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 – Systéme International
  - Agreed to in 1960 by an international committee
  - Main system used in this text

Fundamental Quantities and Their Units

Quantity	SI Unit
Length	meter
Mass	kilogram
Time	second
Temperature	Kelvin
Electric Current	Ampere
Luminous Intensity	Candela
Amount of Substance	mole

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

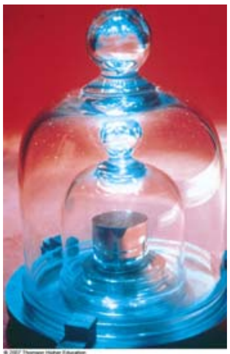
Length

- *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



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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

Quantity	Unit
Length	foot
Mass	slug
Time	second

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

TABLE 1.4

Prefixes for Powers of Ten

Power	Prefix	Abbreviation	Power	Prefix	Abbreviation
10^{-24}	yocto	y	10^{3}	kilo	k
10^{-21}	zepto	z	10^{6}	mega	M
10^{-18}	atto	a	10^{9}	giga	G
10^{-15}	femto	f	10^{12}	tera	T
10^{-12}	pico	p	10^{15}	peta	P
10^{-9}	nano	n	10^{18}	exa	E
10^{-6}	micro	μ	10^{21}	zetta	Z
10^{-3}	milli	m	10^{24}	yotta	Y
10^{-2}	centi	c			
10^{-1}	deci	d			

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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

Dimensions and Units of Four Derived Quantities

Quantity	Area	Volume	Speed	Acceleration
Dimensions	L^2	L^3	L/T	L/T^2
SI units	m^2	m^3	m/s	m/s^2
U.S. customary units	ft^2	ft^3	ft/s	ft/s^2

Dimensional Analysis, example

- Given the equation: $x = ½\, at^2$
- Check dimensions on each side:

$$L = \frac{L}{\cancel{T^2}} \cdot \cancel{T^2} = L$$

- 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 $x \propto a^m t^n$
    - 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

$$15.0\,in = ?\,cm$$

$$15.0\,in\left(\frac{2.54\,cm}{1\,\cancel{in}}\right) = 38.1\,cm$$

  - 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: 7.5×10^{-3} 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 1.5×10^3 m for 2 significant figures
  - Use 1.50×10^3 m for 3 significant figures
  - Use 1.500×10^3 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 m^2
  - The 2.45 m limits your result to 3 significant figures

Operations with Significant Figures – Adding or Subtracting

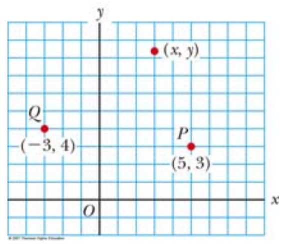
- When adding or subtracting, the number of decimal places in the result should equal the smallest number of decimal places in any term in the sum.
- Example: 135 cm + 3.25 cm = 138 cm
  - The 135 cm limits your answer to the units decimal value

Chapter 3

Vectors

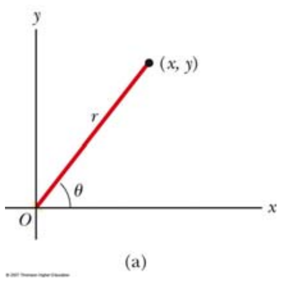
Cartesian Coordinate System

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



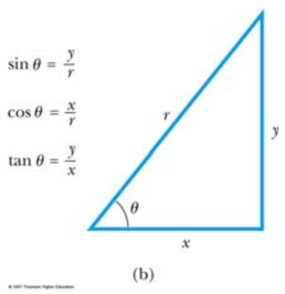
Polar Coordinate System

- 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)



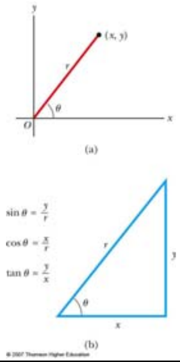
Polar to Cartesian Coordinates

- 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



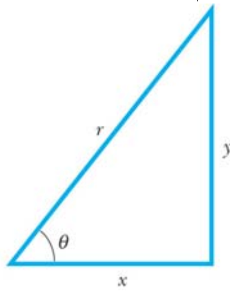
Cartesian to Polar Coordinates

- r is the hypotenuse and θ an angle

$$\tan\theta = \frac{y}{x}$$

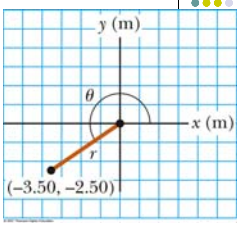
$$r = \sqrt{x^2 + y^2}$$

- θ 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,

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

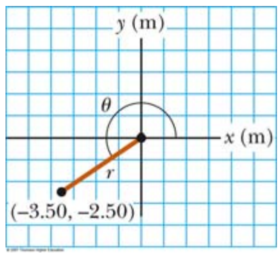
and from Equation 3.3,

$$\tan\theta = \frac{y}{x} = \frac{-2.50\text{ m}}{-3.50\text{ m}} = 0.714$$

$$\theta = 216° \quad \text{(signs give quadrant)}$$

Example 3.1, cont.

