Physics 111 Sections 003 and 005

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Textbook: Serway and Jewett, Physics for Scientists and Engineers, 7th Edition

iClicker required

Physics for Scientists and Engineers

Week 1
Chapter 1: Measurements and
Chapter 3: Vectors

Introduction to Clickers

1. What is your discipline?

A. Engineering
B. Science
C. Math
D. Humanities
E. Other

Introduction to Clickers

2. How many years have you been at NJIT?

A. Less than 1 year
B. 1 year
C. 2 years
D. 3 years
E. More than 3 years

Physics

- Fundamental Science
  - Concerned with the fundamental principles of the Universe
  - Foundation of other physical sciences
  - Has simplicity of fundamental concepts
- Divided into six major areas
  - Classical Mechanics
  - Relativity
  - Thermodynamics
  - Electromagnetism
  - Optics
  - Quantum Mechanics

Classical Physics

- Mechanics and electromagnetism are basic to all other branches of classical and modern physics
- Classical physics
  - Developed before 1900
  - Our study will start with Classical Mechanics
    - Also called Newtonian Mechanics or Mechanics
- Modern physics
  - From about 1900 to the present
Measurements
- Used to describe natural phenomena
- Needs defined standards
- Characteristics of standards for measurements
  - Readily accessible
  - Possess some property that can be measured reliably
  - Must yield the same results when used by anyone anywhere
  - Cannot change with time

Standards of Fundamental Quantities
- Standardized systems
  - Agreed upon by some authority, usually a governmental body
- SI – Système International
  - Agreed to in 1960 by an international committee
  - Main system used in this text

Fundamental Quantities and Their Units
<table>
<thead>
<tr>
<th>Quantity</th>
<th>SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>meter</td>
</tr>
<tr>
<td>Mass</td>
<td>kilogram</td>
</tr>
<tr>
<td>Time</td>
<td>second</td>
</tr>
<tr>
<td>Temperature</td>
<td>Kelvin</td>
</tr>
<tr>
<td>Electric Current</td>
<td>Ampere</td>
</tr>
<tr>
<td>Luminous Intensity</td>
<td>Candela</td>
</tr>
<tr>
<td>Amount of Substance</td>
<td>mole</td>
</tr>
</tbody>
</table>

Quantities Used in Mechanics
- In mechanics, three basic quantities are used
  - Length
  - Mass
  - Time
- Will also use derived quantities
  - These are other quantities that can be expressed in terms of the basic quantities
    - Example: Area is the product of two lengths
      - Area is a derived quantity
      - Length is the fundamental quantity

Length
- Length is the distance between two points in space
- Units
  - SI – meter, m
- Defined in terms of a meter – the distance traveled by light in a vacuum during a given time
- See Table 1.1 for some examples of lengths

Mass
- Units
  - SI – kilogram, kg
- Defined in terms of a kilogram, based on a specific cylinder kept at the International Bureau of Standards
- See Table 1.2 for masses of various objects
Standard Kilogram

Time
- Units
  - seconds, s
- Defined in terms of the oscillation of radiation from a cesium atom
- See Table 1.3 for some approximate time intervals

US Customary System
- Still used in the US, but text will use SI

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>foot</td>
</tr>
<tr>
<td>Mass</td>
<td>slug</td>
</tr>
<tr>
<td>Time</td>
<td>second</td>
</tr>
</tbody>
</table>

Prefixes
- Prefixes correspond to powers of 10
- Each prefix has a specific name
- Each prefix has a specific abbreviation

Prefixes, cont.
- The prefixes can be used with any basic units
- They are multipliers of the basic unit
- Examples:
  - 1 mm = 10^{-3} m
  - 1 mg = 10^{-3} g

Basic Quantities and Their Dimension
- Dimension has a specific meaning – it denotes the physical nature of a quantity
- Dimensions are denoted with square brackets
  - Length [L]
  - Mass [M]
  - Time [T]
**Dimensions and Units**
- Each dimension can have many actual units
- Table 1.5 for the dimensions and units of some derived quantities

