# Chapter 1
# Introduction

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# Significant learning outcomes

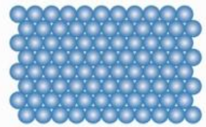
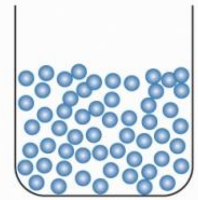
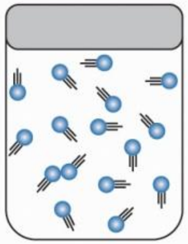
## Conceptual Knowledge

- Describe fluid mechanics.
- Contrast gases and liquids by describing similarities and differences.
- Explain the continuum assumption.

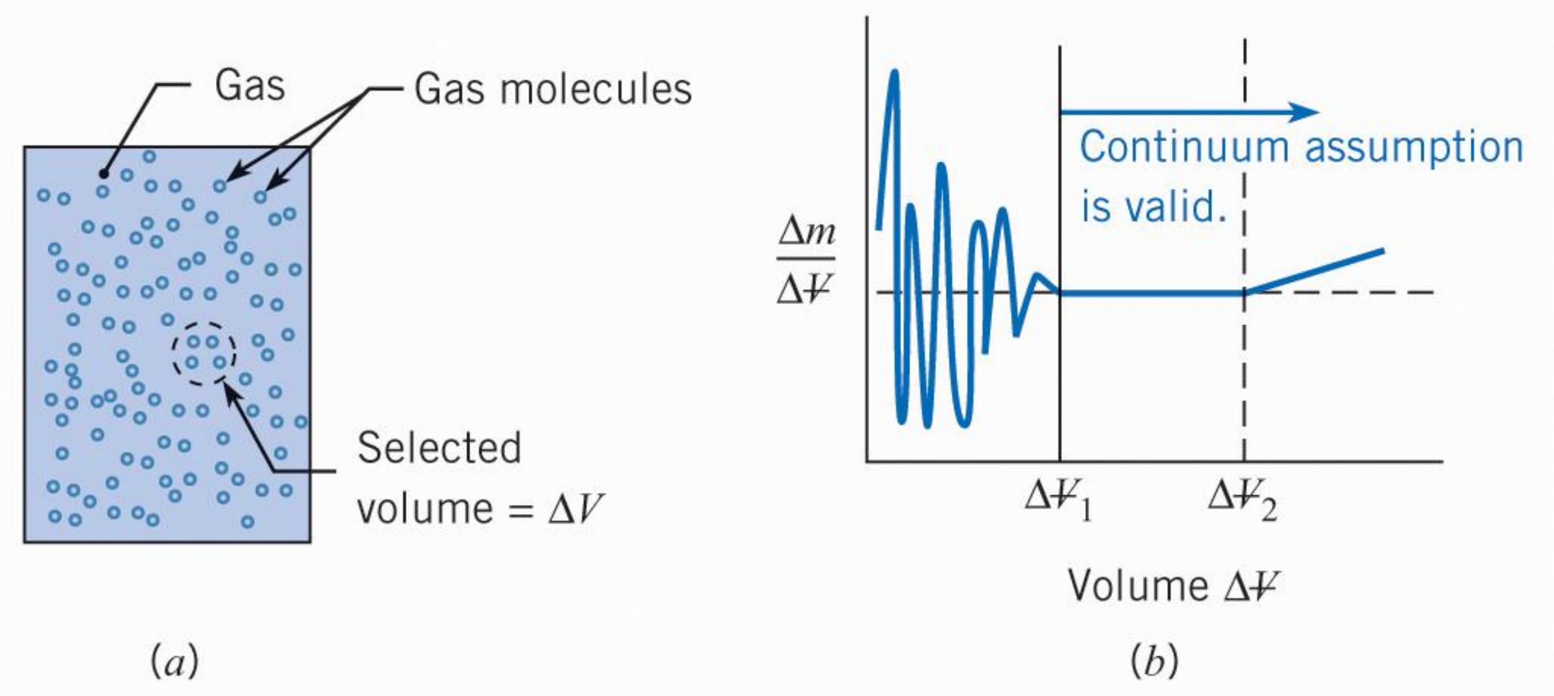
## Procedural Knowledge

- Use primary dimensions to check equations for dimensional homogeneity.
- Apply the grid method to carry and cancel units in calculations.
- Explain the steps in the "Structured Approach for Engineering Analysis"

