Fluid Mechanics by

Assist. Prof. Dr. Moataz Gomaa

Fluid Mechanics

by

Assist. Prof. Dr. Moataz Gomaa

- **Email: A.A.Gomaa@eng.svu.edu.eg**

You can send mail in any time.

Lecture one
Basic Concepts

I. BASIC INFORMATION

Course Title:	**Fluid Mechanics**
Course Code:	**PPT 501**
Credit Hours:	**Number of credits in the Course: 3** **.** **Theoretical** **Practical √**
Program (s) in which the course is given:	

III. COURSE CONTENTS

Week NO.	Topic	NO. of Hours
W1		
W2		
W3		
W4		
W5		
W6		
W7		
W8		
W9		
W10		
W11		
W12		
W13		
W14		
W15		
W16		
Total		

Course Coordinator : Dr/

Dean: Prof. Dr/

VIII. WEIGHING OF ASSESSMENTS	
Quizzes and assignments	Marks 60
Mid-term exam	Marks 30
Practical Examination	Marks
Final-term Examination	Marks 60
Field work	Marks
Total	Marks 150

Course outline

Course Description:	Fluid Properties, hydrostatics, fluid Kinematics, conservation Laws, application of continuity, momentum and energy equations. Reynolds transport theorem, dynamics laws of incompressible flows, Navier-Stokes equations, dimensional analysis and similarity, internal and external flows, compressible flow, turbulence, modern models of turbulence, boundary layer theory, boundary layer applied to submerged and conduit flows, unsteady flow, flow measurement devices, and fluid machinery: Pumps and turbines classification, theory, performance and application.
خصائص السوائل ، الهيدروستاتيكا ، كينماتيكا السوائل ، قوانين الحفظ ، تطبيق الاستمرارية ، قوة الدفع ومعادلات الطاقة. نظرية رينولدز للنقل ، قوانين ديناميكية التدفقات غير القابلة للضغط ، معادلات نافير ستوكس ، تحليل التشابه والأبعاد ، التدفقات الداخلية والخارجية ، التدفق القابل للانضغاط ، الاضطرابات ، النماذج الحديثة من الاضطراب ، نظرية الطبقة الحدودية ، الطبقة الحدودية المطبقة على التدفقات المغمورة والقناة ، التدفق غير المستقر وأجهزة قياس التدفق وآلات الموائع: تصنيف المضخات والتوربينات ، النظرية والأداء والتطبيق.	توصيف المقرر:

Fluid Mechanics

Fluids essential to life

- Human body 65% water
- Earth's surface is 2/3 water
- Atmosphere extends 17km above the earth's surface

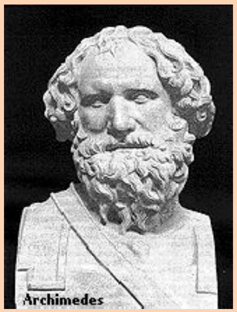
History shaped by fluid mechanics

- Geomorphology
- Human migration and civilization
- Modern scientific and mathematical theories and methods
- Warfare

Affects every part of our lives

History

Faces of Fluid Mechanics



Archimedes
(C. 287-212 BC)

Newton
(1642-1727)

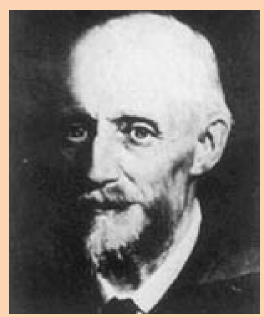
Leibniz
(1646-1716)

Bernoulli
(1667-1748)

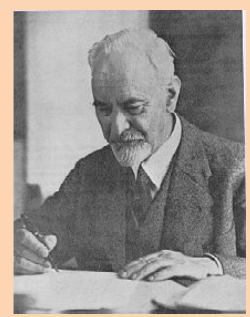
Euler
(1707-1783)

Navier
(1785-1836)

Stokes
(1819-1903)



Reynolds
(1842-1912)



Prandtl
(1875-1953)

Taylor
(1886-1975)

