooling system of the engine block including the radiator and the water pump, and even the tires.
- The sleek streamlined shape of recent model cars is the result of efforts to minimize drag by using extensive analysis of flow over surfaces.

Application Areas of Fluid Mechanics

- On a broader scale, fluid mechanics plays a major part in the design and analysis of aircraft, boats, submarines, rockets, jet engines, wind turbines, biomedical devices, the cooling of electronic components, and the transportation of water, crude oil, and natural gas.
- In the design of buildings, bridges, and even billboards.
- Numerous natural phenomena such as the rain cycle, weather patterns, the rise of ground water to the top of trees, winds, ocean waves, and currents in large water bodies are also governed by the principles of fluid mechanics.

KEEP
CALM
AND
Pass
Fluid Mechanics

Assignment 1

- Write a brief note on history and development of Fluid Mechanics.

Characteristics of Fluid

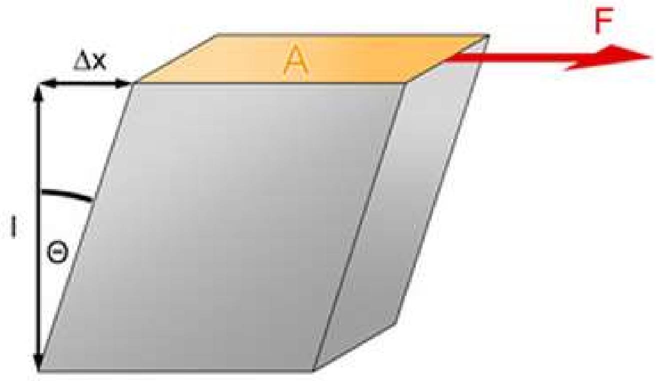
Properties of fluid (Density, mass density, viscosity). Thermodynamic properties (compressibility, surface tension and capillarity).

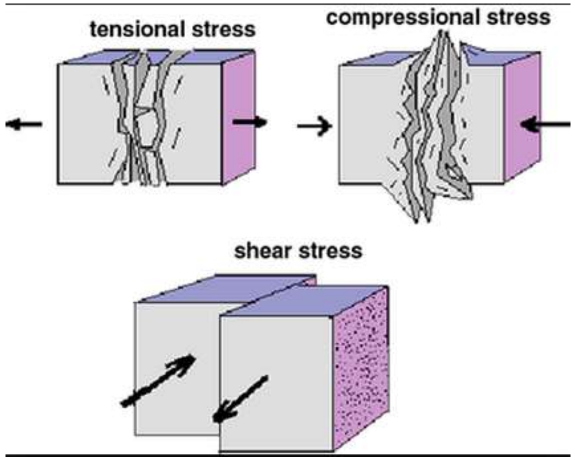
What Is Fluid?

- Substances exist in three primary phases :
  - solid,
  - liquid, and
  - gas.
  - At very high temperatures, it also exists as plasma.
- liquid or gas phase is referred to as FLUID.

What is Fluid?

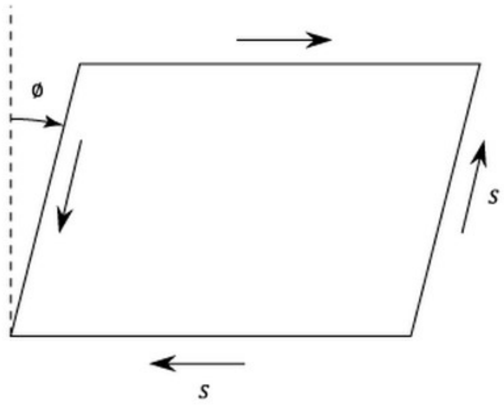
- Distinction between a solid and a fluid is made on the basis of the substance's ability to resist an applied shear (or tangential) stress that tends to change its shape.
- A solid can resist an applied shear stress by deforming, whereas a fluid deforms continuously under the influence of shear stress, no matter how small.