- Change the point in the x-y plane
- Note its Cartesian coordinates
- Note its polar coordinates

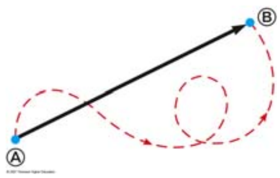


Vectors and Scalars

- 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

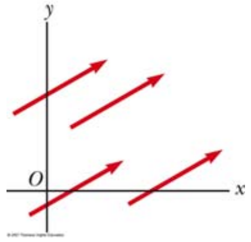


Vector Notation

- Text uses bold with arrow to denote a vector: $\vec{\mathbf{A}}$
- Also used for printing is simple bold print: **A**
- When dealing with just the magnitude of a vector in print, an italic letter will be used: *A* or $|\vec{\mathbf{A}}|$
  - 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
- $\vec{\mathbf{A}} = \vec{\mathbf{B}}$ if $A = B$ and they point along parallel lines
- All of the vectors shown are equal



Adding Vectors

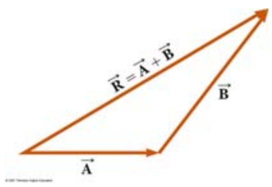
- When adding vectors, their directions must be taken into account
- Units must be the same
- Graphical Methods
  - Use scale drawings
- Algebraic Methods
  - More convenient

Adding Vectors Graphically

- Choose a scale
- Draw the first vector, $\vec{\mathbf{A}}$, 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 $\vec{\mathbf{A}}$ and parallel to the coordinate system used for $\vec{\mathbf{A}}$

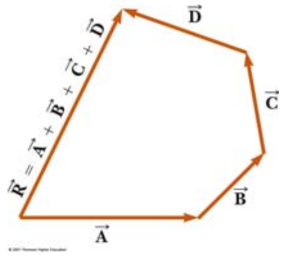
Adding Vectors Graphically, cont.

- Continue drawing the vectors "tip-to-tail"
- The resultant is drawn from the origin of $\vec{\mathbf{A}}$ to the end of the last vector
- Measure the length of $\vec{\mathbf{R}}$ and its angle
  - Use the scale factor to convert length to actual magnitude



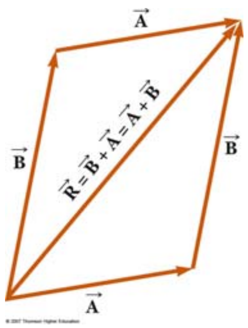
Adding Vectors Graphically, final

- 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



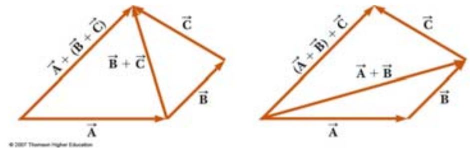
Adding Vectors, Rules

- 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***
- $\vec{A} + \left(\vec{B} + \vec{C}\right) = \left(\vec{A} + \vec{B}\right) + \vec{C}$



Adding Vectors, Rules final

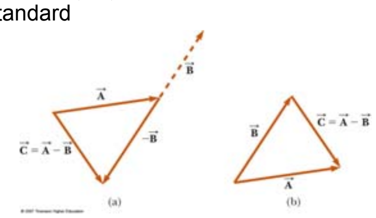
- When adding vectors, all of the vectors must have the same units
- All of the vectors must be of the same type of quantity
  - For example, you cannot add a displacement to a velocity

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 $-\vec{A}$
  - $\vec{A} + \left(-\vec{A}\right) = 0$
- The negative of the vector will have the same magnitude, but point in the opposite direction

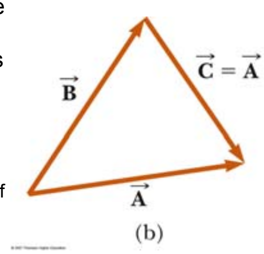
Subtracting Vectors

- Special case of vector addition
- If $\vec{A} - \vec{B}$, then use $\vec{A} + \left(-\vec{B}\right)$
- 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
- $\vec{A} + \left(-\vec{B}\right) = \vec{C}$
  - 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

