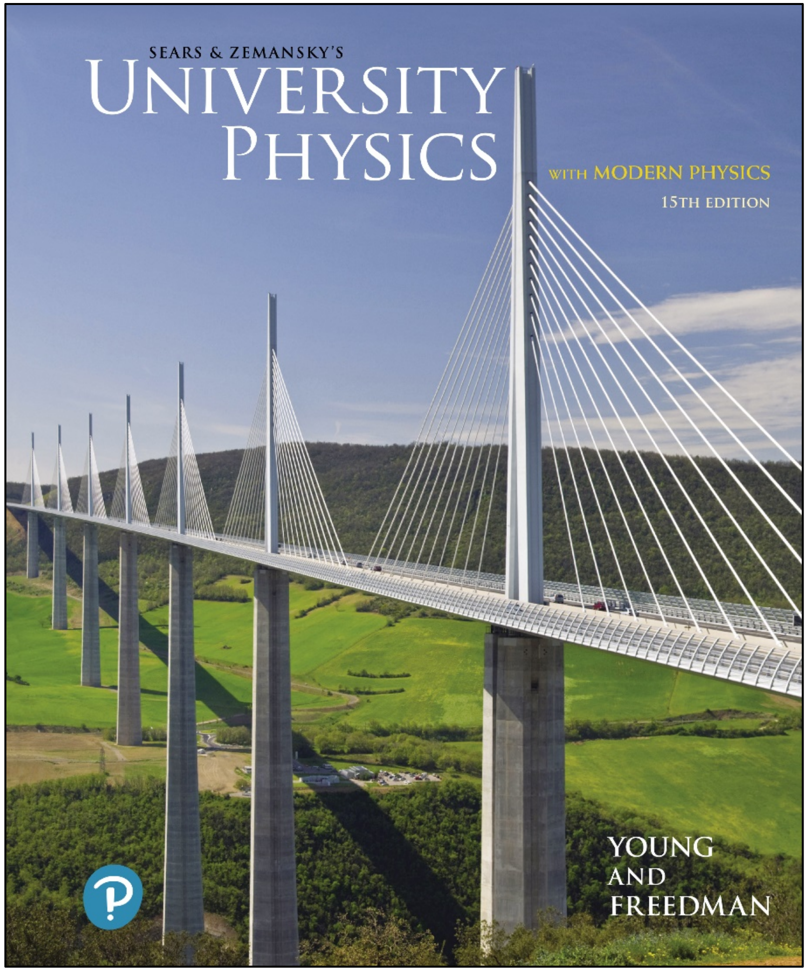
University Physics with Modern Physics

Fifteenth Edition



Chapter 1

Units, Physical Quantities, and Vectors

Pearson

Contact information

- Fall term course director: Prof Paul Delaney
- Office hours: Tuesdays 2 – 3 PM, PSE 329
- Visit the course Moodle site almost daily to keep up-to-date
- Use the Moodle Discussion Forum for course related questions of content, administration.
- Course email address: phys1410@yorku.ca
- Be sure to know when your laboratory section meets. Laboratory location is BC 102. Lab Manual will be online shortly. Contact prof Menary for additional queries: menary@yorku.ca

Course Assessment

Assessment tasks	**Details**	**Weighting (%)**
Fall mid-term test	Saturday October 26, 12-2 PM, CLH I	10
Winter mid-term test	February TBA	10
Chapter (Homework) assignments (85% rule applies)	Throughout Fall and Winter terms via Mastering Physics	15.0
In-class iClicker questions (85% rule applies)	During each chapter, usully multiple choice	5.0
Laboratory exercises	Throughout Fall and Winter terms	10
End-of-term Examination (Fall and date set by Registrar’s Office)	December: Chapters 1-15, short answer and worked problems; on campus.	25.0
End-of-term Examination (Winter and date set by Registrar’s Office)	April: Chapters 21 - 36, short answer and worked problems; on campus.	25.0
Total		**100.0**

You need to have …

- Recommend purchasing the textbook
- Must have a Mastering Physics license to complete the weekly chapter assignments. Login to Mastering ASAP.
- Mastering Physics ID: delaney17829.
- Fall assignments due Wednesday evenings at 10 PM. No late submissions will be accepted. Nominally 12 assignments in the Fall.
- 85% rule applies.

You need to have …

- Daily in class questions will occur and require the iClicker protocols.
- The 85% rule will apply.
- Log into the iClicker app and find our course: ID is PHYS 1410 Physical Science FW19-20
- First “real” use in class Monday September 9.
- Good time management skills (for all courses). Plan to spend 7-10 hours per week on this course **in addition** to class time.

Learning Goals for Chapter 1

Looking forward at …

- the four steps you can use to **solve** any physics problem.
- **three fundamental quantities** of physics and the units physicists use to measure them.
- how to work with **units** and **significant figures** in your calculations.
- how to add and subtract **vectors** graphically, and using vector components.
- two ways to multiply vectors: the **scalar (dot)** product and the **vector (cross)** product.

The nature of physics

- Physics is an ***experimental*** science in which physicists seek patterns that relate the phenomena of nature.
- The patterns are called **physical theories**.
- A very well established or widely used theory is called a **physical law** or **principle**.
- Follows the **scientific method**

According to legend, Galileo investigated falling objects by dropping them from the Leaning Tower of Pisa, Italy, ...