Significance

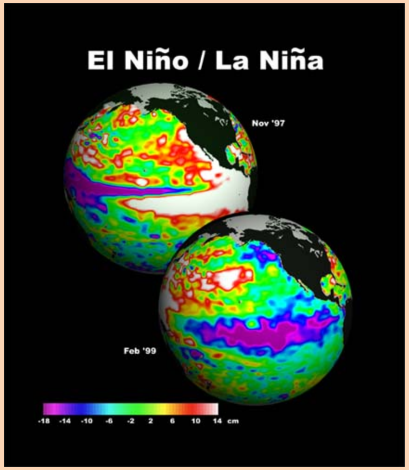
- **Fluids omnipresent**
  - Weather & climate
  - Vehicles: automobiles, trains, ships, and planes, etc.
  - Environment
  - Physiology and medicine
  - Sports & recreation
  - Many other examples!

Weather & Climate

Tornadoes

Thunderstorm

Global Climate



Hurricanes

Vehicles

Aircraft

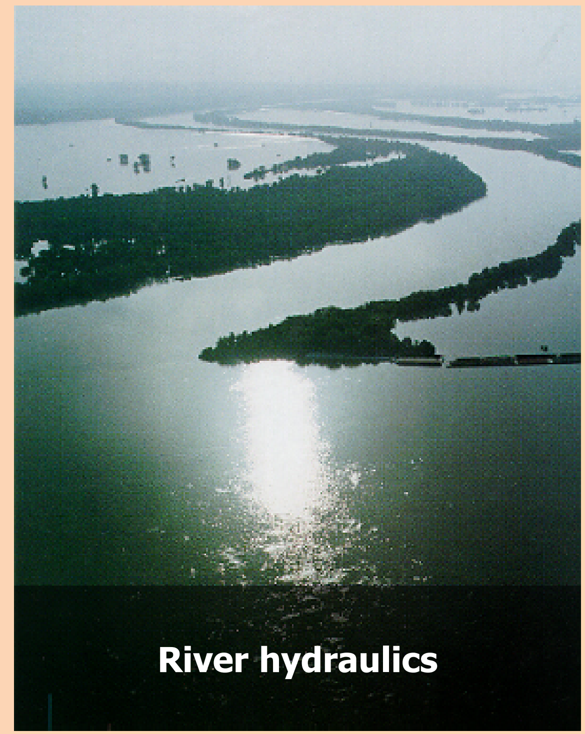
High-speed rail

Surface ships

Submarines

Environment

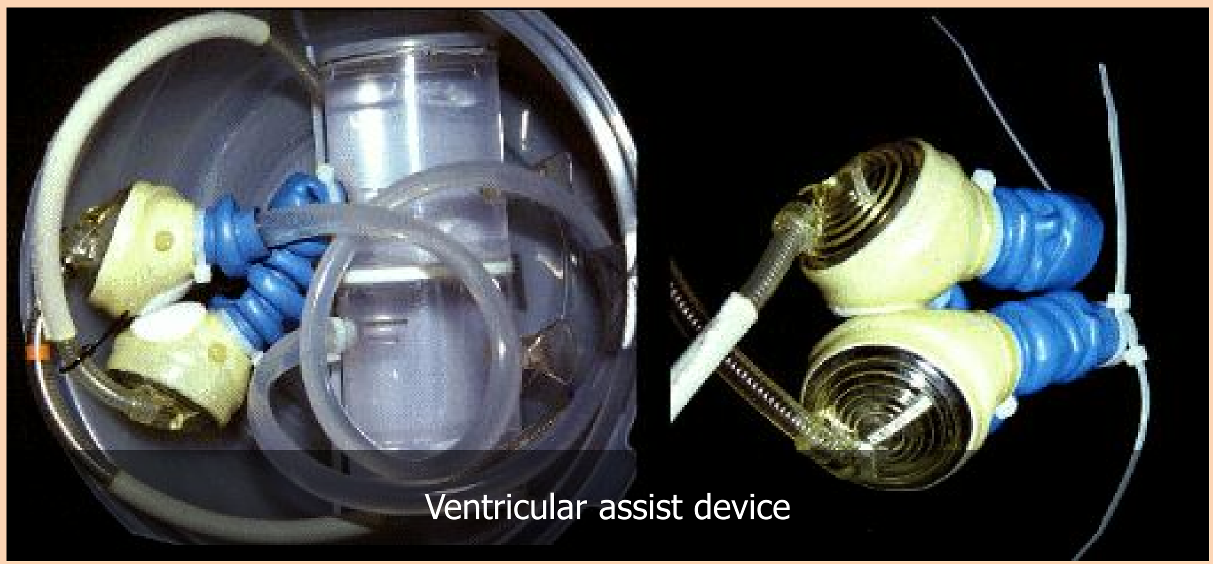
Air pollution



River hydraulics

Physiology and Medicine

Blood pump


Ventricular assist device

Sports & Recreation

Water sports

Offshore racing

Auto racing

Cycling

Surfing

FLUID MECHANICS WITH HYDRAULICS

1 Fluid Properties

2 Mechanics of fluids at rest

3 Mechanics of fluids in motion

4 Energy loss of fluids in motion

5 Flow of fluids in clearances and orifices الخلوص والفتحات

6 Hydraulically sticking

7 Hydraulically shocking صدمة هيدروليكية

8 Cavitation التجويف

Approximate Physical Properties of Some Common Liquids (BG Units)

Liquid	Temperature (°F)	Density, ρ (slugs/ft^3)	Specific Weight, γ (lb/ft^3)	Dynamic Viscosity, μ (lb · s/ft^2)	Kinematic Viscosity, ν (ft^2/s)	Surface Tension,[a] σ (lb/ft)	Vapor Pressure, p_v [lb/in.^{2} (abs)]	Bulk Modulus,[b] E_v (lb/in.^{2})
Carbon tetrachloride	68	3.09	99.5	2.00 E − 5	6.47 E − 6	1.84 E − 3	1.9 E + 0	1.91 E + 5
Ethyl alcohol	68	1.53	49.3	2.49 E − 5	1.63 E − 5	1.56 E − 3	8.5 E − 1	1.54 E + 5
Gasoline[c]	60	1.32	42.5	6.5 E − 6	4.9 E − 6	1.5 E − 3	8.0 E + 0	1.9 E + 5
