Chapter 1: Models, Measurements, and Vectors

TENTH EDITION

SEARS & ZEMANSKY'S

College Physics

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Goals for Chapter 1

- To know standards and units and be able to do unit conversions.

- To express measurements and calculated information with the correct number of significant figures.

- To be able to add and subtract vectors both graphically and analytically.

- To be able to break down vectors into *x*- and *y*- components.

Measurement

- Physics is an experimental science.
  - Observe phenomena in nature.
  - Make predictions.
    - Models
    - Hypotheses
    - Theories
    - Laws

(a)

Units of Measurement

- Cultural
  - "cubit," "span," "foot," "mile"
  - Changes with time and location
- 1889 by the General Conference on Weights and Measures
  - Systéme International
  - [See Appendix A in back of book]

# Three Fundamental S.I. Units Which We Will Use:

- Time
  - Second (s)
- Length
  - Meter (m)
- Mass
  - Kilogram (kg)

The Second

- Originally tied to the length of a day.
- Now, exceptionally accurate.
  - Atomic clock
  - 9,192,631,770 oscillations of a low-energy transition in Cs
  - In the microwave region

The Meter – The Original Definition of 1791

The meter was originally defined as 1/10,000,000 of this distance.

North Pole

10^7 m

Equator
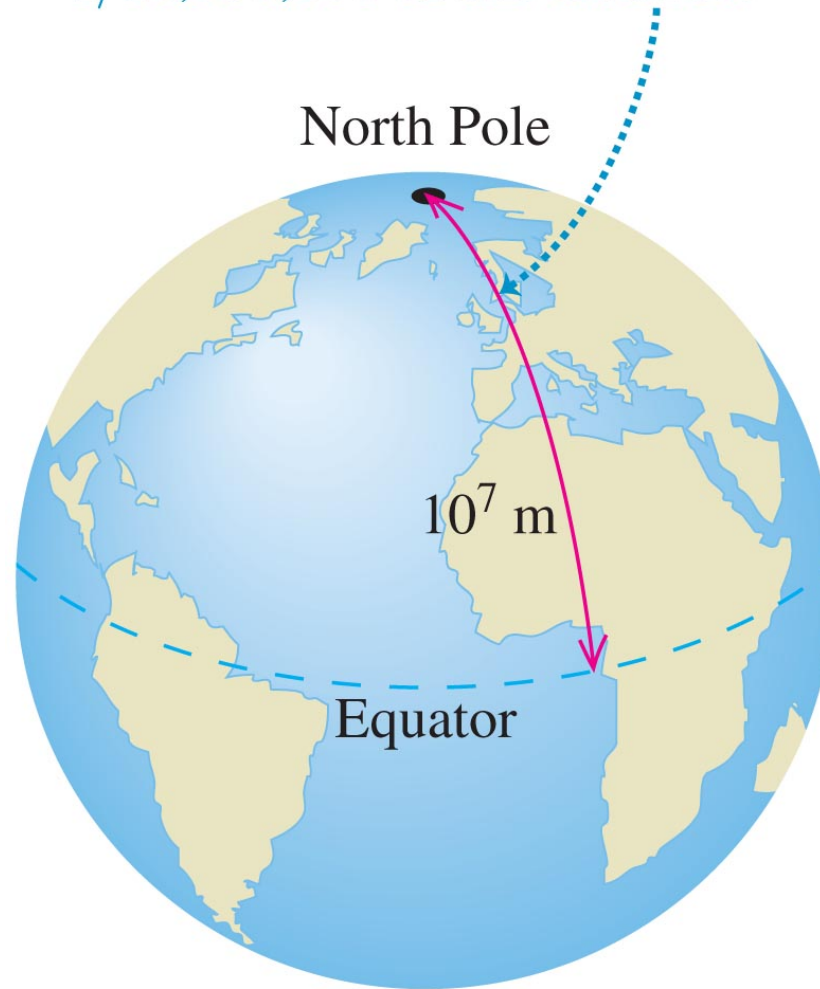
The Meter – More Recently

- Now tied to Kr discharge and counting a certain number of wavelengths.