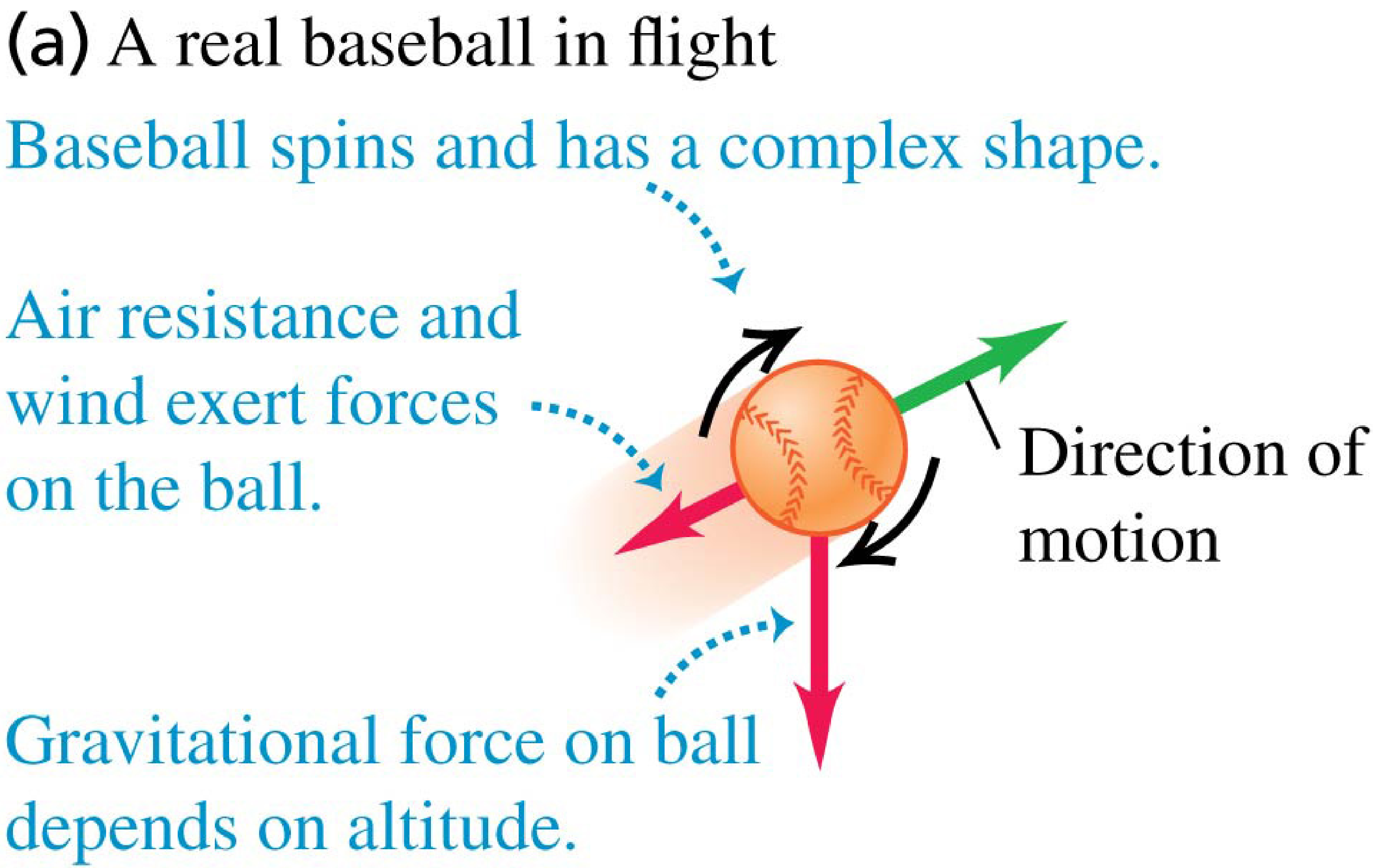
... and he studied pendulum motion by observing the swinging chandelier in the adjacent cathedral.

Solving problems in physics … PRACTICE!

- All of the *Problem-Solving Strategies* and *Examples* in this book will follow these four steps:
- **Identify** the relevant concepts, target variables, and known quantities, as stated or implied in the problem.
- **Set Up** the problem: Choose the equations that you'll use to solve the problem, and draw a sketch of the situation.
- **Execute** the solution: This is where you "do the math."
- **Evaluate** your answer: Compare your answer with your estimates, and reconsider things if there's a discrepancy.