**Table 1.5**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Area</th>
<th>Volume</th>
<th>Speed</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>L²</td>
<td>L³</td>
<td>L/T</td>
<td>L/T²</td>
</tr>
<tr>
<td>SI units</td>
<td>m²</td>
<td>m³</td>
<td>m/s</td>
<td>m/s²</td>
</tr>
<tr>
<td>U.S. customary</td>
<td>ft²</td>
<td>ft³</td>
<td>ft/s</td>
<td>ft/s²</td>
</tr>
</tbody>
</table>

**Dimensional Analysis, example**
- Given the equation: \( x = \frac{1}{2} at^2 \)
- Check dimensions on each side:
  \[ L = \frac{L}{T^2} \times T = L \]
- The \( T^2 \)'s cancel, leaving \( L \) for the dimensions of each side
- The equation is dimensionally correct
- There are no dimensions for the constant

**Dimensional Analysis to Determine a Power Law**
- Determine powers in a proportionality
  - Example: find the exponents in the expression \( x \propto a^n t^m \)
  - You must have lengths on both sides
  - Acceleration has dimensions of \( L/T^2 \)
  - Time has dimensions of \( T \)
  - Analysis gives \( x \propto at^2 \)

**Conversion**
- Always include units for every quantity, you can carry the units through the entire calculation
- Multiply original value by a ratio equal to one
- Example
  \[ 15.0 \text{ in} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = 38.1 \text{ cm} \]
  - Note the value inside the parentheses is equal to 1 since 1 in. is defined as 2.54 cm

**Significant Figures**
- A significant figure is one that is reliably known
- Zeros may or may not be significant
  - Those used to position the decimal point are not significant
  - To remove ambiguity, use scientific notation
- In a measurement, the significant figures include the first estimated digit

**Significant Figures, examples**
- 0.0075 m has 2 significant figures
  - The leading zeros are placeholders only
  - Can write in scientific notation to show more clearly: \( 7.5 \times 10^{-3} \text{ m} \) for 2 significant figures
- 10.0 m has 3 significant figures
  - The decimal point gives information about the reliability of the measurement
- 1500 m is ambiguous
  - Use \( 1.5 \times 10^3 \text{ m} \) for 2 significant figures
  - Use \( 1.50 \times 10^3 \text{ m} \) for 3 significant figures
  - Use \( 1.500 \times 10^3 \text{ m} \) for 4 significant figures
Operations with Significant Figures – Multiplying or Dividing

- When multiplying or dividing, the number of significant figures in the final answer is the same as the number of significant figures in the quantity having the lowest number of significant figures.
- Example: 25.57 m x 2.45 m = 62.6 m²
  - The 2.45 m limits your result to 3 significant figures

Operations with Significant Figures – Adding or Subtracting

- When adding or subtracting, the number of decimal places in the result should equal the smallest number of decimal places in any term in the sum.
- Example: 135 cm + 3.25 cm = 138 cm
  - The 135 cm limits your answer to the units decimal value

Chapter 3

Vectors

Cartesian Coordinate System

- Also called rectangular coordinate system
- x- and y- axes intersect at the origin
- Points are labeled (x, y)

Polar Coordinate System

- Origin and reference line are noted
- Point is distance r from the origin in the direction of angle θ, ccw from reference line
- Points are labeled (r, θ)

Polar to Cartesian Coordinates

- Based on forming a right triangle from r and θ
- \( x = r \cos \theta \)
- \( y = r \sin \theta \)
### Trigonometry Review
- Given various radius vectors, find
  - Length and angle
  - x- and y-components
  - Trigonometric functions: sin, cos, tan

### Cartesian to Polar Coordinates
- \( r \) is the hypotenuse and \( \theta \) an angle

\[
\tan \theta = \frac{y}{x} \\
r = \sqrt{x^2 + y^2}
\]
- \( \theta \) must be ccw from positive x axis for these equations to be valid

### Example 3.1
- The Cartesian coordinates of a point in the xy plane are \((x,y) = (-3.50, -2.50)\) m, as shown in the figure. Find the polar coordinates of this point.