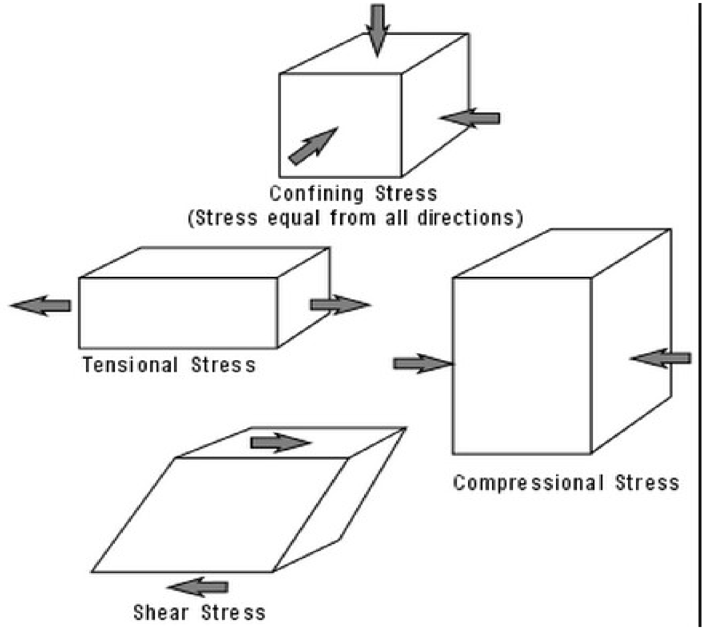


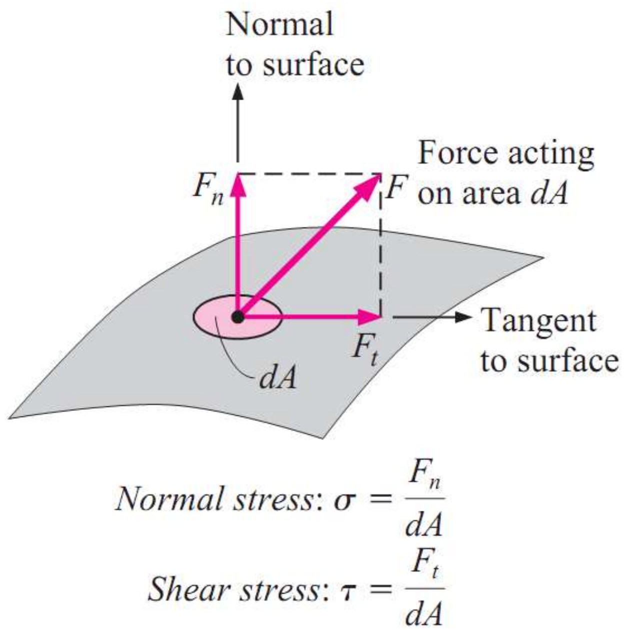
What Is Fluid?

- In solids, stress is proportional to strain. $\sigma = E\varepsilon$
- In fluids, stress is proportional to strain rate.
- When a constant shear force is applied, a solid eventually stops deforming, at some fixed strain angle, whereas a fluid never stops deforming and approaches a certain rate of strain.



- Stress is defined as force per unit area (dividing the force by the area upon which it acts).
- The normal component of the force acting on a surface per unit area is called the normal stress.
- The tangential component of a force acting on a surface per unit area is called shear stress.