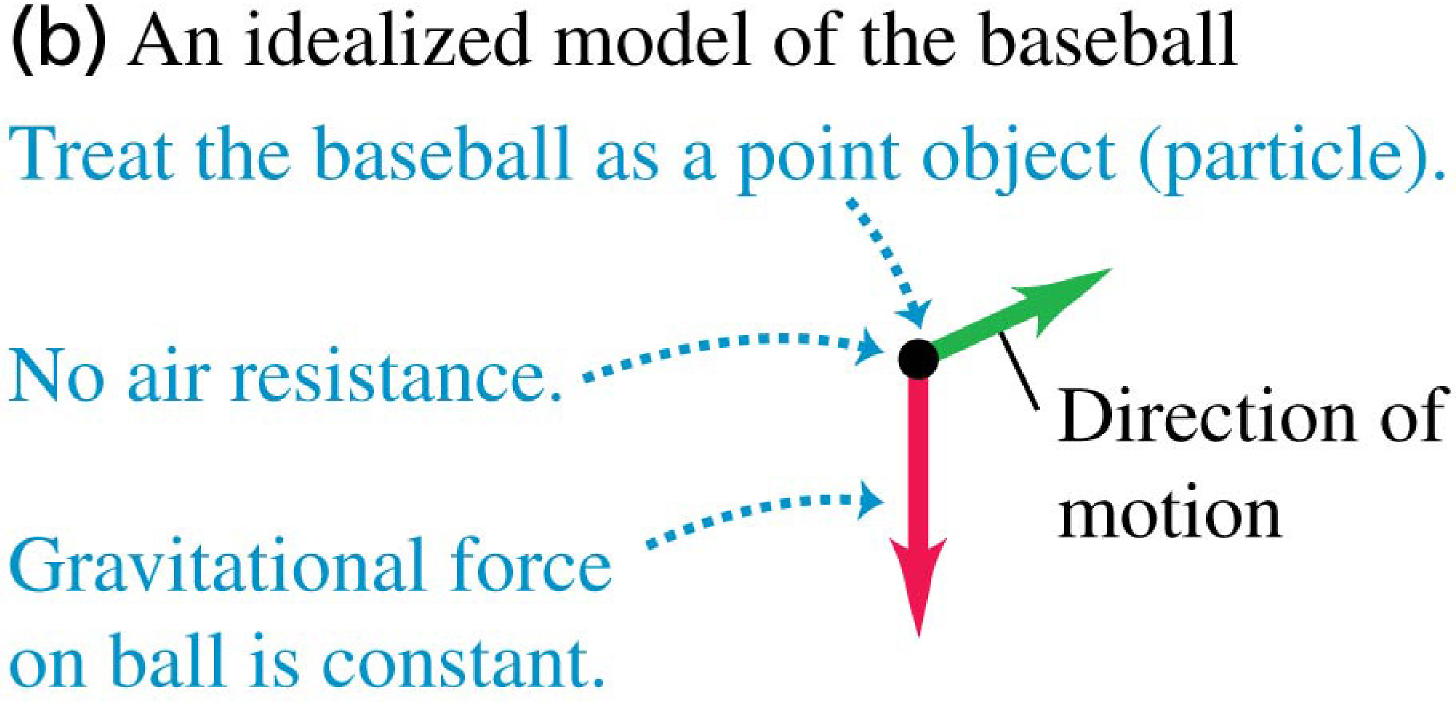
Idealized models

To simplify the analysis of
(a) a baseball in flight



Idealized models

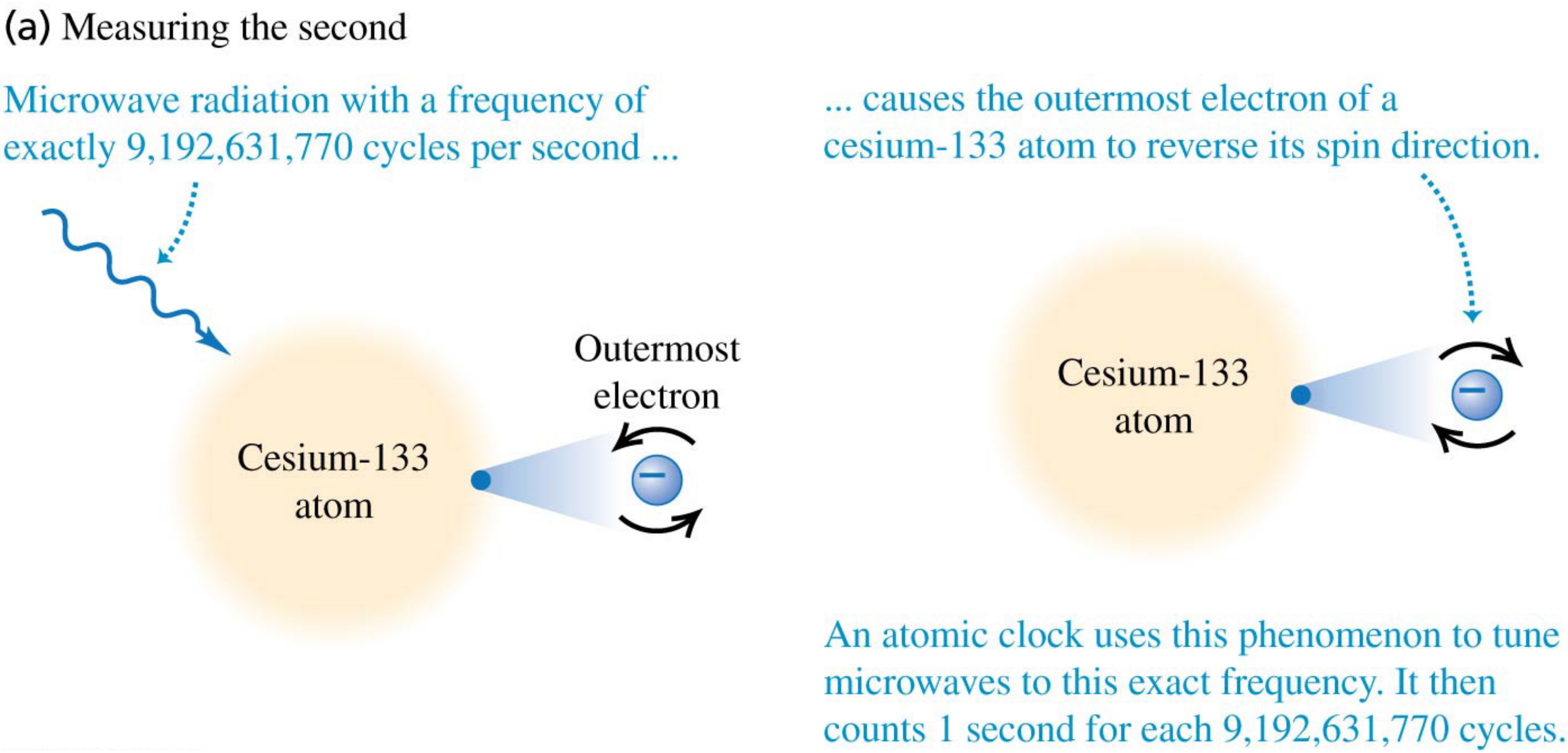
To simplify the analysis of
we use (b) an idealized
model.



Standards and units

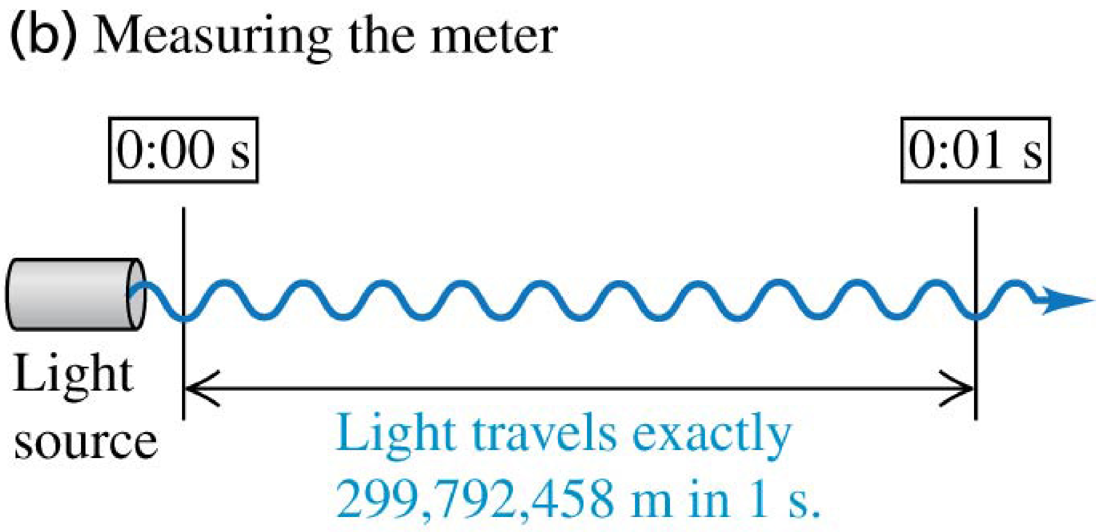
- Length, time, and mass are **three *fundamental* quantities** of physics.
- The *International System* (**SI** for *Système International*) is the most widely used system of units.
- In SI units, length is measured in ***meters***, time in ***seconds***, and mass in ***kilograms***.