**Solution:** From Equation 3.4,

\[
r = \sqrt{x^2 + y^2} = \sqrt{(-3.50 \text{ m})^2 + (-2.50 \text{ m})^2} = 4.30 \text{ m}
\]

and from Equation 3.3,

\[
\tan \theta = \frac{-2.50 \text{ m}}{-3.50 \text{ m}} = 0.714
\]

\( \theta = 216^\circ \) (signs give quadrant)

### Vectors and Scalars
- A **scalar quantity** is completely specified by a single value with an appropriate unit and has no direction.
- A **vector quantity** is completely described by a number and appropriate units plus a direction.

### Vector Example
- A particle travels from A to B along the path shown by the dotted red line
- This is the distance traveled and is a scalar
- The displacement is the solid line from A to B
- The displacement is independent of the path taken between the two points
- Displacement is a vector
Vector Notation
- Text uses bold with arrow to denote a vector: \( \vec{A} \)
- Also used for printing is simple bold print: \( \mathbf{A} \)
- When dealing with just the magnitude of a vector in print, an italic letter will be used: \( A \) or \( |\vec{A}| \)
  - The magnitude of the vector has physical units
  - The magnitude of a vector is always a positive number
- When handwritten, use an arrow: \( \vec{A} \)

Equality of Two Vectors
- Two vectors are equal if they have the same magnitude and the same direction
- \( \vec{A} = \vec{B} \) if \( A = B \) and they point along parallel lines
- All of the vectors shown are equal

Adding Vectors
- When adding vectors, their directions must be taken into account
- Units must be the same
- Graphical Methods
  - Use scale drawings
  - Algebraic Methods
    - More convenient

Adding Vectors Graphically
- Choose a scale
- Draw the first vector, \( \vec{A} \), with the appropriate length and in the direction specified, with respect to a coordinate system
- Draw the next vector with the appropriate length and in the direction specified, with respect to a coordinate system whose origin is the end of vector \( \vec{A} \) and parallel to the coordinate system used for \( \vec{A} \)

Adding Vectors Graphically, cont.
- Continue drawing the vectors “tip-to-tail”
- The resultant is drawn from the origin of \( \vec{A} \) to the end of the last vector
- Measure the length of \( \vec{R} \) and its angle
  - Use the scale factor to convert length to actual magnitude

Adding Vectors Graphically, final
- When you have many vectors, just keep repeating the process until all are included
- The resultant is still drawn from the tail of the first vector to the tip of the last vector
Adding Vectors, Rules

- When two vectors are added, the sum is independent of the order of the addition. This is the Commutative Law of Addition.
- \( \vec{A} + \vec{B} = \vec{B} + \vec{A} \)

Adding Vectors, Rules cont.

- When adding three or more vectors, their sum is independent of the way in which the individual vectors are grouped. This is called the Associative Property of Addition.
- \( \vec{A} + (\vec{B} + \vec{C}) = (\vec{A} + \vec{B}) + \vec{C} \)

Adding Vectors, Rules final

- When adding vectors, all of the vectors must have the same units.
- All of the vectors must be of the same type of quantity.
- For example, you cannot add a displacement to a velocity.

Negative of a Vector

- The negative of a vector is defined as the vector that, when added to the original vector, gives a resultant of zero.
- Represented as \(-\vec{A}\).
- \(\vec{A} + (-\vec{A}) = 0\)
- The negative of the vector will have the same magnitude, but point in the opposite direction.

Subtracting Vectors

- Special case of vector addition.
- If \(\vec{A} - \vec{B}\), then use \(\vec{A} + (-\vec{B})\).
- Continue with standard vector addition procedure.

Subtracting Vectors, Method 2

- Another way to look at subtraction is to find the vector that, added to the second vector gives you the first vector.
- \(\vec{A} + (-\vec{B}) = \vec{C}\).
- As shown, the resultant vector points from the tip of the second to the tip of the first.
Multiplying or Dividing a Vector by a Scalar

- The result of the multiplication or division of a vector by a scalar is a vector.
- The magnitude of the vector is multiplied or divided by the scalar.
- If the scalar is positive, the direction of the result is the same as that of the original vector.
- If the scalar is negative, the direction of the result is opposite that of the original vector.