- Exceptionally accurate, in fact redefining *c*, speed of light.

- New definition is the distance that light can travel in a vacuum in 1/299,792,458 s.

- So accurate that it loses only 1 second in 30 million years.

The Kilogram

- The reference cylinder is kept in Sevres, France.
- A more modern, atomic reference is hoped for, waiting for a precise atomic technique.

The Reference Kilogram - Figure 1.3

You Can Adjust the Fundamental Units – Powers of 10

- Imagine trying to measure the distance from San Francisco, CA to Charlotte, NC in meters.

- Instead, we attach prefixes to the units that adjust their size by powers of ten.

  - In this case, kilo (or "x10^3") would likely be chosen.

  - The distance would then be reported as 4,621 km or 4.6 Mm.

    - Getting good at converting units will be very important to us.

    - Use Table 1.1.

$$4,621,000 \text{ m} = 4,621 \times 10^3 \text{ m} = 4,621 \text{ km} = 4.62 \times 10^3 \text{ km} = 4.6 \text{ Mm}$$

Table 1.1

TABLE 1.1 **Prefixes for powers of ten**

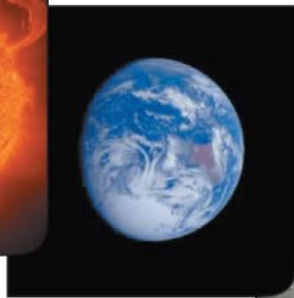| Power of ten	Prefix	Abbreviation
10^{-18}	atto-	a
10^{-15}	femto-	f
10^{-12}	pico-	p
10^{-9}	nano-	n
10^{-6}	micro-	μ
10^{-3}	milli-	m
10^{-2}	centi-	c
10^{3}	kilo-	k
10^{6}	mega-	M
10^{9}	giga-	G
10^{12}	tera-	T
10^{15}	peta-	P
10^{18}	exa-	E

The Powers of Ten are Dramatic – Figure 1.4

(a) 10^{26} m
Limit of the observable universe

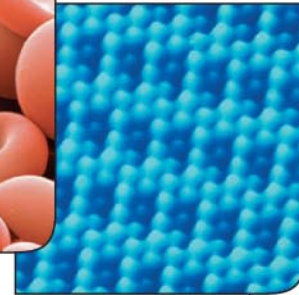(b) 10^{11} m
Distance to the sun
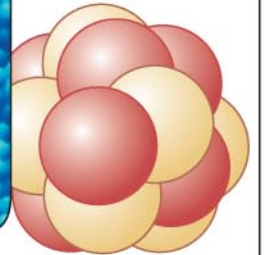
(c) 10^7 m
Diameter of the earth

(d) 1 m
Human dimensions

(e) 10^{-5} m
Diameter of a red blood cell

(f) 10^{-10} m
Radius of an atom

(g) 10^{-14} m
Radius of an atomic nucleus

Conversions

- "Practice, practice, practice."
  - Problems will come in many different styles of measurement, but you will ultimately need to get back to (m), (kg), and (s) if your answers are going to fit other calculations.
  - You'll need to overcome two hurdles:
    - Derived units
    - English → S.I.
  - Let's examine each.

Derived Units

- The science will wait until we find it in a subsequent chapter. First, we should examine some units from those chapters.

  - Imagine you need to work with energy.

  - The unit for energy is the Joule (J) and it's built from other units: in this case, $kg\ m^2/s^2$.

  - Having mass in g or distance in cm … errors like that will destroy your answer.

English → S.I.

- In the United States, we often encounter measurements in miles, feet, pounds, quarts and gallons.

- It's useful to memorize one conversion for displacement, one for volume, and one for mass. Everything else could be reached by converting orders of magnitude.

- Mass is tricky. English units assume standard earth gravity and relate kg to lb even though kg is a mass and lb is a force.

English → S.I. II

- Personal favorites for English to SI are listed below.

  - Displacement: 2.54 centimeters = 1 inch.
  - Mass: 454 grams = 1 pound.
  - Volume: 1 liter = 1.06 quarts.