Glycerin	68	2.44	78.6	3.13 E − 2	1.28 E − 2	4.34 E − 3	2.0 E − 6	6.56 E + 5
Mercury	68	26.3	847	3.28 E − 5	1.25 E − 6	3.19 E − 2	2.3 E − 5	4.14 E + 6
SAE 30 oil[c]	60	1.77	57.0	8.0 E − 3	4.5 E − 3	2.5 E − 3	—	2.2 E + 5
Seawater	60	1.99	64.0	2.51 E − 5	1.26 E − 5	5.03 E − 3	2.56 E − 1	3.39 E + 5
Water	60	1.94	62.4	2.34 E − 5	1.21 E − 5	5.03 E − 3	2.56 E − 1	3.12 E + 5

[a]In contact with air.

[b]Isentropic bulk modulus calculated from speed of sound.

[c]Typical values. Properties of petroleum products vary.

Approximate Physical Properties of Some Common Liquids (SI Units)

Approximate Physical Properties of Some Common Liquids (SI Units)

Liquid	Temperature (°C)	Density, ρ (kg/m^3)	Specific Weight, γ (kN/m^3)	Dynamic Viscosity, μ (N · s/m^2)	Kinematic Viscosity, ν (m^2/s)	Surface Tension,[a] σ (N/m)	Vapor Pressure, p_v [N/m^2 (abs)]	Bulk Modulus,[b] E_v (N/m^2)
Carbon tetrachloride	20	1,590	15.6	9.58 E − 4	6.03 E − 7	2.69 E − 2	1.3 E + 4	1.31 E + 9
Ethyl alcohol	20	789	7.74	1.19 E − 3	1.51 E − 6	2.28 E − 2	5.9 E + 3	1.06 E + 9
Gasoline[c]	15.6	680	6.67	3.1 E − 4	4.6 E − 7	2.2 E − 2	5.5 E + 4	1.3 E + 9
Glycerin	20	1,260	12.4	1.50 E + 0	1.19 E − 3	6.33 E − 2	1.4 E − 2	4.52 E + 9
Mercury	20	13,600	133	1.57 E − 3	1.15 E − 7	4.66 E − 1	1.6 E − 1	2.85 E + 10
SAE 30 oil[c]	15.6	912	8.95	3.8 E − 1	4.2 E − 4	3.6 E − 2	—	1.5 E + 9
Seawater	15.6	1,030	10.1	1.20 E − 3	1.17 E − 6	7.34 E − 2	1.77 E + 3	2.34 E + 9
Water	15.6	999	9.80	1.12 E − 3	1.12 E − 6	7.34 E − 2	1.77 E + 3	2.15 E + 9

[a]In contact with air.