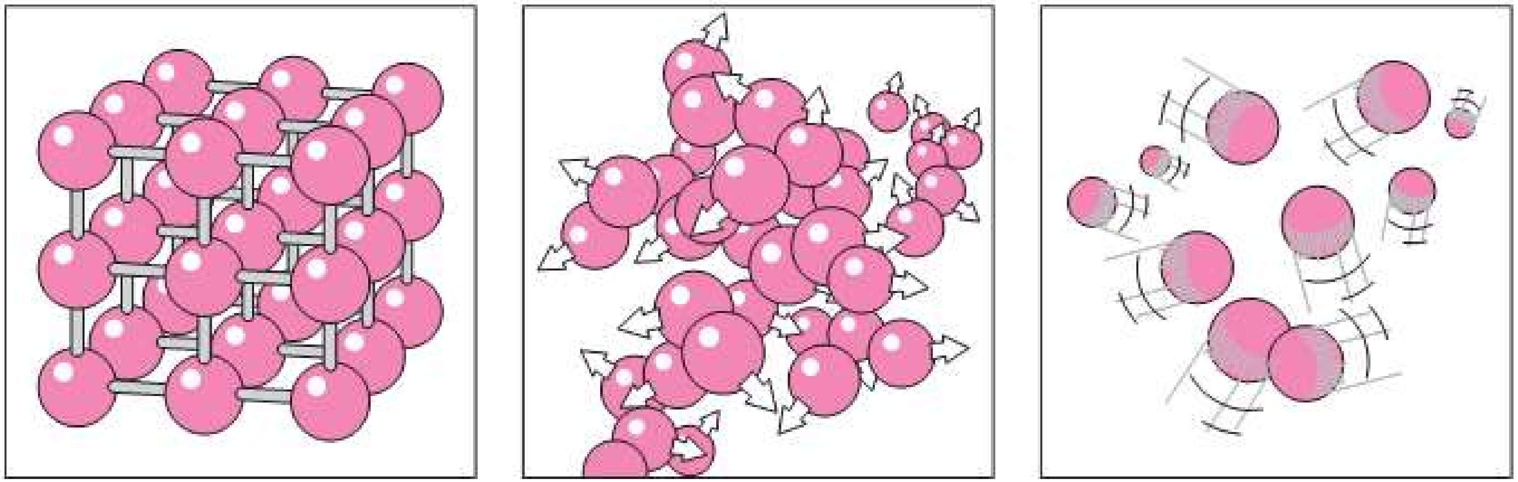




- In a fluid at rest, the normal stress is called pressure.
- The supporting walls of a fluid eliminate shear stress, and thus a fluid at rest is at a state of zero shear stress.

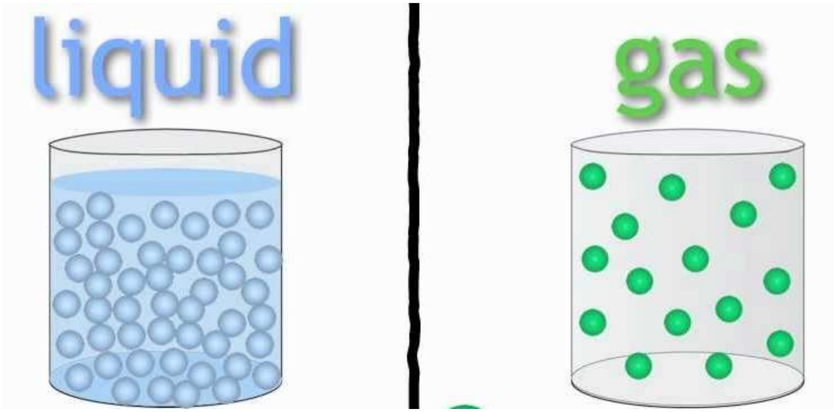
DISTINCTION BETWEEN SOLID AND FLUID

- The molecules of a solid are usually closer and the attractive forces between the molecules are so large that a solid tends to retain its shape.
- The intermolecular cohesive forces in a fluid are not great enough to hold the various elements of the fluid together making the fluid to flow under the action of the slightest stress and flow will continue as long as the stress is present.