## Table 1.1 COMPARISON OF SOLIDS, LIQUIDS, AND GASES

| Attribute | Solid | Liquid | Gas |
|---|---|---|---|
| **Typical Visualization** |  |  |  |
| **Macroscopic Description** | Solids hold their shape; no need for a container | Liquids take the shape of the container and will stay in open container | Gases expand to fill a closed container |
| **Mobility of Molecules** | Molecules have low mobility because they are bound in a structure by strong intermolecular forces | Liquids typically flow easily even though there are strong intermolecular forces between molecules | Molecules move around freely with little interaction except during collisions; this is why gases expand to fill their container |
| **Typical Density** | Often high; e.g., density of steel is 7700 $kg/m^3$ | Medium; e.g., density of water is 1000 $kg/m^3$ | Small; e.g., density of air at sea level is 1.2 $kg/m^3$ |
| **Molecular Spacing** | Small—molecules are close together | Small—molecules are held close together by intermolecular forces | Large—on average, molecules are far apart |
| **Effect of Shear Stress** | Produces deformation | Produces flow | Produces flow |
| **Effect of Normal Stress** | Produces deformation that may associate with volume change; can cause failure | Produces deformation associated with volume change | Produces deformation associated with volume change |
| **Viscosity** | NA | High; decreases as temperature increases | Low; increases as temperature increases |
| **Compressibility** | Difficult to compress; bulk modulus of steel is $160 \times 10^9$ Pa | Difficult to compress; bulk modulus of liquid water is $2.2 \times 10^9$ Pa | Easy to compress; bulk modulus of a gas at room conditions is about $1.0 \times 10^5$ Pa |

# 1-2 The continuum assumption




$$\rho = \frac{\Delta M}{\Delta V}$$

# 1-3 Dimensions, units and resources

**Table 1.2 PRIMARY DIMENSIONS**

| Dimension | Symbol | Unit (SI) |
|---|---|---|
| Length | $L$ | meter (m) |
| Mass | $M$ | kilogram (kg) |
| Time | $T$ | second (s) |
| Temperature | $\theta$ | kelvin (K) |
| Electric current | $i$ | ampere (A) |
| Amount of light | $C$ | candela (cd) |
| Amount of matter | $N$ | mole (mol) |

# 1-4 Topics in dimensional analysis

- Dimensionless groups

**Mach Number (Ma) = Speed of flow / Speed of Sound**

**Speed of sound= 346 m/s = 1246 km/h**

- Subsonic (Ma<1)
- Sonic (Ma=1)
- Supersonic (Ma>1)
- Hypersonic (Ma >>1)

**Concorde**, Speed : 2.04 Mac
Highly uneconomical, therefore grounded in 2003.

# 1-4 Topics in dimensional analysis

- Dimensional homogeneity

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

$$[L] = [LT^{-2}][T^2] + [LT^{-1}][T] + [L] = [L]$$

**EXAMPLE 1.1 PRIMARY DIME!SIONS OF THE REYNOLDS NUMBER**

Show that the Reynolds number, given in Eq. (1.4), is a dimensionless group.

***Problem Definition***

**Situation: The Reynolds number is given by Re = (ρ*VL)/μ*.**

**Find: Show that Re is a dimensionless group.**

***Plan***

1. Identify the variables by using Table A.6.
2. Find the primary dimensions by using Table A.6.
3. Show that Re is dimensionless by canceling primary dimensions.

***Solution***

Variables and primary dimensions

- **mass density, ρ = [M/L³]**
- **velocity, *V* = [L/T]**
- **Length, *L* = [L]**
- **viscosity, μ= [M/LT]**

Cancel primary dimensions:

$$\left[\frac{\rho VL}{\mu}\right]=\left[\frac{M}{L^3}\right]\left[\frac{L}{T}\right]\left[L\right]\left[\frac{LT}{M}\right]=\left[-\right]$$

Since the primary dimensions cancel, the Reynolds number (ρ*VL)/μ is a dimensionless group.*

# 1-4 Topics in dimensional analysis

- Unity conversion ratios

$$1.0 = \frac{1\text{m/s}}{3.6\text{km/h}} \qquad 1.0 = \frac{1\text{N}}{0.102\text{kgf}}$$