Figure 1.3a Time standard uses Cesium-133 ground state's hyperfine structure



Microwave frequency of 9,192,631,770 Hz (wavelength ~3.26 cm) causes the "flip" transition.

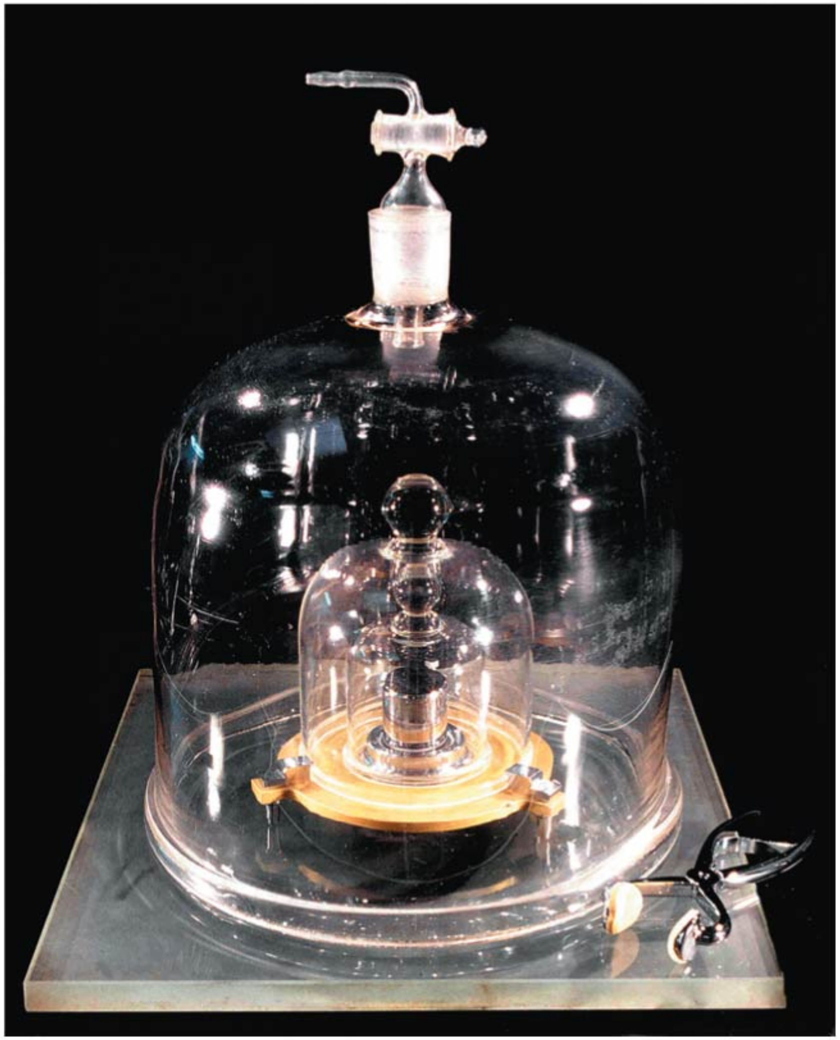
Figure 1.3b Length standard uses Krypton-86



Remember that distance is defined as speed x time

Figure 1.4 Mass standard: platinum-iridium alloy

Planck constant to be exactly $6.62607015 \times 10^{-34}\ kg \cdot m^2 \cdot s^{-1}$,



Unit prefixes

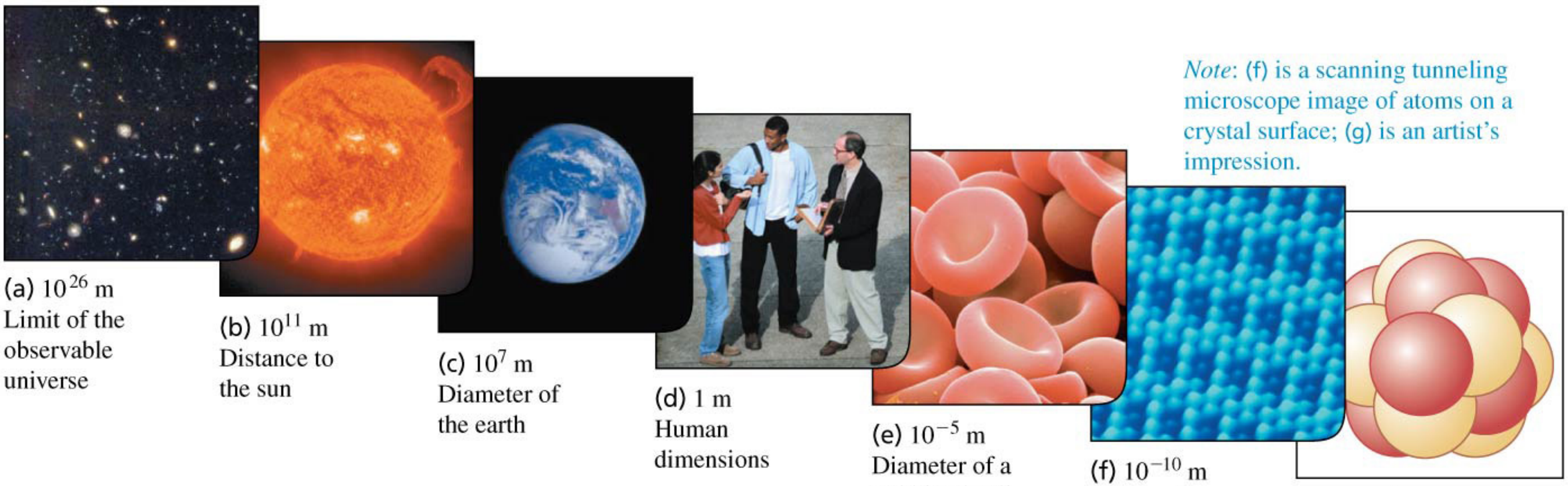
- Prefixes can be used to create larger and smaller units for the fundamental quantities. Some examples are:
- 1 μm = 10^{-6} m (size of some bacteria and living cells)
- 1 km = 10^{3} m (a 10-minute walk)
- 1 mg = 10^{-6} kg (mass of a grain of salt)
- 1 g = 10^{-3} kg (mass of a paper clip)
- 1 ns = 10^{-9} s (time for light to travel 0.3 m)

