Chapter 1

Introduction
The Purpose of Physics

• What does the word physics mean?
• A connection with natural philosophy
• Organized around a collection of natural laws
• Wants to predict how the world works
• Wants to understand why the world works the way it does
What is Physics?

• The science of matter and energy, and the interactions between them
  • Matter and energy are fundamental to all areas of science
  • Physics is a foundational subject
  • Principles of physics form the basis of understanding other sciences
  • Allows us to understand things from very large to very small
What is Physics?, cont.

• The study of the natural or material world and phenomena
  • Meaning of physics from the Greek for nature

• Natural philosophy
  • Oldest science
  • All scientists were originally physicists
Studying Physics

• Goal is to predict and understand how the universe works
• Organized around physical laws
  • What do the laws say?
  • How can we apply the laws to new situations?
• Mathematics
  • The laws are generally expressed mathematically
Isaac Newton

• Mechanics will be the first area studied
• Laws were developed by Sir Isaac Newton
  • 1642 - 1727
• Laws of Motion
  • Apply to a wide variety of objects
Overall Goals

• Predicting how the world works
  • Use the physical laws for predictions
• Understanding why it works the way it does
  • Where do the physical laws come from?
  • May be helpful to examine the form of the physical law
Problem Solving

• Problem solving is the process of applying a general physical law to a particular case
• An essential part of physics
  • Processes apply to many different situations
  • Takes practice
Types of Problems

• We will encounter various types of problems
  • Quantitative problems
    • Give numerical information and use calculations
  • Concept checks
    • Test your general understanding of a law and its application
  • Reasoning and relationship problems
    • Identify what important information might be “missing”
• Successfully dealing with these types of problems is essential to gaining a thorough understanding of physics
Problem Solving Strategies

• **Recognize** the key physics principles
  • Need a conceptual understanding of the laws, how they are applied, and how they are interrelated

• **Sketch the problem**
  • Show the given information
  • Generally includes a coordinate system
Problem Solving Strategies, cont.

• **Identify the important relationships**
  • Use the given information and the unknown quantities to determine what laws apply
  • May involve substeps

• **Solve for the unknown quantities**

• **Check**
  • What does it mean?
  • Does the answer make sense?
  • Think about your answer
Dealing With Numbers

• There are numerous techniques you will encounter when dealing with numbers including
  • Scientific notation
  • Significant figures
    • Recognizing them
    • Using them in calculations
Scientific Notation

- Scientific notation is a useful way to write numbers that are very large or very small.
- To write a number in scientific notation:
  - Move the decimal point to create a new number between 1 and 10
    - Not including 10
  - Count the number of places the decimal point was moved
    - This is the exponent of 10
    - The exponent is positive if the original number is greater than one
    - The exponent is negative if the original number is less than one
Significant Figures

- There is an uncertainty associated with all measurements
  - Uncertainty is also called experimental error
- Values are written using significant figures
  - A digit is significant if it is meaningful with regard to the accuracy of the value
- Zeros may be ambiguous
  - Scientific notation helps clarify the significance of any zeros
Significant Figures, Examples

- **Example: 100**
  - May have 1 significant figure
    - Zeros are ambiguous
  - Rewrite in scientific notation
    - $1.00 \times 10^2$ shows 3 significant figures

- **Example: 0.00123**
  - 3 significant figures
  - In numbers less than 1, zeros immediately to the right of the decimal point are not significant
  - Can also be clarified by writing in scientific notation: $1.23 \times 10^{-3}$
Significant Figures in Calculations

• Multiplication and division
  • Use the full accuracy of all known quantities when doing the computation
  • At the end of the calculation, round the answer to the number of significant figures present in the least accurate starting quantity
  • Example: $976 \times 0.000064 \text{ m} = 0.062464 \text{ m} \approx 0.062 \text{ m}$
    • Due to the 2 significant figures in the 0.000064 m

Section 1.3
Rounding Error

- In multiple step problems, you could round at different steps
- Different final values may be obtained
  - These differences are the *rounding error*
- Carry an extra significant figure through intermediate steps in the computation and perform the final rounding at the very end
Significant Figures in Calculations, cont.