- You could certainly choose a different set.

Unit Conversion

Alpha Centauri is the closest "star." It is 4.3 light-years away. How many kilometers away is the star from earth?

Write down: *What do you know?* *What are we trying to get to?*

4.3 light-years = time it takes for

light to travel distance

Distance = time × speed   *What's the speed (rate)?*

Now do it…   *Speed of light = 3 × 10^8 m/s*

$$\text{distance} = (4.3 \text{ years})\left(\frac{3.15 \times 10^7 \text{ s}}{1 \text{ year}}\right)\left(\frac{3 \times 10^8 \text{ m}}{\text{s}}\right)\left(\frac{1 \text{ km}}{1000 \text{ m}}\right)$$

$$\underbrace{\phantom{(4.3 \text{ years})\left(\frac{3.15 \times 10^7 \text{ s}}{1 \text{ year}}\right)}}_{\text{time}} \underbrace{\phantom{\left(\frac{3 \times 10^8 \text{ m}}{\text{s}}\right)\left(\frac{1 \text{ km}}{1000 \text{ m}}\right)}}_{\text{speed}}$$

$$= 40 \times 10^{12} \text{ km} \text{ or } 40 \text{ petameters (Pm)}$$

Precision and Significant Figures

- Your measurement tools have limitations, and your reported results need to reflect those limitations.
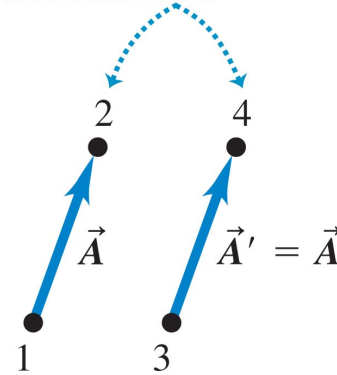

135 mm

424 mm
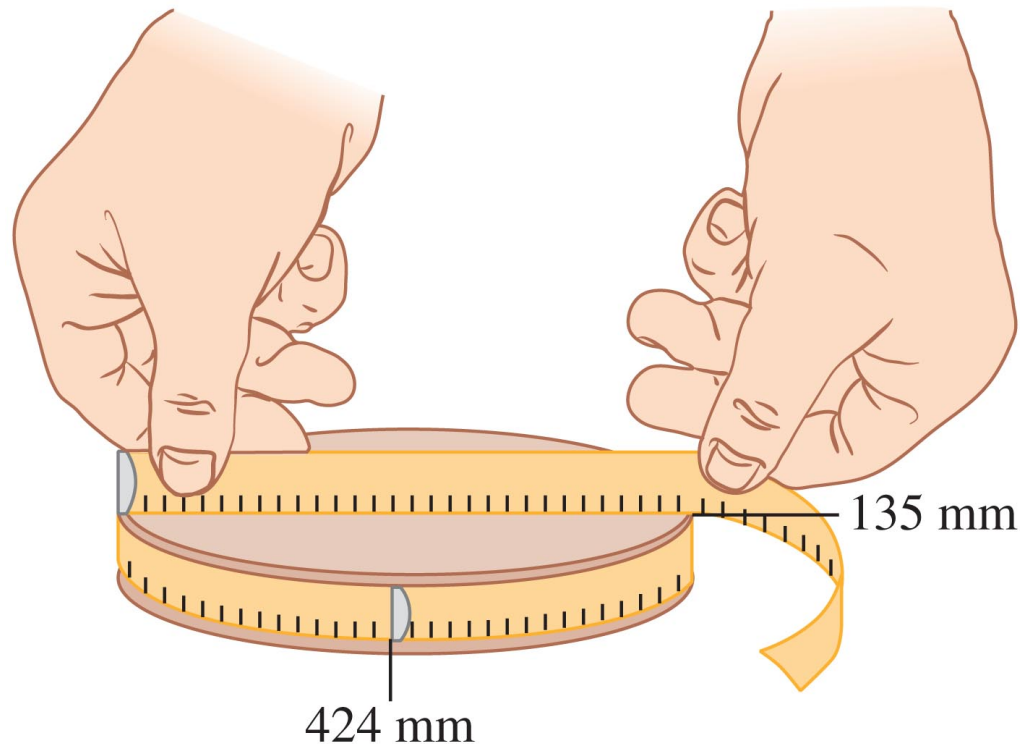
"Am I significant?"