Table 1.1

TABLE 1.1 Some Units of Length, Mass, and Time

Length	Mass	Time
1 nanometer = 1 nm = 10^{-9} m (a few times the size of the largest atom)	1 microgram = 1 μg = 10^{-6} g = 10^{-9} kg (mass of a very small dust particle)	1 nanosecond = 1 ns = 10^{-9} s (time for light to travel 0.3 m)
1 micrometer = 1 μm = 10^{-6} m (size of some bacteria and other cells)	1 milligram = 1 mg = 10^{-3} g = 10^{-6} kg (mass of a grain of salt)	1 microsecond = 1 μs = 10^{-6} s (time for space station to move 8 mm)
1 millimeter = 1 mm = 10^{-3} m (diameter of the point of a ballpoint pen)	1 gram = 1 g = 10^{-3} kg (mass of a paper clip)	1 millisecond = 1 ms = 10^{-3} s (time for a car moving at freeway speed to travel 3 cm)
1 centimeter = 1 cm = 10^{-2} m (diameter of your little finger)		
1 kilometer = 1 km = 10^{3} m (distance in a 10-minute walk)		

Figure 1.5



Note: (f) is a scanning tunneling microscope image of atoms on a crystal surface; (g) is an artist's impression.

(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

Unit consistency and conversions

- An equation must be *dimensionally consistent*. Terms to be added or equated must *always* have the same units. (Be sure you're adding "apples to apples.")
- Always carry units through calculations.
- Convert to standard units as necessary, by forming a ratio of the same physical quantity in two different units, and using it as a multiplier.
- For example, to find the number of seconds in 3 min, we write:

$$3 \text{ min} = (3 \cancel{\text{min}})\left(\frac{60 \text{ s}}{1 \cancel{\text{min}}}\right) = 180 \text{ s}$$

Uncertainty and significant figures

- The uncertainty or error of a measured quantity depends upon the method/tool being used.
- The **accuracy** of a measurement is how close it likely is to the true value.
- For a measurement of 23.65 +/- .02 mm then the actual value is likely to be between 23.63 and 23.67 mm. The accuracy can be given as a percent error.
- The uncertainty or error of a measured quantity is indicated by its number of ***significant figures***.

Significant figures

- For **multiplication and division**, the answer can have no more significant figures than the ***smallest*** number of significant figures in the factors.
- For **addition and subtraction**, the number of significant figures is determined by the term having the **fewest** digits to the right of the decimal point.
- As this train mishap illustrates, even a small percent error can have spectacular results!

Table 1.2

TABLE 1.2 Using Significant Figures

Multiplication or division:

Result can have no more significant figures than the factor with the fewest significant figures:

$$\frac{0.745 \times 2.2}{3.885} = 0.42$$

$$1.32578 \times 10^{7} \times 4.11 \times 10^{-3} = 5.45 \times 10^{4}$$

Addition or subtraction:

Number of significant figures is determined by the term with the largest uncertainty (i.e., fewest digits to the right of the decimal point):

$$27.153 + 138.2 - 11.74 = 153.6$$

Accuracy and Precision

- Accuracy is **not** the same as precision!
- A digital time piece can display time to the nearest second and can be considered **precise** but if it is unable to keep good time it is considered inaccurate.
- Conversely if an analog time piece is known to maintain **accurate** time over long periods but only displays time to the nearest minute, it is not precise.
- High quality measurements are both accurate **and** precise!

Scientific Notation

- Powers of 10 notation. In essence a short form for very large and very small numbers.
- For example, 1,327,000 can be rewritten as 1.327×10^{6}
- As well, .0000246 can be rewritten as 2.46×10^{-5}

Order of magnitude approximations

- Being aware of the order of magnitude answer for a calculation is extremely useful.
- Sometimes referred to as a “back of the envelop” approximation, being able to simplify a problem and get an appreciation (idea) of what your answer should be is an important skill to cultivate.
- Such a skill can often be honed (tested) by answering “Fermi questions”!

Vectors and scalars

- A **scalar quantity** can be described by a *single number*.
- A **vector quantity** has both a *magnitude* and a *direction* in space.
- Temperature – a scalar quantity: Wind – a vector quantity

Vectors and scalars

- In this book, a vector quantity is represented in **boldface** italic type with an **arrow** over it: $\vec{A}$.
- The magnitude of $\vec{A}$ is written as A or $|\vec{A}|$.
- Distance between 2 points is considered a **scaler** quantity.
- Displacement between 2 points is considered a **vector** quantity.

Figure 1.9a

(a) We represent a displacement by an arrow that points in the direction of displacement.