[b]Isentropic bulk modulus calculated from speed of sound.

[c]Typical values. Properties of petroleum products vary.

Approximate Physical Properties of Some Common Gases at Standard Atmospheric Pressure (BG Units)

Gas	Temperature (°F)	Density, ρ (slugs/ft^3)	Specific Weight, γ (lb/ft^3)	Dynamic Viscosity, μ (lb · s/ft^2)	Kinematic Viscosity, ν (ft^2/s)	Gas Constant,[a] R (ft · lb/slug · °R)	Specific Heat Ratio,[b] k
Air (standard)	59	2.38 E − 3	7.65 E − 2	3.74 E − 7	1.57 E − 4	1.716 E + 3	1.40
Carbon dioxide	68	3.55 E − 3	1.14 E − 1	3.07 E − 7	8.65 E − 5	1.130 E + 3	1.30
Helium	68	3.23 E − 4	1.04 E − 2	4.09 E − 7	1.27 E − 3	1.242 E + 4	1.66
Hydrogen	68	1.63 E − 4	5.25 E − 3	1.85 E − 7	1.13 E − 3	2.466 E + 4	1.41
Methane (natural gas)	68	1.29 E − 3	4.15 E − 2	2.29 E − 7	1.78 E − 4	3.099 E + 3	1.31
Nitrogen	68	2.26 E − 3	7.28 E − 2	3.68 E − 7	1.63 E − 4	1.775 E + 3	1.40
Oxygen	68	2.58 E − 3	8.31 E − 2	4.25 E − 7	1.65 E − 4	1.554 E + 3	1.40

[a] Values of the gas constant are independent of temperature.

[b] Values of the specific heat ratio depend only slightly on temperature.

Approximate Physical Properties of Some Common Gases at Standard Atmospheric Pressure (SI Units)

Gas	Temperature (°C)	Density, ρ (kg/m^3)	Specific Weight, γ (N/m^3)	Dynamic Viscosity, μ ($N \cdot s/m^2$)	Kinematic Viscosity, ν (m^2/s)	Gas Constant,[a] R ($J/kg \cdot K$)	Specific Heat Ratio,[b] k
Air (standard)	15	1.23 E + 0	1.20 E + 1	1.79 E − 5	1.46 E − 5	2.869 E + 2	1.40
Carbon dioxide	20	1.83 E + 0	1.80 E + 1	1.47 E − 5	8.03 E − 6	1.889 E + 2	1.30
Helium	20	1.66 E − 1	1.63 E + 0	1.94 E − 5	1.15 E − 4	2.077 E + 3	1.66
Hydrogen	20	8.38 E − 2	8.22 E − 1	8.84 E − 6	1.05 E − 4	4.124 E + 3	1.41
Methane (natural gas)	20	6.67 E − 1	6.54 E + 0	1.10 E − 5	1.65 E − 5	5.183 E + 2	1.31
Nitrogen	20	1.16 E + 0	1.14 E + 1	1.76 E − 5	1.52 E − 5	2.968 E + 2	1.40
Oxygen	20	1.33 E + 0	1.30 E + 1	2.04 E − 5	1.53 E − 5	2.598 E + 2	1.40