- At the risk of making data feel unwanted, we dare not report everything our calculator tells us. (Please forgive the anthropomorphism.)

  - Try this. Divide 10 (one SF) by 3 (one SF) and your calculator will tell you 3.33333333.

  - If you report this answer, the reader will believe you have measured carefully to billionths of the unit you are using.

  - What can happen? It's possible that bolt holes will fail to line up.

Vector addition

- In the "world of vectors" 1+1 does not necessarily equal 2.

- Graphically?

Vectors $\vec{A}$ and $\vec{A}'$ are equal because they have the same length and direction.

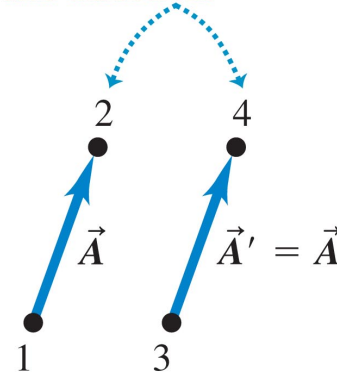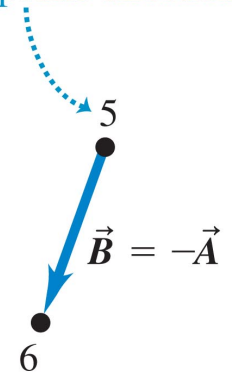This vector is different from $\vec{A}$; it points in the opposite direction.

$\vec{A}$

$\vec{A}' = \vec{A}$

$\vec{B} = -\vec{A}$
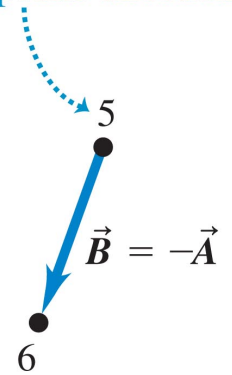
Adding graphically
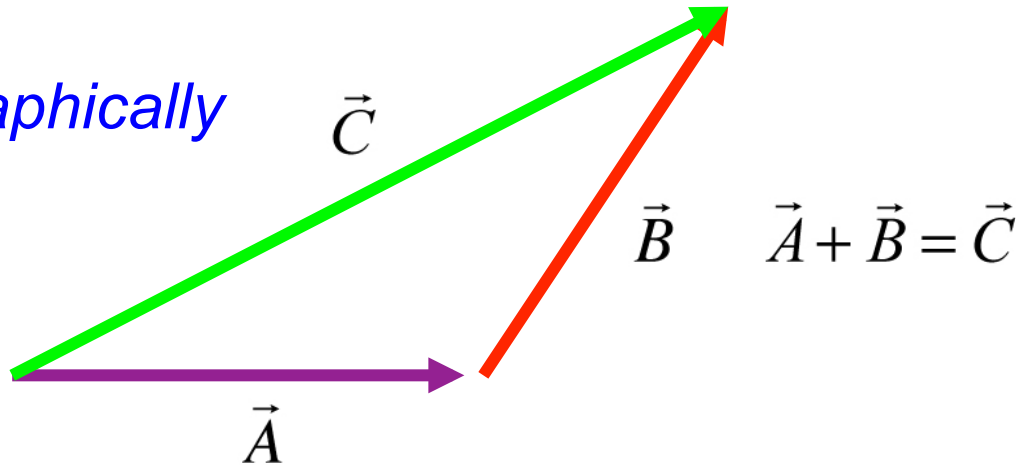
$\vec{C}$

$\vec{B}$ $\vec{A} + \vec{B} = \vec{C}$

$\vec{A}$

Vector addition

- In the "world of vectors" 1+1 does not necessarily equal 2.