Component Method of Adding Vectors

- Graphical addition is not recommended when:
  - High accuracy is required.
  - If you have a three-dimensional problem.
- Component method is an alternative method.
  - It uses projections of vectors along coordinate axes.

Components of a Vector, Introduction

- A component is a projection of a vector along an axis.
  - Any vector can be completely described by its components.
  - It is useful to use rectangular components.
    - These are the projections of the vector along the x- and y-axes.

Vector Component Terminology

- \( \vec{A}_x \) and \( \vec{A}_y \) are the component vectors of \( \vec{A} \).
  - They are vectors and follow all the rules for vectors.
- \( A_x \) and \( A_y \) are scalars, and will be referred to as the components of \( \vec{A} \).

Components of a Vector

- Assume you are given a vector \( \vec{A} \).
- It can be expressed in terms of two other vectors, \( \vec{A}_x \) and \( \vec{A}_y \).
- These three vectors form a right triangle.
- \( \vec{A} = \vec{A}_x + \vec{A}_y \).

Components of a Vector, 2

- The y-component is moved to the end of the x-component.
- This is due to the fact that any vector can be moved parallel to itself without being affected.
  - This completes the triangle.
**Components of a Vector, 3**
- The x-component of a vector is the projection along the x-axis.
  \[ A_x = A \cos \theta \]
- The y-component of a vector is the projection along the y-axis.
  \[ A_y = A \sin \theta \]
- This assumes the angle \( \theta \) is measured with respect to the x-axis.
  - If not, do not use these equations, use the sides of the triangle directly.

**Components of a Vector, 4**
- The components are the legs of the right triangle whose hypotenuse is the length of the vector.
  \[ A = \sqrt{A_x^2 + A_y^2} \]
  \[ \theta = \tan^{-1} \frac{A_y}{A_x} \]
  - May still have to find \( \theta \) with respect to the positive x-axis.

**Components of a Vector, final**
- The components can be positive or negative and will have the same units as the original vector.
- The signs of the components will depend on the angle.

**Unit Vectors**
- A *unit vector* is a dimensionless vector with a magnitude of exactly 1.
- Unit vectors are used to specify a direction and have no other physical significance.

**Unit Vectors, cont.**
- The symbols \( \hat{i}, \hat{j}, \) and \( \hat{k} \) represent unit vectors.
- They form a set of mutually perpendicular vectors in a right-handed coordinate system.
- Remember, \( |\hat{i}| = |\hat{j}| = |\hat{k}| = 1 \)

**Viewing a Vector and Its Projections**
- Rotate the axes for various views.
- Study the projection of a vector on various planes:
  - x, y
  - x, z
  - y, z
Unit Vectors in Vector Notation
- \( \mathbf{A}_x \) is the same as \( A_x \mathbf{i} \) and \( \mathbf{A}_y \) is the same as \( A_y \mathbf{j} \) etc.
- The complete vector can be expressed as \( \mathbf{A} = A_x \mathbf{i} + A_y \mathbf{j} \).

Adding Vectors Using Unit Vectors
- Using \( \mathbf{R} = \mathbf{A} + \mathbf{B} \)
- Then \( \mathbf{R} = (A_x \mathbf{i} + A_y \mathbf{j}) + (B_x \mathbf{i} + B_y \mathbf{j}) \)
- \( \mathbf{R} = (A_x + B_x) \mathbf{i} + (A_y + B_y) \mathbf{j} \)
- \( \mathbf{R} = R_x \mathbf{i} + R_y \mathbf{j} \)
- and so \( R_x = A_x + B_x \) and \( R_y = A_y + B_y \)
- \( R = \sqrt{R_x^2 + R_y^2} \quad \theta = \tan^{-1} \frac{R_y}{R_x} \)

Adding Vectors with Unit Vectors
- Note the relationships among the components of the resultant and the components of the original vectors
- \( R_x = A_x + B_x \)
- \( R_y = A_y + B_y \)