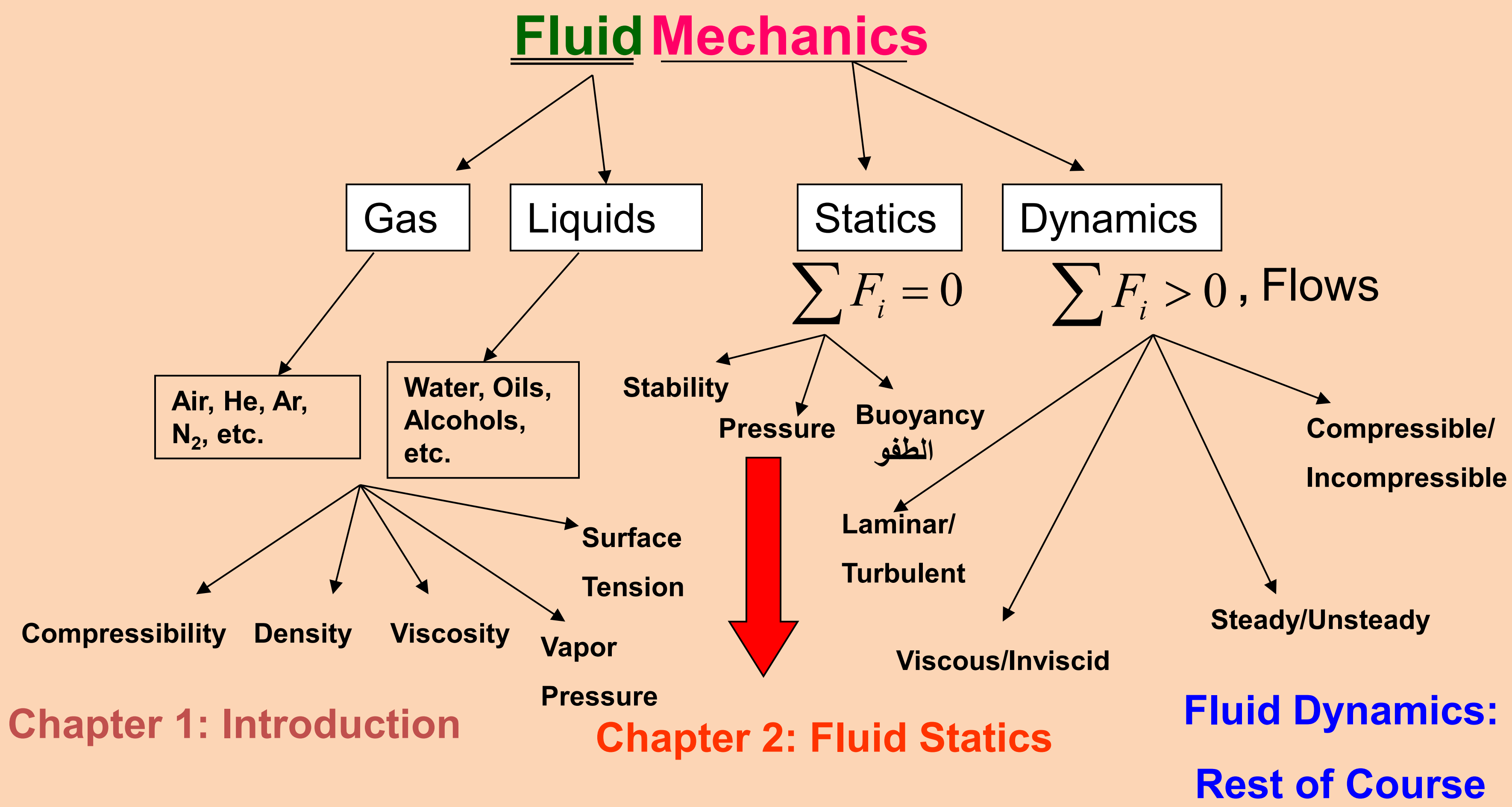
[a]Values of the gas constant are independent of temperature.

[b]Values of the specific heat ratio depend only slightly on temperature.

Lecture Two

Overview

Fluid Mechanics Overview



Introduction

- Fluid mechanics is a study of the behavior of fluids, either at rest (fluid statics) or in motion (fluid dynamics).
- The analysis is based on the fundamental laws of mechanics, which relate continuity of mass and energy with force and momentum.
- An understanding of the properties and behavior of fluids at rest and in motion is of great importance in engineering.

Introduction

1.1 **Definition of Fluid**

- A fluid is a substance, which deforms continuously, or flows, when subjected to shearing force
- In fact if a shear stress is acting on a fluid it will flow and if a fluid is at rest there is no shear stress acting on it.