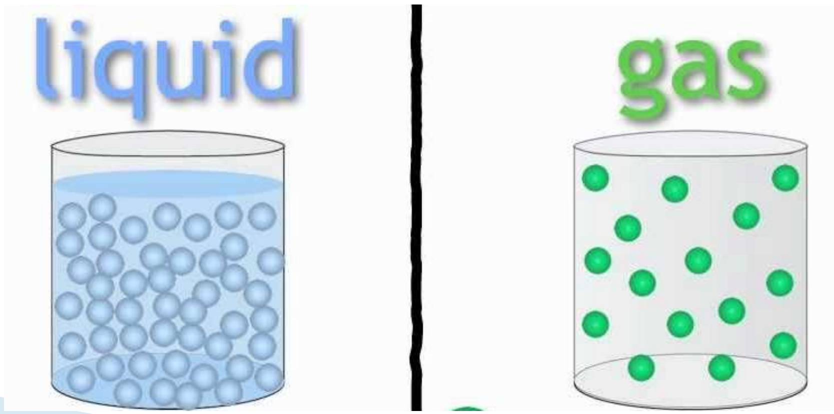
DISTINCTION BETWEEN A GAS AND A LIQUID

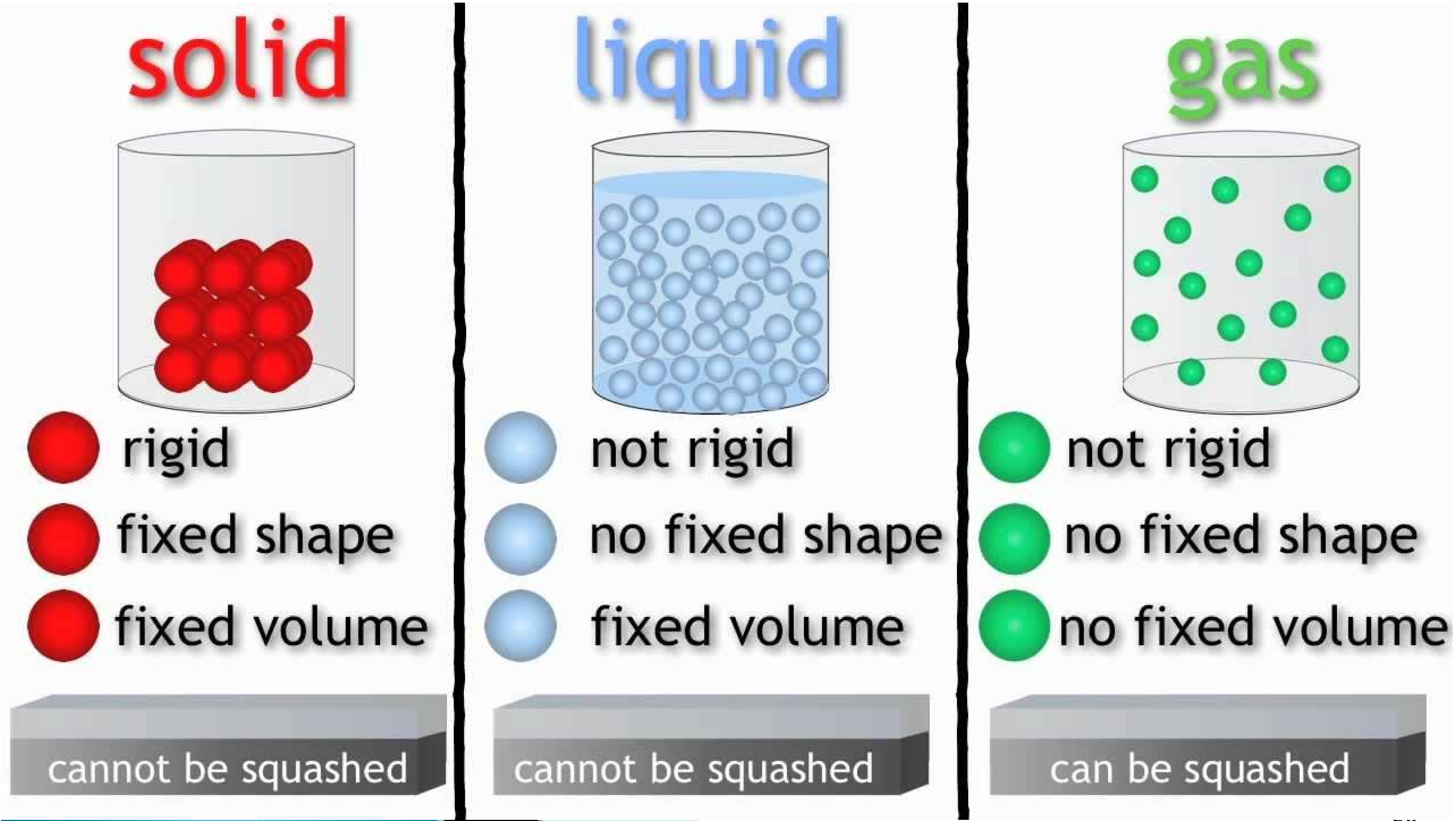
- A fluid may be either a gas or a liquid.
- The molecules of a gas are much farther apart than those of a liquid.
- Gas is very compressible, and when all external pressure is removed, it tends to expand indefinitely.
- A gas is in equilibrium only when it is completely enclosed.