Three-Dimensional Extension
- Using \( \mathbf{R} = \mathbf{A} + \mathbf{B} \)
- Then \( \mathbf{R} = (A_x \mathbf{i} + A_y \mathbf{j} + A_z \mathbf{k}) + (B_x \mathbf{i} + B_y \mathbf{j} + B_z \mathbf{k}) \)
- \( \mathbf{R} = (A_x + B_x) \mathbf{i} + (A_y + B_y) \mathbf{j} + (A_z + B_z) \mathbf{k} \)
- \( \mathbf{R} = R_x \mathbf{i} + R_y \mathbf{j} + R_z \mathbf{k} \)
- and so \( R_x = A_x + B_x \), \( R_y = A_y + B_y \), and \( R_z = A_z + B_z \)
- \( R = \sqrt{R_x^2 + R_y^2 + R_z^2} \quad \theta = \cos^{-1} \frac{R_z}{R} \), etc.

Example 3.5 – Taking a Hike
- A hiker begins a trip by first walking 25.0 km southeast from her car. She stops and sets up her tent for the night. On the second day, she walks 40.0 km in a direction 60.0° north of east, at which point she discovers a forest ranger’s tower.

Example 3.5
- (A) Determine the components of the hiker’s displacement for each day.

Solution: We conceptualize the problem by drawing a sketch as in the figure above. If we denote the displacement vectors on the first and second days by \( \mathbf{A} \) and \( \mathbf{B} \) respectively, and use the car as the origin of coordinates, we obtain the vectors shown in the figure. Drawing the resultant \( \mathbf{R} \), we can now categorize this problem as an addition of two vectors.
Example 3.5

We will analyze this problem by using our new knowledge of vector components. Displacement \( \mathbf{A} \) has a magnitude of 25.0 km and is directed 45.0° below the positive x axis.

From Equations 3.8 and 3.9, its components are:
\[
A_x = A \cos(45.0°) = (25.0 \text{ km})(0.707) = 17.7 \text{ km} \\
A_y = A \sin(45.0°) = (25.0 \text{ km})(-0.707) = -17.7 \text{ km}
\]

The negative value of \( A_y \) indicates that the hiker walks in the negative y direction on the first day. The signs of \( A_x \) and \( A_y \) also are evident from the figure above.

Example 3.5

The second displacement \( \mathbf{B} \) has a magnitude of 40.0 km and is 60.0° north of east.

Its components are:
\[
B_x = B \cos(60.0°) = (40.0 \text{ km})(0.500) = 20.0 \text{ km} \\
B_y = B \sin(60.0°) = (40.0 \text{ km})(0.866) = 34.6 \text{ km}
\]

Example 3.5

(B) Determine the components of the hiker’s resultant displacement \( \mathbf{R} \) for the trip. Find an expression for \( \mathbf{R} \) in terms of unit vectors.

Solution: The resultant displacement for the trip \( \mathbf{R} = \mathbf{A} + \mathbf{B} \) has components given by Equation 3.15:
\[
R_x = A_x + B_x = 17.7 \text{ km} + 20.0 \text{ km} = 37.7 \text{ km} \\
R_y = A_y + B_y = -17.7 \text{ km} + 34.6 \text{ km} = 16.9 \text{ km}
\]

In unit-vector form, we can write the total displacement as
\[
\mathbf{R} = (37.7 \hat{i} + 16.9 \hat{j}) \text{ km}
\]

Example 3.5

Using Equations 3.16 and 3.17, we find that the resultant vector has a magnitude of 41.3 km and is directed 24.1° north of east.

Let us finalize. The units of \( \mathbf{R} \) are km, which is reasonable for a displacement. Looking at the graphical representation in the figure above, we estimate that the final position of the hiker is at about (38 km, 17 km) which is consistent with the components of \( \mathbf{R} \) in our final result. Also, both components of \( \mathbf{R} \) are positive, putting the final position in the first quadrant of the coordinate system, which is also consistent with the figure.