Fluid Flow → Shear stress - Yes

Fluid Rest → Shear stress - No

Fluid Statics

- By definition, the fluid is at rest.
- Or, no there is no relative motion between adjacent particles.
- No shearing forces is placed on the fluid.
- There are only pressure forces, and no shear.
- Results in relatively “simple” analysis
- Generally look for the pressure variation in the fluid

Introduction to Fluid Mechanics

Fluids are:

- Shapeless and do not resist being sheared
- When a force is exerted on fluid the pressure increases, whereas the force is directional the pressure is omnidirectional (exerted in all directions)
- Viscous (Oil has a high viscosity whilst water has a low viscosity)
- Oil has a higher viscosity when cold. As the temperature increases the viscosity becomes lower so the oil becomes thinner.

Introduction to Fluid Mechanics

Fluids are:

- Subject to turbulence when force is applied

There are two types of fluids

Hydraulic fluids are:

- Incompressible (when a pressure is exerted no volumetric change occurs). Oil is often used as a hydraulic fluid.

Pneumatic fluids are:

- Gases can be compressed. An example is Liquid Petroleum Gas (LPG). This is pressurised into a gas tank to be sored as a liquid. When released it turns back to a gas.

Differences between liquid and gases

Liquid	Gases
Difficult to compress and often regarded as incompressible	Easily to compress – changes of volume is large, cannot normally be neglected and are related to temperature
Occupies a fixed volume and will take the shape of the container	No fixed volume, it changes volume to expand to fill the containing vessels
A free surface is formed if the volume of container is greater than the liquid.	Completely fill the vessel so that no free surface is formed.

Introduction to Fluid Mechanics

Advantages of hydraulic systems include:

- Appropriate method of power transmission over long distances (Example: trucks use hydraulic power instead of fuel)
- Good flexibility
- Variable speed control
- Safe and reliable

Disadvantages:

- Need to be in a confined space
- Fire hazard
- Leaks can pose a safety hazard or environmental hazard
- Oil filtration must be maintained.

Fluid Mechanics

Fluid statics = equilibrium situations
Fluid dynamics = fluids in motion

$$\boxed{\text{Density} = \rho = \frac{m}{V} = \frac{mass}{volume}\ [\text{kg/m}^3]}$$

The density ρ has a wide range

Osmium = $22.5\text{x}10^3$ kg/m^3
Gold = $19.3\text{x}10^3$ kg/m^3
Lead = $11.3\text{x}10^3$ kg/m^3
Air (gases) = 1.2 kg/m^3
Water = 1.0 kg/m^3
Ice = 0.92 kg/m^3

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

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

Specific volume

$$v = \frac{V}{m} = \frac{1}{\rho}$$

$$V = 12\ \mathrm{m^3}$$
$$m = 3\ \mathrm{kg}$$
$$\downarrow$$
$$\rho = 0.25\ \mathrm{kg/m^3}$$
$$v = \frac{1}{\rho} = 4\ \mathrm{m^3/kg}$$

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

Specific weight: The weight of a unit volume of a substance.

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

Specific gravities of some substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3–0.9
Gold	19.2
Bones	1.7–2.0
Ice	0.92
Air (at 1 atm)	0.0013

Fluid Mechanics

Properties

Property	Symbol & Equation	Definition	Etc.
Density	$\rho = \frac{m}{\forall}$	$\frac{mass}{volume}$	
Specific Weight	$\gamma = \rho g$	*density x gravity*	
Specific Gravity	$SG = \frac{\rho_x}{\rho_{water}} = \frac{\gamma_x}{\gamma_{water}}$		
Viscosity	$\mu = \frac{\tau}{du/dy}$	$\frac{shear\ stress}{velocity\ gradient}$	
Kinematic viscosity	$v = \frac{\mu}{\rho}$	$\frac{viscosity}{density}$	
Ideal Gas Law	$p = \rho R_{gas} T$	*Use to find properties of gasses*	$R_{gas} = \frac{\bar{R}}{molec.wt.}$

Make sure you know the relationship between density, specific weight, and specific gravity!