DISTINCTION BETWEEN A GAS AND A LIQUID

- A liquid is relatively incompressible, and if all pressure, except that of its own vapor pressure, is removed, the cohesion between molecules holds them together, so that the liquid does not expand indefinitely.
- A liquid may have a free surface, (i.e., a surface from which all pressure is removed, except that of its own vapor.)

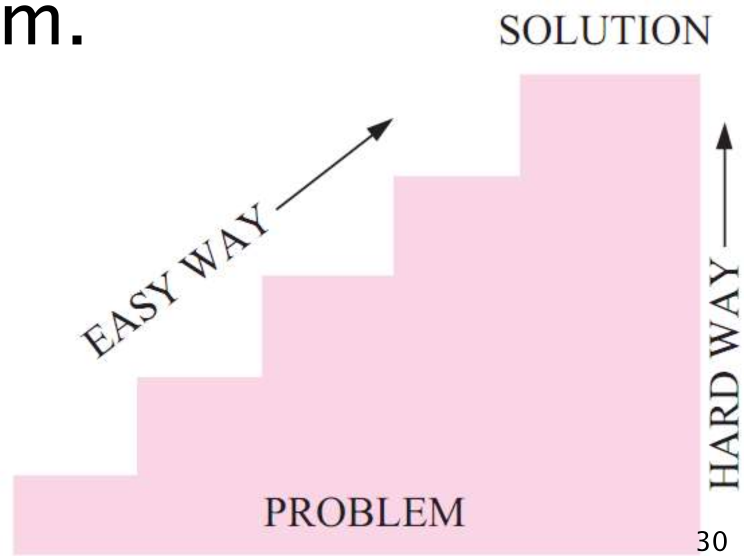



solid
rigid
fixed shape
fixed volume
cannot be squashed
liquid
not rigid
no fixed shape
fixed volume
cannot be squashed
gas
not rigid
no fixed shape
no fixed volume
can be squashed

PROBLEM-SOLVING TECHNIQUE

Step 1: Problem Statement

- In your own words,
  - briefly state the problem,
  - the key information given, and
  - the quantities to be found.
- This is to make sure that you understand the problem and the objectives before you attempt to solve the problem.



Step 2: Schematic

- Draw a realistic sketch of the physical system involved, and list the relevant information on the figure.
- The sketch does not have to be something elaborate, but it should resemble the actual system and show the key features.
- Indicate any energy and mass interactions with the surroundings. Listing the given information on the sketch helps one to see the entire problem at once.
- Also, check for properties that remain constant during a process (such as temperature during an isothermal process), and indicate them on the sketch.

Step 3: Assumptions and Approximations

- State any appropriate assumptions and approximations made to simplify the problem to make it possible to obtain a solution.
- Justify the questionable assumptions.
- Assume reasonable values for missing quantities that are necessary.
  - For example, in the absence of specific data for atmospheric pressure, it can be taken to be 1 atm.

Step 4: Physical Laws

- Apply all the relevant basic physical laws and principles (such as the conservation of mass), and reduce them to their simplest form by utilizing the assumptions made.
- However, the region to which a physical law is applied must be clearly identified first.
  - For example, the increase in speed of water flowing through a nozzle is analyzed by applying conservation of mass between the inlet and outlet of the nozzle.

Step 5: Properties

- Determine the unknown properties at known states necessary to solve the problem from property relations or tables.
- List the properties separately, and
- Indicate their source, if applicable.

