Applied Mechanics

Workbook

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Preface

This workbook presents a collection of lecture notes on Applied Mechanics, designed to provide learners with succinct yet essential insights into key topics covered in class. Each chapter is accompanied by a problem set to facilitate comprehension and reinforce understanding.

Chapter 1: The International System of Units (SI) is the globally accepted standard for measurement. Established to provide a consistent framework for scientific and technical measurements, SI units facilitate clear communication and data comparison across various fields and countries. The system is based on seven fundamental units: the meter for length, the kilogram for mass, the second for time, the ampere for electric current, the kelvin for temperature, the mole for substance, and the candela for luminous intensity.

1 International System of Units

1.1 Objectives

- Recall the based and derived units.
- Practice the application of unity fraction.

1.2 SI Units

The International System of Units (SI) is the globally accepted standard for measurement. Established to provide a consistent framework for scientific and technical measurements, SI units facilitate clear communication and data comparison across various fields and countries. The system is based on seven fundamental units: the meter for length, the kilogram for mass, the second for time, the ampere for electric current, the kelvin for temperature, the mole for substance, and the candela for luminous intensity.

Table 1.1: Base SI units.

Physical Quantity	SI Base Unit	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric Current	Ampere	A
Temperature	Kelvin	K

Physical Quantity	SI Base Unit	Symbol
Amount of Substance	Mole	mol
Luminous Intensity	Candela	cd

Table 1.2: Derived SI units.

Physical Quantity	Derived SI Unit	Symbol
Area	Square meter	m^2
Volume	Cubic meter	m^3
Speed	Meter per second	m/s
Acceleration	Meter per second squared	m/s^2
Force	Newton	N
Pressure	Pascal	Pa
Energy	Joule	J
Power	Watt	W
Electric Charge	Coulomb	C
Electric Potential	Volt	V
Resistance	Ohm	Ω
Capacitance	Farad	F
Frequency	Hertz	Hz
Luminous Flux	Lumen	lm
Illuminance	Lux	lx
Specific Energy	Joule per kilogram	J/kg
Specific Heat Capacity	Joule per kilogram Kelvin	$J/(kg \cdot K)$

Table 1.3: Common multiples and submultiples for SI units.

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M

Factor	Prefix	Symbol
10^3	kilo	k
10^2	hecto	h
10^1	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ

1.3 Unity Fraction

The **unity fraction** method, or **unit conversion using unity fractions**, is a systematic way to convert one unit of measurement into another. This method relies on multiplying by fractions that are equal to one, where the numerator and the denominator represent the same quantity in different units. Since any number multiplied by one remains the same, unity fractions allow for seamless conversion without changing the value.

1.3.1 How Unity Fraction Works

The principle of unity fractions is based on:

1. **Setting up equal values**: Write a fraction where the numerator and denominator are equivalent values in different units, so the fraction equals one. For example, $\frac{1km}{1000m}$ is a unity fraction because 1 km equals 1000 m.

2. **Multiplying by unity fractions**: Multiply the initial quantity by the unity fraction(s) so that the undesired units cancel out, leaving only the desired units.

1.3.2 Example of Unity Fraction in Action

Suppose we want to convert 5 kilometers to meters.

1. Start with 5 kilometers:
$$5\,\mathrm{km}$$
2. Multiply by a unity fraction that cancels kilometers and introduces meters. We use $(\frac{1000\,\mathrm{m}}{1\,\mathrm{km}}), since\ 1\,\mathrm{km} = 1000\,\mathrm{m}$:
$$5\,\mathrm{km} \times \frac{1000\,\mathrm{m}}{1\,\mathrm{km}} = 5000\,\mathrm{m}$$
3. The kilometers km cancel out, leaving us with meters m:
$$5\,\mathrm{km} = 5000\,\mathrm{m}$$

This step-by-step approach illustrates how the unity fraction cancels the undesired units and achieves the correct result in meters.

Unity fractions can be extended by using multiple conversion steps. For example, converting hours to seconds would require two unity fractions: one to convert hours to minutes and another to convert minutes to seconds. This approach ensures accuracy and is widely used in science, engineering, and other fields that require precise unit conversions.

1.4 Problem Set

Instructions:

1. Use unity fractions to convert between derived SI units.
2. Show each step of your work to ensure accuracy.

3. Simplify your answers and include correct units.

1.4.1 Example Problem

Convert 15 m/s to km/h.