Example 1.1

Given m = 80 kg and a=10 m/s2. Find the force

Solution

- $F = ma$
- $F = 80\ kg \times 10\ m/s^2 = 800\ kg.m/s^2$
- **$F = 800N$**

EXAMPLE 2–1 Density, Specific Gravity, and Mass of Air in a Room

Determine the density, specific gravity, and mass of the air in a room whose dimensions are 4 m × 5 m × 6 m at 100 kPa and 25°C (Fig. 2–4).

Solution The density, specific gravity, and mass of the air in a room are to be determined.
Assumptions At specified conditions, air can be treated as an ideal gas.
Properties The gas constant of air is $R = 0.287$ kPa · m³/kg · K.
Analysis The density of the air is determined from the ideal-gas relation $P = \rho RT$ to be

$$\rho = \frac{P}{RT} = \frac{100 \text{ kPa}}{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(25 + 273.15) \text{ K}} = \mathbf{1.17 \text{ kg/m}^3}$$

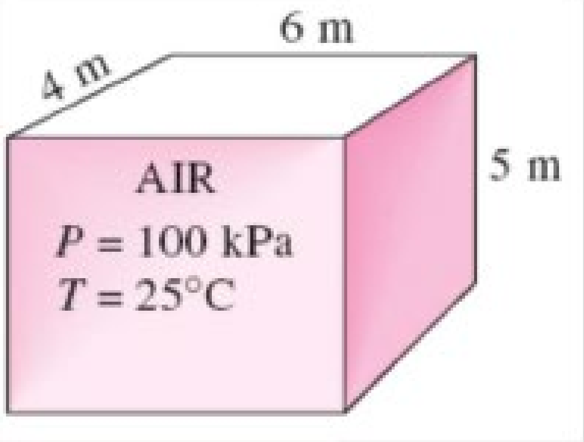
Then the specific gravity of the air becomes

$$\text{SG} = \frac{\rho}{\rho_{H_2O}} = \frac{1.17 \text{ kg/m}^3}{1000 \text{ kg/m}^3} = \mathbf{0.00117}$$

Finally, the volume and the mass of the air in the room are

$$V = (4 \text{ m})(5 \text{ m})(6 \text{ m}) = 120 \text{ m}^3$$

$$m = \rho V = (1.17 \text{ kg/m}^3)(120 \text{ m}^3) = \mathbf{140 \text{ kg}}$$



Discussion Note that we converted the temperature to the unit K from °C before using it in the ideal-gas relation.

A reservoir of glycerin (glyc) has a mass of 1200 kg and a volume of 0.952 m^3. Find the glycerin's weight (W), mass density (ρ), specific weight (γ), and specific gravity (s.g.).

$$F = W = ma = (1200)(9.81) = 11\,770 \text{ N} \quad \text{or} \quad 11.77 \text{ kN}$$

$$\rho = m/V = 1200/0.952 = 1261 \text{ kg/m}^3$$

$$\gamma = W/V = 11.77/0.952 = 12.36 \text{ kN/m}^3$$

$$\text{s.g.} = \gamma_{\text{glyc}}/\gamma_{\text{H}_2\text{O at 4 °C}} = 12.36/9.81 = 1.26$$

A body requires a force of 100 N to accelerate it at a rate of 0.20 m/s^2. Determine the mass of the body in kilograms and in slugs.

$$F = ma$$

$$100 = (m)(0.20)$$

$$m = 500 \text{ kg} = 500/14.59 = 34.3 \text{ slugs}$$

A reservoir of carbon tetrachloride (CCl_4) has a mass of 500 kg and a volume of 0.315 m^3. Find the carbon tetrachloride's weight, mass density, specific weight, and specific gravity.

$$F = W = ma = (500)(9.81) = 4905\ \text{N} \quad \text{or} \quad 4.905\ \text{kN}$$

$$\rho = m/V = 500/0.315 = 1587\ \text{kg/m}^3$$

$$\gamma = W/V = 4.905/0.315 = 15.57\ \text{kN/m}^3$$

$$\text{s.g.} = \gamma_{CCl_4}/\gamma_{H_2O\ \text{at}\ 4\,^\circ\text{C}} = 15.57/9.81 = 1.59$$