- Graphically?

Vectors $\vec{A}$ and $\vec{A}'$ are equal because they have the same length and direction.
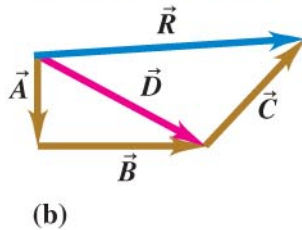
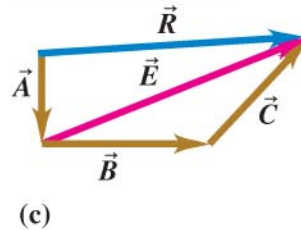This vector is different from $\vec{A}$; it points in the opposite direction.

$\vec{A}$

$\vec{A}' = \vec{A}$

$\vec{B} = -\vec{A}$

To find the sum of these three vectors ...

$\vec{C}$

$\vec{A}$ $\vec{B}$

(a)
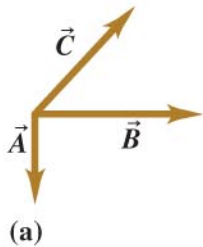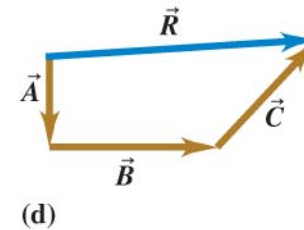
we could add $\vec{A}$ and $\vec{B}$ to get $\vec{D}$ and then add $\vec{C}$ to $\vec{D}$ to get the final sum (resultant) $\vec{R}$, ...

$\vec{R}$
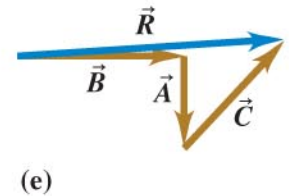
$\vec{A}$ $\vec{D}$ $\vec{C}$

$\vec{B}$

(b)

or we could add $\vec{B}$ and $\vec{C}$ to get $\vec{E}$ and then add $\vec{A}$ to $\vec{E}$ to get $\vec{R}$, ...

$\vec{R}$

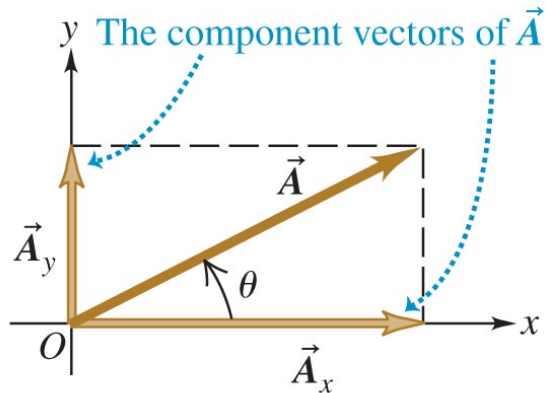$\vec{A}$ $\vec{E}$ $\vec{C}$

$\vec{B}$

(c)

or we could add $\vec{A}$, $\vec{B}$, and $\vec{C}$ to get $\vec{R}$ directly, ...

$\vec{R}$

$\vec{A}$ $\vec{C}$

$\vec{B}$

(d)

or we could add $\vec{A}$, $\vec{B}$, and $\vec{C}$ in any other order and still get $\vec{R}$.

$\vec{R}$

$\vec{B}$ $\vec{A}$

$\vec{C}$

(e)

Or, decompose the vectors into components, then solve.