- The Grid method

$$P = F \times V = \left| \frac{2\text{kgf}}{\phantom{x}} \right| \frac{30\text{km/h}}{\phantom{x}} \left| \frac{1.0\text{m/s}}{3.6\text{km/h}} \right| \frac{1.0\text{N}}{0.102\text{kgf}} \left| \frac{\text{W.s}}{\text{N.m}} \right.$$

$$= 163.4\text{W}$$

**Table 1.3 APPLYING THE GRID METHOD (TWO EXAMPLES)**

| Process Step | Example 1 | Example 2 |
|---|---|---|
| | **Situation:** Convert a pressure of 2.00 psi to pascals. | **Situation:** Find the force in newtons that is needed to accelerate a mass of 10 g at a rate of 15 ft/s$^2$. |
| Step 1. **Problem:** Write the term or equation. Include numbers and units. | $p = 2.00$ psi | $F = ma$<br>$F\ (\text{N}) = (0.01\ \text{kg})(15\ \text{ft/s}^2)$ |
| Step 2. **Conversion Ratios:** Look up unit conversion formula(s) in Table F.1 and represent these as unity conversion ratios. | $1.0 = \dfrac{1\ \text{Pa}}{1.45 \times 10^{-4}\ \text{psi}}$ | $1.0 = \dfrac{1.0\ \text{m}}{3.281\ \text{ft}}$ $\quad 1.0 = \dfrac{\text{N} \cdot \text{s}^2}{\text{kg} \cdot \text{m}}$ |
| Step 3. **Algebra:** Multiply variables and cancel units. Fix any errors. | $p = [2.00\ \cancel{\text{psi}}]\left[\dfrac{1\ \text{Pa}}{1.45 \times 10^{-4}\ \cancel{\text{psi}}}\right]$ | $F = [0.01\ \cancel{\text{kg}}]\left[\dfrac{15\ \cancel{\text{ft}}}{\cancel{\text{s}^2}}\right]\left[\dfrac{1.0\ \cancel{\text{m}}}{3.281\ \cancel{\text{ft}}}\right]\left[\dfrac{\text{N} \cdot \cancel{\text{s}^2}}{\cancel{\text{kg}} \cdot \cancel{\text{m}}}\right]$ |
| Step 4. **Calculations:** Perform the indicated calculations. Round the answer to the correct number of significant figures. | $p = 13.8$ kPa | $F = 0.0457$ N |

| Table 1.4 STRUCTURED APPROACH FOR ENGINEERING ANALYSIS | | |
|---|---|---|
| **What To Do** | **Why Do This?** | **Typical Actions** |
| **Problem Definition:** This involves figuring out what the problem is, what is involved, and what the end state (i.e., goal state) is.<br>Problem definition is done before trying to solve the problem. | • To visualize the situation (present state).<br>• To visualize the goal (end state). | • Read and interpret the problem statement.<br>• Look up and learn unfamiliar knowledge.<br>• Document your interpretation of the situation.<br>• Interpret and document problem goals.<br>• Make an engineering sketch.<br>• Document main assumptions.<br>• Look up fluid properties; document sources. |
| **Plan:** This involves figuring out a solution path or "how to solve the problem."<br>Planning is done prior to jumping into action. | • To find an easy way to solve the problem.<br>• Saves you time. | • Generate multiple ideas for solving the problem<br>• Identify useful equations from Table F.2.<br>• Inventory past solutions.<br>• Analyze equations using a term-by-term approach.<br>• Balancing number of equations with number of unknowns.<br>• Make a step-by-step plan. |
| **Solution:** This involves solving the problem by executing the plan. | • To reach the problem goal state. | • Use computer programs.<br>• Perform calculations.<br>• Double-check work.<br>• Carry and cancel units. |
| **Review:** This involves validating the solution, exploring implications of the solution, and looking back to learn from the experience you just had. | • Gain confidence that your answer can be trusted.<br>• Increases your understanding.<br>• Gain ideas for applications.<br>• To learn. | • Check the units of answer.<br>• Check that problem goals have been reached.<br>• Validate the answer with a simpler estimate.<br>• Write down knowledge that you want to remember.<br>• List "what worked" and "ideas for improvement." |