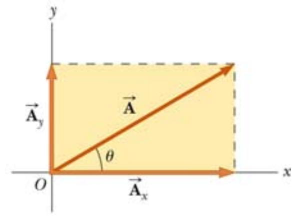
- The result of the multiplication or division of a vector by a scalar is a vector
- The magnitude of the vector is multiplied or divided by the scalar
- If the scalar is positive, the direction of the result is the same as of the original vector
- If the scalar is negative, the direction of the result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



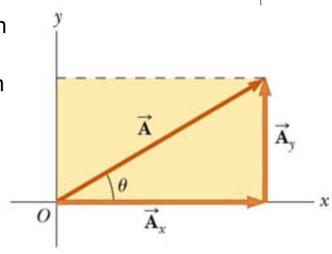
(a)

Vector Component Terminology

- $\vec{\mathbf{A}}_x$ *and* $\vec{\mathbf{A}}_y$ are the ***component vectors*** of $\vec{\mathbf{A}}$
  - 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 $\vec{\mathbf{A}}$

Components of a Vector

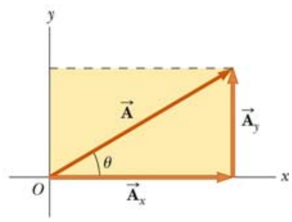
- Assume you are given a vector $\vec{\mathbf{A}}$
- It can be expressed in terms of two other vectors, $\vec{\mathbf{A}}_x$ and $\vec{\mathbf{A}}_y$
- These three vectors form a right triangle
- $\vec{\mathbf{A}} = \vec{\mathbf{A}}_x + \vec{\mathbf{A}}_y$



(b)

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



(b)

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 θ is measured with respect to the x-axis
  - If not, do not use these equations, use the sides of the triangle directly

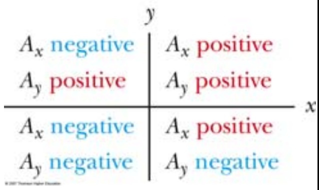
Components of a Vector, 4

- The components are the legs of the right triangle whose hypotenuse is the length of *A*

  $$A = \sqrt{A_x^2 + A_y^2} \quad \text{and} \quad \theta = \tan^{-1}\frac{A_y}{A_x}$$
  - May still have to find θ 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

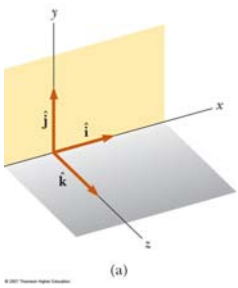
- A ***unit vector*** is a dimensionless vector with a magnitude of exactly 1.
- Unit vectors are used to specify a direction and have no other physical significance

Unit Vectors, cont.

- The symbols

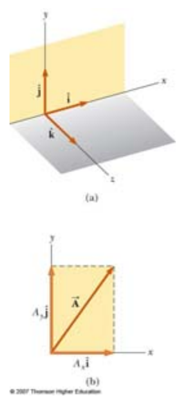
  $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$

  represent unit vectors
- They form a set of mutually perpendicular vectors in a right-handed coordinate system
- Remember, $|\hat{\mathbf{i}}| = |\hat{\mathbf{j}}| = |\hat{\mathbf{k}}| = 1$



Viewing a Vector and Its Projections

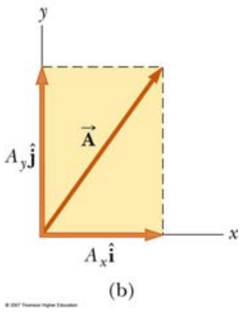
- Rotate the axes for various views
- Study the projection of a vector on various planes
  - x, y
  - x, z
  - y, z



Unit Vectors in Vector Notation

- $\mathbf{A}_x$ is the same as $A_x\,\hat{\mathbf{i}}$ and $\mathbf{A}_y$ is the same as $A_y\hat{\mathbf{j}}$ etc.
- The complete vector can be expressed as

$$\vec{\mathbf{A}} = A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}$$



Adding Vectors Using Unit Vectors

- Using $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$
- Then $\vec{\mathbf{R}} = \left(A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}\right) + \left(B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}}\right)$

$$\vec{\mathbf{R}} = \left(A_x + B_x\right)\hat{\mathbf{i}} + \left(A_y + B_y\right)\hat{\mathbf{j}}$$