(a)

(b)

vector $\vec{A}$ as a sum of component vectors

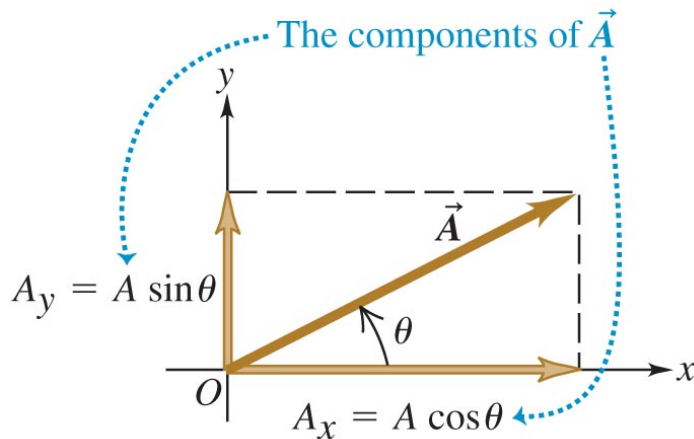$$\vec{A} = \vec{A}_x + \vec{A}_y$$

vector component of $\vec{A}$

$$A_x = A \cos \theta$$

$$A_y = A \sin \theta$$

magnitude and direction of $\vec{A}$
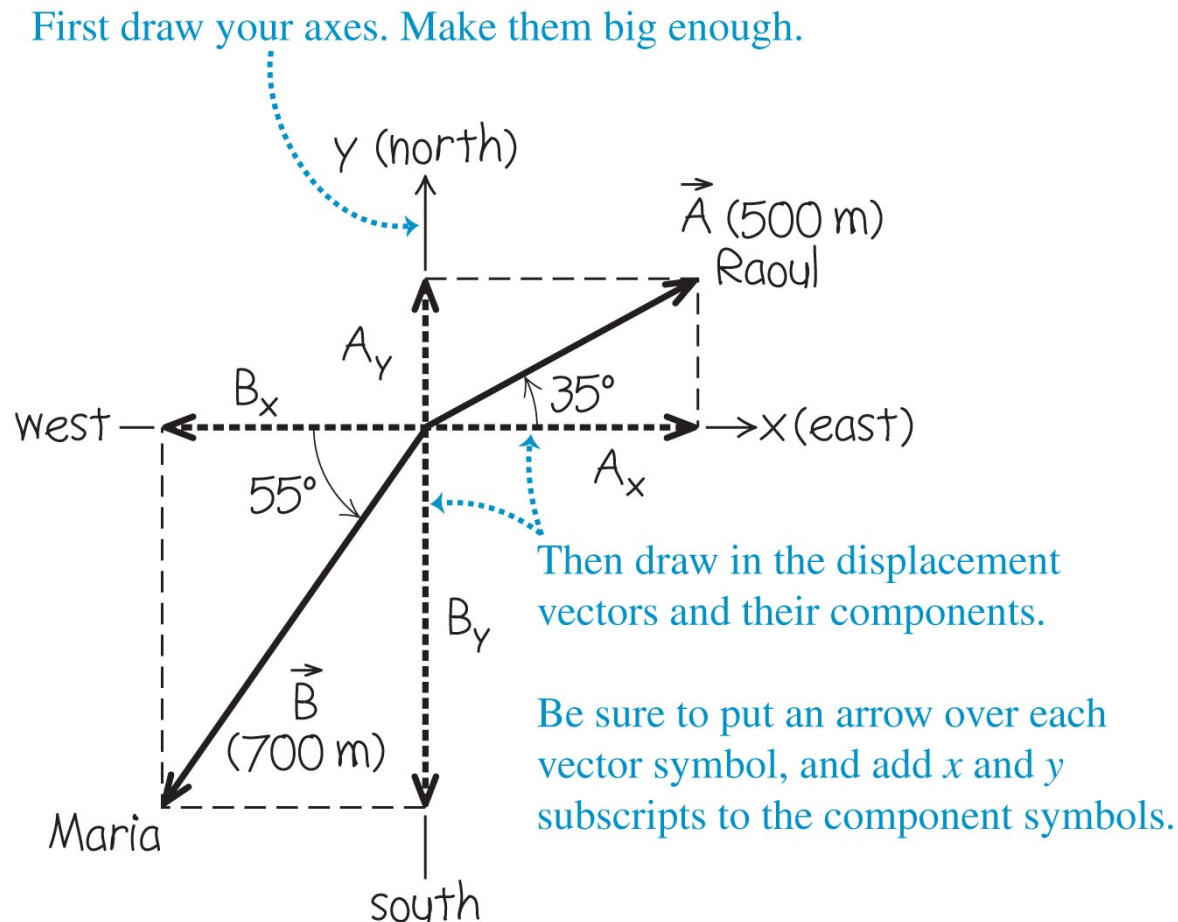
$$A = \sqrt{A_x^2 + A_y^2}$$

$$\tan \theta = \frac{A_y}{A_x}$$

Just in case your trigonometry is rusty, let's review.