Solution:

1. Start with 15 m/s.
2. To convert meters to kilometers, multiply by $\frac{1\,\text{km}}{1000\,\text{m}}$.
3. To convert seconds to hours, multiply by $\frac{3600\,\text{s}}{1\,\text{h}}$.

$$15\,\text{m/s} \times \frac{1\,\text{km}}{1000\,\text{m}} \times \frac{3600\,\text{s}}{1\,\text{h}} = 54\,\text{km/h}$$

The meters and seconds cancel out, leaving kilometers per hour: 54 km/h.

1.4.2 Practice Problems

Convert each of the following using unity fractions. Show all steps!

1. **Speed**
   Convert 72 km/h to m/s.

2. **Force**
   Convert 980 N (newtons) to $\text{kg} \cdot \text{m/s}^2$.

3. **Energy**
   Convert 2500 J (joules) to kJ.

4. **Power**
   Convert 1500 W (watts) to kW.
5. **Pressure**
   Convert 101325 Pa (pascals) to kPa.
6. **Volume Flow Rate**
   Convert $3\,\mathrm{m}^3/\mathrm{min}$ to L/s.
7. **Density**
   Convert $1000\,\mathrm{kg/m}^3$ to $\mathrm{g/cm}^3$.
8. **Acceleration**
   Convert $9.8\,\mathrm{m/s}^2$ to $\mathrm{cm/s}^2$.
9. **Torque**
   Convert $50\,\mathrm{N}\cdot\mathrm{m}$ to $\mathrm{kN}\cdot\mathrm{cm}$.
10. **Frequency**
    Convert 500 Hz (hertz) to kHz.

1.4.3 Challenge Problems

1. **Work to Energy Conversion**
   A force of 20 N moves an object 500 cm. Convert the work done to joules.
2. **Kinetic Energy Conversion**
   Calculate the kinetic energy in kilojoules of a 1500 kg car moving at 72 km/h.
3. **Power to Energy Conversion**
   A machine operates at 2 kW for 3 hours. Convert the energy used to megajoules.

4. **Pressure to Force Conversion**
   Convert a pressure of $200\,\text{kPa}$ applied to an area of $0.5\,\text{m}^2$ to force in newtons.

5. **Density to Mass Conversion**
   Convert $0.8\,\text{g/cm}^3$ for an object with a volume of $250\,\text{cm}^3$ to mass in grams.

1.4.4 Answer Key

1. $72\,\text{km/h} = 20\,\text{m/s}$
2. $980\,\text{N} = 980\,\text{kg} \cdot \text{m/s}^2$
3. $2500\,\text{J} = 2.5\,\text{kJ}$
4. $1500\,\text{W} = 1.5\,\text{kW}$
5. $101325\,\text{Pa} = 101.325\,\text{kPa}$
6. $3\,\text{m}^3/\text{min} = 50\,\text{L/s}$
7. $1000\,\text{kg/m}^3 = 1\,\text{g/cm}^3$
8. $9.8\,\text{m/s}^2 = 980\,\text{cm/s}^2$
9. $50\,\text{N} \cdot \text{m} = 0.5\,\text{kN} \cdot \text{cm}$
10. $500\,\text{Hz} = 0.5\,\text{kHz}$

Challenge Problems

1. $20\,\text{N} \times 5\,\text{m} = 100\,\text{J}$
2. Kinetic energy $= 1500\,\text{kg} \times (20\,\text{m/s})^2/2 = 300\,\text{kJ}$
3. $2\,\text{kW} \times 3\,\text{hours} = 21.6\,\text{MJ}$
4. $200\,\text{kPa} \times 0.5\,\text{m}^2 = 100,000\,\text{N}$
5. $0.8\,\text{g/cm}^3 \times 250\,\text{cm}^3 = 200\,\text{g}$

1.5 Further Reading

Introduction in Russell, Jackson, and Embleton (2021) and SI units in Bolton (2021) for additional information.

2 Summary

In summary, we have used several books by Ahrens (2022), Russell, Jackson, and Embleton (2021), Bolton (2021), Polya and Conway (2014), Bird and Ross (2020) and Bird (2021)

Chapter 1: The International System of Units (SI) is the globally accepted standard for measurement. Established to provide a consistent framework for scientific and technical measurements, SI units facilitate clear communication and data comparison across various fields and countries. The system is based on seven fundamental units: the meter for length, the kilogram for mass, the second for time, the ampere for electric current, the kelvin for temperature, the mole for substance, and the candela for luminous intensity.

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