- Addition and subtraction
  - The location of the least significant digit in the answer is determined by the location of the least significant digit in the starting quantity that is known with the least accuracy
  - Example: $4.52 \, + \, 1.2 = 5.72 \, \sim \, 5.7$
    - Due to the location of the significant digit in the 1.2
Exact Numbers

• Some values are exact
  • Not measured
  • Defined
  • Examples
    • 1 min = 60 sec
      • Appears to have 1 significant figure, but it is a definition
      • Can be thought of as 60.00000000… seconds
  • The number of significant figures in a calculation is determined by the number of significant figures in other quantities involved
Physical Quantities and Units of Measure

- When conducting experiments, you must be able to measure various physical quantities
- Will often deal with units of
  - Length
  - Time
  - Mass
- Will use SI system
  - Include prefixes and powers of 10
Units of Measure

• Each measured quantity must have a unit of measure for that quantity
• Three basic quantities
  • Length (or distance)
  • Mass
  • Time
Definition of the Meter

• The original definition of a meter was in terms of the Earth’s circumference
• Then changed to be based on this platinum-iridium bar
• Now defined in terms of the wavelength of light emitted by krypton atoms
• See table 1.1 for some common length values
Converting Between Units

• Use a conversion factor
  • Relates the two units of interest
  • Express in fractional form
    • The fraction will be equal to 1 and so not change the actual value, just how it is expressed
  • Multiply the original quantity by the conversion factor to obtain the new expression of the quantity
Definition of a Second

- The value of the second is based on the frequency of light emitted by cesium atoms
- Shown is a cesium clock in the National Institute of Standards and Technology
- See table 1.2 for some example times

Section 1.4
Definition of Kilogram

- Mass is related to the amount of material contained in the object
- Defined in terms of a standard kilogram
  - Composed of platinum and iridium
- See table 1.3 for some common mass values
Standard Units

• Units of measure must be standardized
  • Makes the units useful
  • Makes communication about the units possible

• Système International d’Unitès
  • Commonly called the SI system
  • Primary units of length, mass and time are the meter, kilogram and second
Other Systems

- CGS
  - Uses centimeters (length), grams (mass) and seconds (time)
- U.S. Customary System
  - Uses feet (length), slugs (mass), and seconds (time)
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<th>SI</th>
<th>CGS</th>
<th>U.S. Customary Units</th>
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<tr>
<td>time</td>
<td>second (s)</td>
<td>second (s)</td>
<td>second (s)</td>
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</tbody>
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Prefixes

- Prefixes can also be used to express very large or very small numbers
- Prefixes represent various powers of 10
- Can be used with any unit
- See table 1.5 for various prefixes and their corresponding power of 10
Dimensions and Units

• Units of other quantities may be derived from the units discussed so far
  • There are seven primary units in the SI system
  • All other units can be derived from these primary units

• Dimensional analysis
  • Can be used to check problems
Derived Units

- The primary units can be combined into derived units
  - Some will be given special names
- Examples:
  - m³
  - kg/m³
- In mechanics, three primary quantities are needed to build all the other necessary quantities
  - Length, time, and mass
Dimensions

- Dimensional analysis can be used to check problems
- Dimensions are
  - Length – L
  - Time – T
  - Mass – M
- Dimensions are independent of the particular units
Using Dimensional Analysis

• The dimensions must be the same on both sides of the equals sign in an equation

• The dimensions will correspond to the units
  • The dimensions are independent of the particular units used to measure quantities

• Using dimensions as a check can sometimes reveal errors in a calculation
Algebra and Simultaneous Equations

- Mathematical methods you may need to use include
  - Algebra
  - Trigonometry
  - Vectors
- Chapter 1 reviews these
- Also information in Appendix B
Checking Units

- The same approach used with dimensions can be used with units
- The units need to be in the same system
- The units should be correct for the quantity being calculated
- Always check the dimensions and units of your answer
Trigonometry

- Generally will use only right triangles
- Pythagorean Theorem
  - \( r^2 = x^2 + y^2 \)
- Trig functions
  - \( \sin \theta = \frac{y}{r} \)
  - \( \cos \theta = \frac{x}{r} \)
  - \( \tan \theta = \frac{y}{x} \)
- Trigonometric identities
  - \( \sin^2 \theta + \cos^2 \theta = 1 \)
  - Other identities are given in appendix B and the back cover