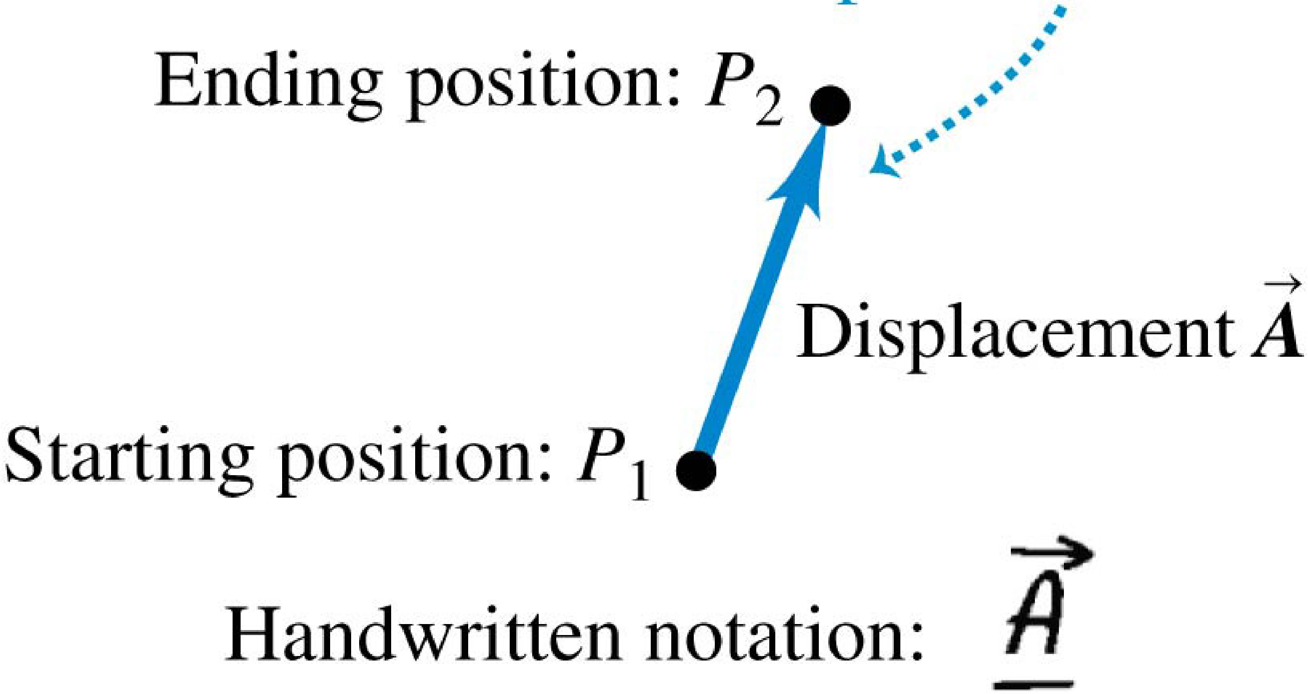


Figure 1.9b

(b) A displacement is always a straight arrow directed from the starting position to the ending position. It does not depend on the path taken, even if the path is curved.

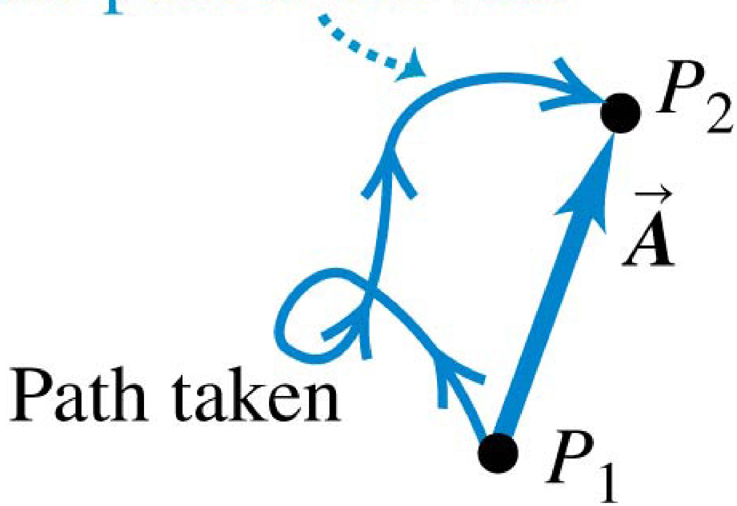
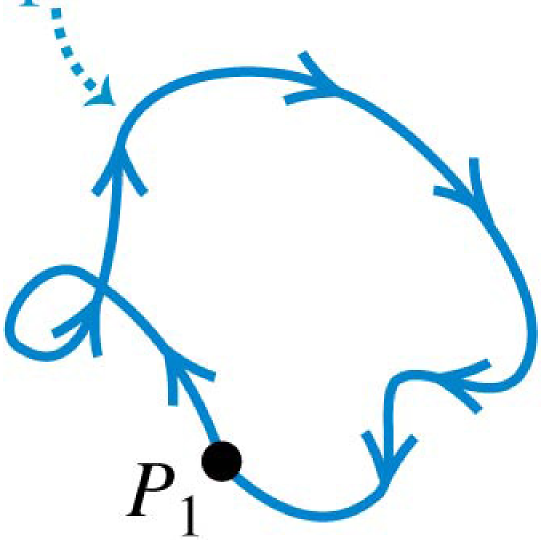


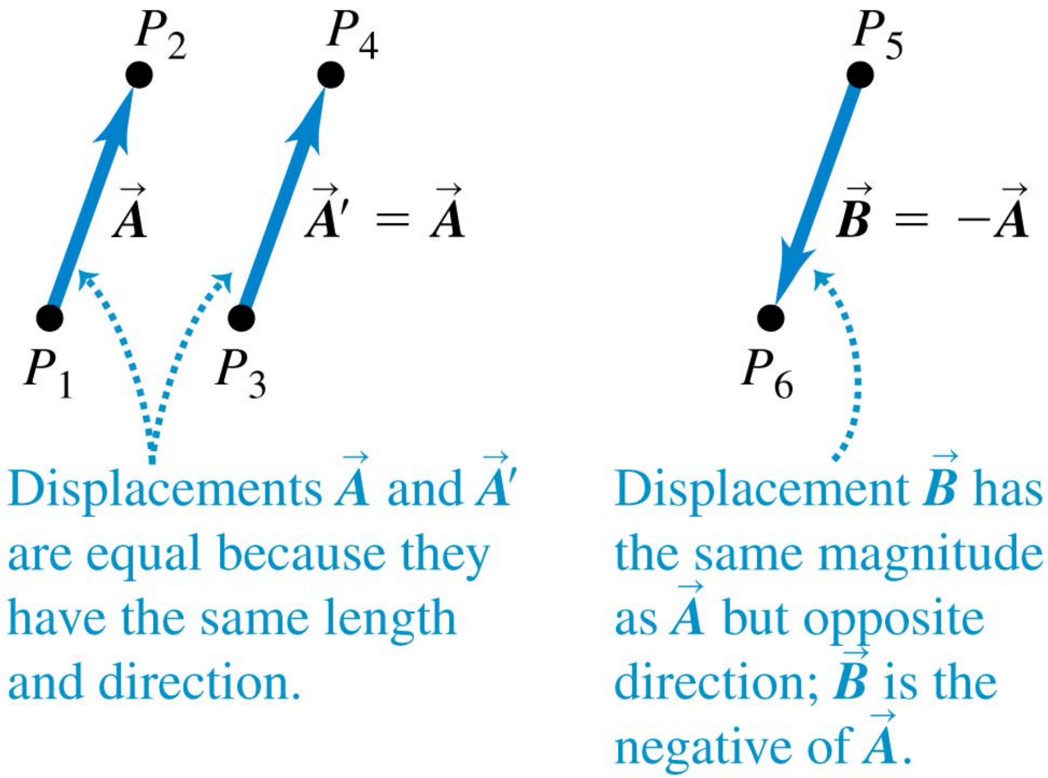
Figure 1.9c

(c) Total displacement for a round trip is 0, regardless of the path taken or distance traveled.