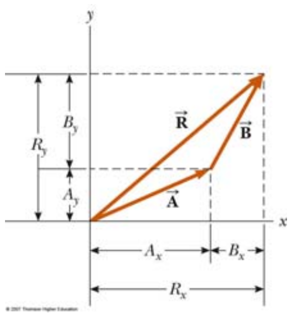
$$\vec{\mathbf{R}} = R_x\hat{\mathbf{i}} + R_y\hat{\mathbf{j}}$$

- and so $R_x = A_x + B_x$ and $R_y = A_y + B_y$

$$R = \sqrt{R_x^2 + R_y^2} \qquad \theta = \tan^{-1}\frac{R_y}{R_x}$$

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 $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$
- Then $\vec{\mathbf{R}} = \left(A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}} + A_z\hat{\mathbf{k}}\right) + \left(B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}} + B_z\hat{\mathbf{k}}\right)$

$$\vec{\mathbf{R}} = \left(A_x + B_x\right)\hat{\mathbf{i}} + \left(A_y + B_y\right)\hat{\mathbf{j}} + \left(A_z + B_z\right)\hat{\mathbf{k}}$$

$$\vec{\mathbf{R}} = R_x\hat{\mathbf{i}} + R_y\hat{\mathbf{j}} + R_z\hat{\mathbf{k}}$$

- and so $R_x = A_x+B_x$, $R_y = A_y+B_y$, and $R_z = A_x+B_z$

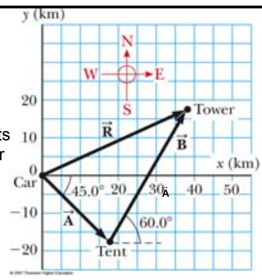
$$R = \sqrt{R_x^2 + R_y^2 + R_z^2} \qquad \theta = \cos^{-1}\frac{R_x}{R}, \textit{etc.}$$

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.

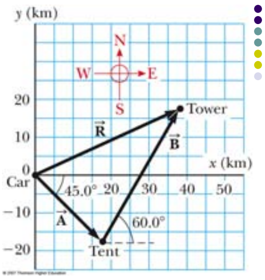
Example 3.5

- (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 $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ respectively, and use the car as the origin of coordinates, we obtain the vectors shown in the figure. Drawing the resultant $\vec{\mathbf{R}}$, 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 $\vec{\mathbf{A}}$ has a magnitude of 25.0 km and is directed 45.0° below the positive *x* axis.

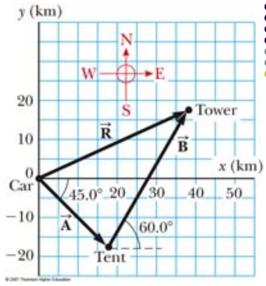
From Equations 3.8 and 3.9, its components are:

$$A_x = A\cos(-45.0°) = (25.0\text{ km})(0.707) = 17.7\text{ km}$$

$$A_y = A\sin(-45.0°) = (25.0\text{ km})(-0.707) = -17.7\text{ km}$$

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



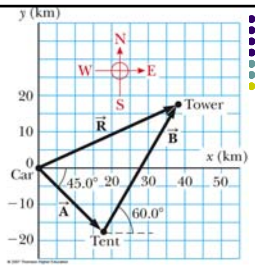
- The second displacement $\vec{\mathbf{B}}$ has a magnitude of 40.0 km and is 60.0° north of east.

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 $\vec{\mathbf{R}}$ for the trip. Find an exp$\vec{\mathbf{R}}$ession for in terms of unit vectors.

Solution: The resultant displacement for the trip $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$ has components given by Equation 3.15:

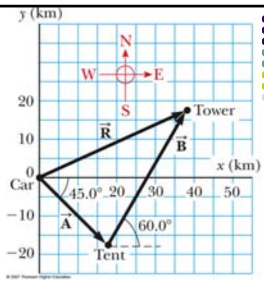
$$R_x = A_x + B_x = 17.7\text{ km} + 20.0\text{ km} = 37.7\text{ km}$$

$$R_y = A_y + B_y = -17.7\text{ km} + 34.6\text{ km} = 16.9\text{ km}$$

In unit-vector form, we can write the total displacement as

$\vec{R}$ = (37.7**i** + 16.9**j**) 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 $\vec{\mathbf{R}}$ 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 $\vec{\mathbf{R}}$ in our final result. Also, both components of $\vec{\mathbf{R}}$ are positive, putting the final position in the first quadrant of the coordinate system, which is also consistent with the figure.