- Try Example 1.6 to check yourself.

First draw your axes. Make them big enough.

Then draw in the displacement vectors and their components.

Be sure to put an arrow over each vector symbol, and add x and y subscripts to the component symbols.

Using Components to Add Vectors

Example 1.7: Vector $\vec{A}$ has a magnitude of 50 cm and direction of 30º, and vector $\vec{B}$ has a magnitude of 35 cm and direction 110º (both angles measured *ccw* from $+\hat{x}$). What is the resultant vector $\vec{R}$?
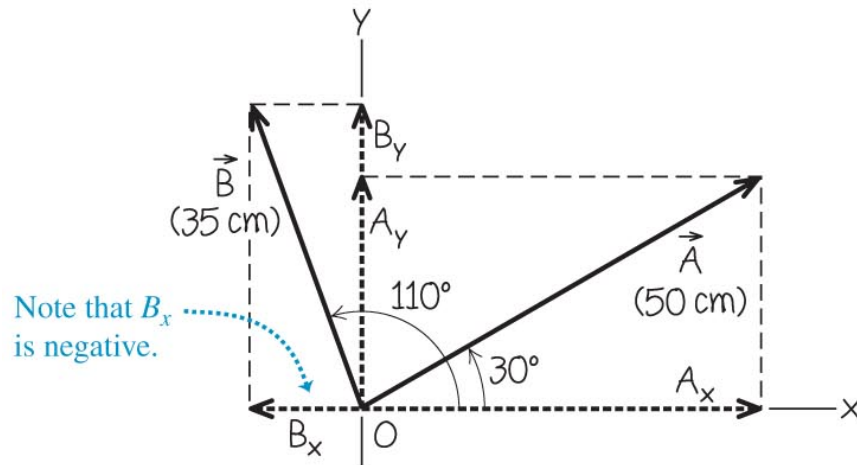
(a) Our diagram for this problem
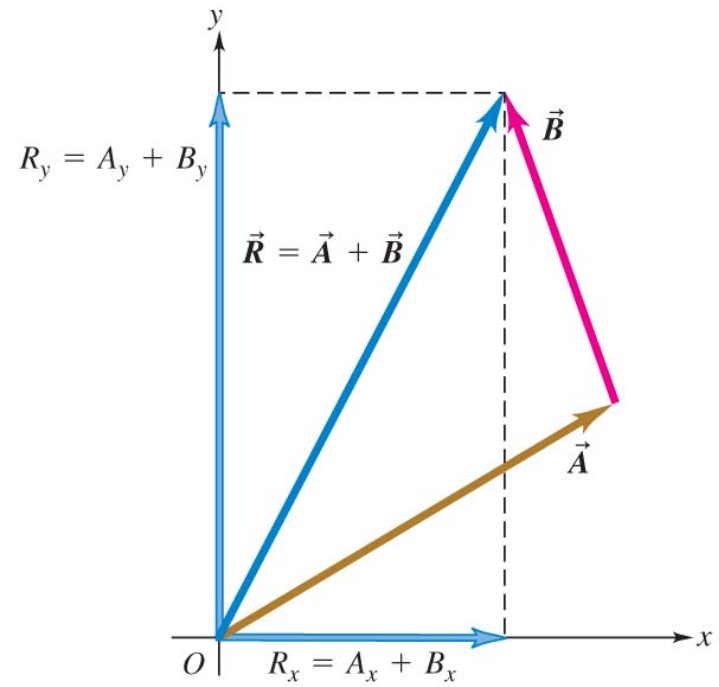
(b) The resultant $\vec{R}$ and its components