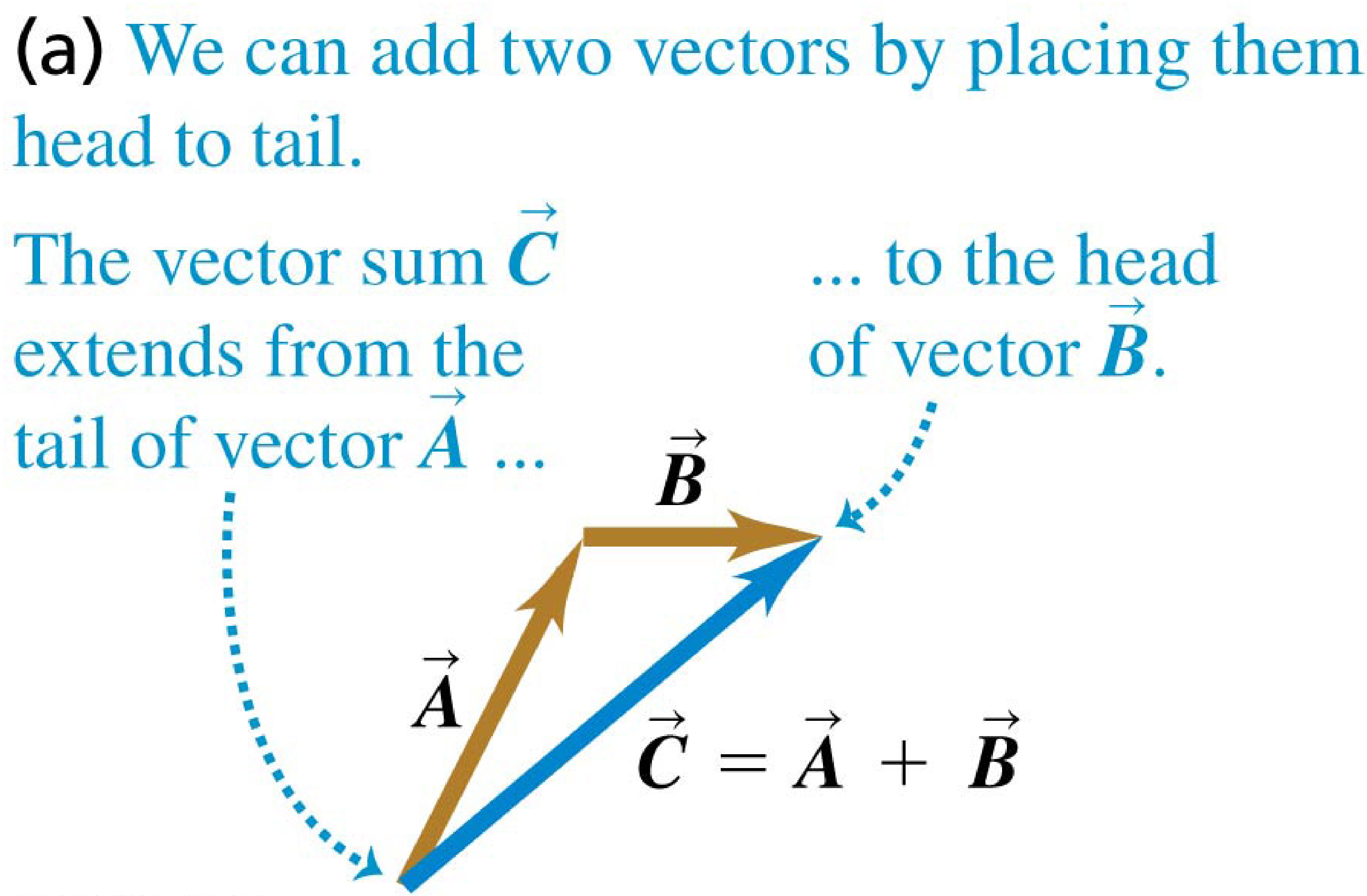


Drawing vectors

- Draw a vector as a line with an arrowhead at its tip.
- The ***length*** of the line shows the vector's *magnitude*.
- The ***direction*** of the line shows the vector's *direction*.

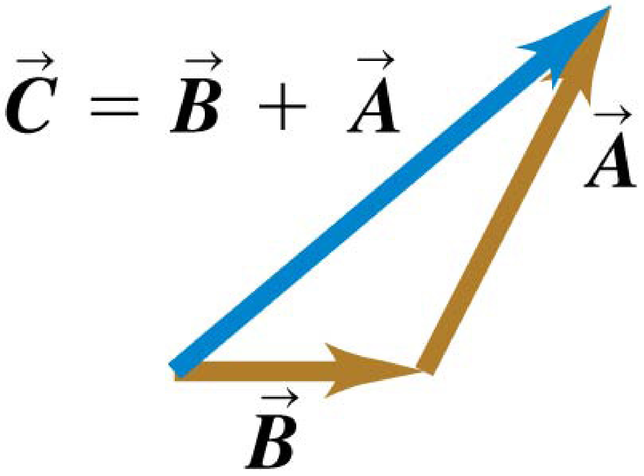


Adding two vectors graphically



Adding two vectors graphically

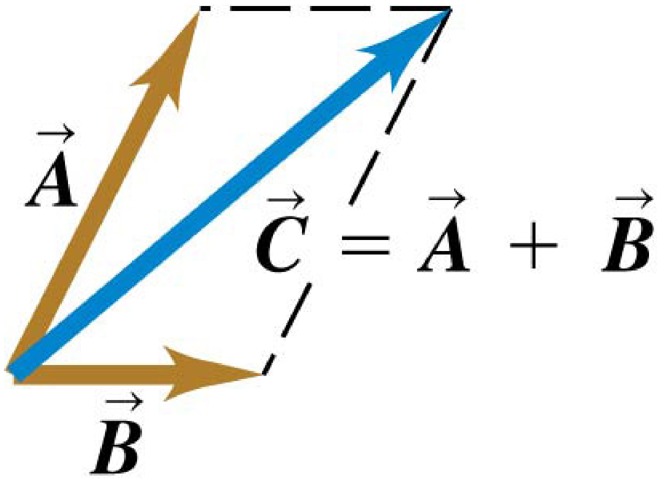
(b) Adding them in reverse order gives the same result: $\vec{A} + \vec{B} = \vec{B} + \vec{A}$. The order doesn't matter in vector addition.