Step 6: Calculations

- Substitute the known quantities into the simplified relations and perform the calculations to determine the unknowns.
- Pay particular attention to the units and unit cancellations, and remember that a dimensional quantity without a unit is meaningless.
- Also, don’t give a false implication of high precision by copying all the digits from the screen of the calculator.
  - (round the results to an appropriate number of significant digits).

Step 7: Reasoning, Verification, and Discussion

- Check to make sure that the results obtained are reasonable and intuitive, and verify the validity of the questionable assumptions.
- Repeat the calculations that resulted in unreasonable values.
  - For example, under the same test conditions the aerodynamic drag acting on a car should not increase after streamlining the shape of the car.
- Point out the significance of the results, and discuss their implications.
- State the conclusions that can be drawn from the results, and any recommendations that can be made from them.
- Emphasize the limitations under which the results are applicable, and caution against any possible misunderstandings and using the results in situations where the underlying assumptions do not apply.

Step 7: Reasoning, Verification, and Discussion

- Keep in mind that the solutions you present to your instructors, and any engineering analysis presented to others, is a form of communication.
- Therefore neatness, organization, completeness, and visual appearance are of utmost importance for maximum effectiveness.
- Besides, neatness also serves as a great checking tool since it is very easy to spot errors and inconsistencies in neat work.
- Carelessness and skipping steps to save time often end up costing more time and unnecessary anxiety.

Units and Dimensions

Units and Dimensions

- A *dimension* is a category that represents a physical quantity
  - mass,
  - length,
  - time,
  - momentum,
  - force,
  - acceleration, and
  - energy.
- Primary and Secondary Dimensions

Units and Dimensions

- Primary dimensions are the most fundamental dimensions
- Primary dimensions are independent dimensions, from which all other dimensions can be obtained
- All other dimensions are *secondary dimensions* and can be constructed from combinations of primary dimensions
- Dimensions have no numbers associated with them

Units and Dimensions

- Force is not a *primary* dimension in fluid mechanics. Yet, force can be written as a combination of the four primary dimensions, i.e. in terms of mass, length, time, and temperature.

$$\{\vec{F}\} = \{m \cdot \vec{a}\} = \left\{m \cdot \frac{L}{t^2}\right\} = \left\{\frac{mL}{t^2}\right\}$$

- Power is not a *primary* dimension in fluid mechanics. Yet, power can be written as a combination of the four primary dimensions, i.e. in terms of mass, length, time, and temperature.

$$\{\dot{W}\} = \left\{\frac{\text{work}}{\text{time}}\right\} = \left\{\frac{\text{force} \cdot \text{length}}{\text{time}}\right\} = \left\{\frac{\left(mLt^{-2}\right) \cdot L}{t}\right\} = \left\{\frac{mL^2}{t^3}\right\}$$

Units and Dimensions

- A *unit* is a way to assign a number/value or measurement to a dimension.
- A unit of measurement is a definite magnitude of a physical quantity,
- They are defined and adopted by convention, and is used as a standard for measurement of the same physical quantity.
- There are three primary unit systems in use:
  - the International System of Units (SI units – kg, N, m, s, K)
  - the English Engineering System of Units (commonly called English units – lbm, lbf, ft, s, R)
  - the British Gravitational System of Units (BG – slug, lbf, ft, s, °R)
- Units must always have numbers associated with them.
- For example, length is a *dimension*, but it is measured in *units* of feet (ft) or meters (m).

Units and Dimensions

- Primary Dimensions

Dimension	Symbol	Unit (SI)
Length	L	meter (m)
Mass	M	kilogram (kg)
Time	T	second (s)
Temperature	θ	Kelvin (K)
Electric current	i	ampere (A)
Amount of light	C	(cd)
Amount of matter	N	mole (mol)

Dimensional Homogeneity

- Dimensional homogeneity is the quality of an equation having quantities of same units on both sides.
- A valid equation must be homogeneous, since equality cannot apply between quantities of different nature.

$$s = \frac{gt^2}{2} + v_0 t + s_0$$