Right angle = 90°
Inverse Functions and Angles

- To find an angle, you need to use the inverse of a trig function
  - If \( \sin \theta = \frac{y}{r} \) then \( \theta = \sin^{-1} \left( \frac{y}{r} \right) \)
- Angles in the triangle add up to 90°
  - \( \alpha + \beta = 90° \)
- Complementary angles
  - \( \sin \alpha = \cos \beta \)

\( \alpha + \beta = 90° \)

Right angle = 90°
Angle Measurements

• Various units
  • Degrees
  • Radians
  • $360^\circ = 2\pi$ rad

• Definition of radian
  • $\theta = \frac{s}{r}$
    • $s$ is the length of arc
    • $r$ is the radius
    • $s$ and $r$ must be measured in the same units

An angle of approximately $57^\circ$ corresponds to 1 radian.

The angle $\theta$ here is approximately 1 radian.
Vectors vs. Scalars

- A scalar is a quantity that requires only a magnitude (with unit)
- A vector is a quantity that requires a magnitude and a direction
Vectors

- Vector quantities need special techniques
- Vectors may be
  - Added
  - Multiplied by a scalar
  - Subtracted
  - Resolved into components
Vector Representation

- The length of the arrow indicates the magnitude of the vector.
- The direction of the arrow indicates the direction of the vector with respect to a given coordinate system.
- Vectors are written with an arrow over a boldface letter.
- Mathematical operations can be performed with vectors.
Adding Vectors

• Draw the first vector
• Draw the second vector starting at the tip of the first vector
• Continue to draw vectors “tip-to-tail”
• The sum is drawn from the tail of the first vector to the tip of the last vector
• Example: \( \vec{A} + \vec{B} = \vec{C} \)

These are the same vector \( \vec{B} \) even though they are drawn at different locations.

The dashed versions of \( \vec{B} \) and \( \vec{A} \) show that \( \vec{A} + \vec{B} = \vec{B} + \vec{A} \).

For vector addition the order does not matter.
Multiplying Vectors by Scalars

- Multiplying a vector by a positive scalar only affects the vector’s magnitude
  - It will have no effect on the vector’s direction
- Example:
  \[ \vec{B} = K \vec{A} \]
- If \( \vec{A} = 10.0 \text{ km @ } 10.0° \) and \( K = 2 \), then
  \[ \vec{B} = 20.0 \text{ km @ } 10.0° \]

Some examples of \( \vec{B} = K \vec{A} \) with different values of \( K \):

- \( \vec{B} = 0.5 \times \vec{A} \)
- \( \vec{B} = 2 \times \vec{A} \)
- \( \vec{B} = (-1) \times \vec{A} = -\vec{A} \)
Multiplying Vectors by Scalars, cont.

- If $K > 1$, then the resultant vector is longer than the original vector.
- If $K < 1$ and positive, then the resultant vector is shorter than the original vector.
- If $K$ is negative, then the resultant vector is in the opposite direction from the original vector.
  - If $\vec{A} = 10.0 \text{ km } @ 10.0^\circ$ and $K = -2$ then $\vec{B} = 20.0 \text{ km } @ 190.0^\circ$
Subtracting Vectors

- To subtract a vector, you add its opposite

\[
\vec{C} = \vec{A} - \vec{B}
\]
Components of Vectors

- The x- and y-components of a vector are its projections along the x- and y-axes.
- Calculation of the x- and y-components involves trigonometry.
  - $A_x = A \cos \theta$
  - $A_y = A \sin \theta$
Vector from Components

- If you know the components, you can find the vector.
- Use the Pythagorean Theorem for the magnitude: \( A = \sqrt{A_x^2 + A_y^2} \)
- Use the \( \tan^{-1} \) to find the direction:

\[
\theta = \tan^{-1} \frac{A_y}{A_x}
\]
Adding Vectors Using Components

- Assume you are adding two vectors: $\vec{C} = \vec{A} + \vec{B}$
- To add the vectors, add their components
  - $C_x = A_x + B_x$
  - $C_y = A_y + B_y$
- Then the magnitude and direction of $C$ can be determined

Section 1.8
Other Operations with Vectors

• To subtract vectors, again add the opposite vector using the component method
• Multiplication of a vector by a scalar is done by multiplying each component by the scalar
• These component techniques can also be applied in three dimensions