Vector addition is a commutative process

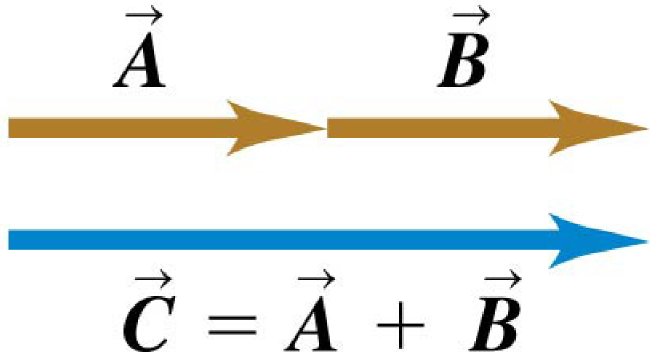
Adding two vectors graphically

(c) We can also add two vectors by placing them tail to tail and constructing a parallelogram.



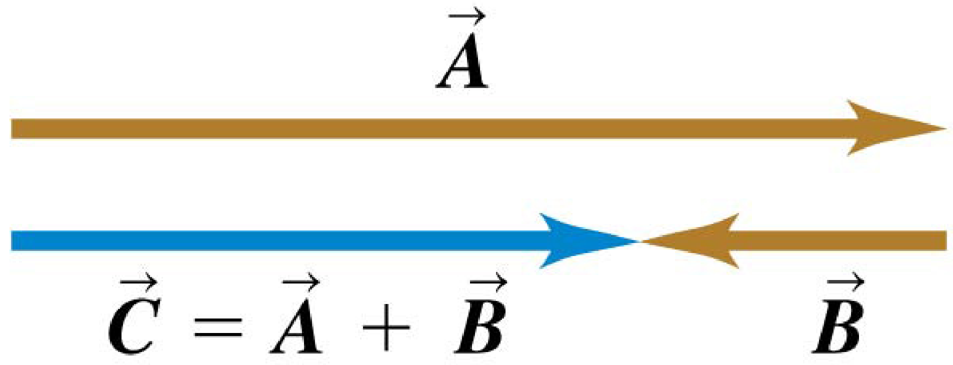
Adding two vectors graphically

(a) Only when vectors $\vec{A}$ and $\vec{B}$ are parallel does the magnitude of their vector sum $\vec{C}$ equal the sum of their magnitudes: $C = A + B$.



Adding two vectors graphically

(b) When $\vec{A}$ and $\vec{B}$ are antiparallel, the magnitude of their vector sum $\vec{C}$ equals the *difference* of their magnitudes: $C = |A - B|$.

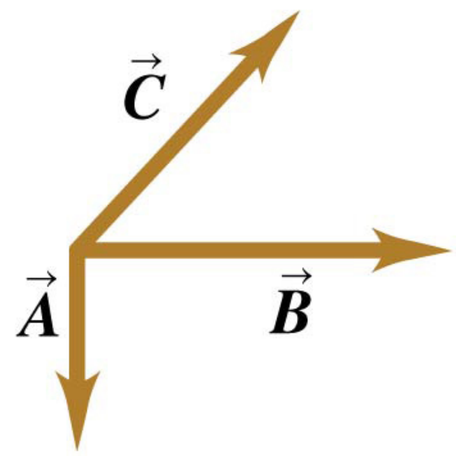


Adding more than two vectors graphically

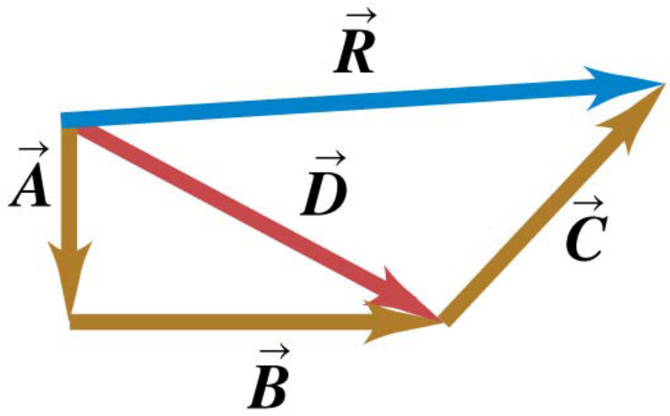
- To add several vectors, use the head-to-tail method.

- The vectors can be added in any order.

(a) To find the sum of these three vectors ...



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



Adding more than two vectors graphically

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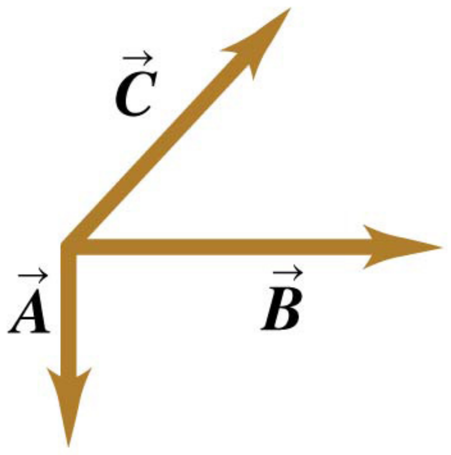
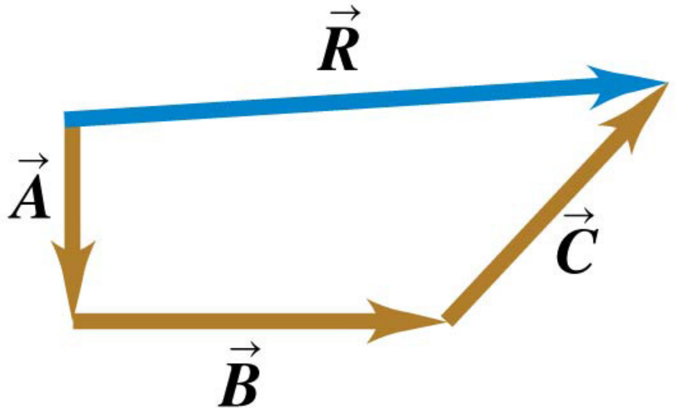


(d) ... or add $\vec{A}$, $\vec{B}$, and $\vec{C}$ to get $\vec{R}$ directly ...



Adding more than two vectors graphically

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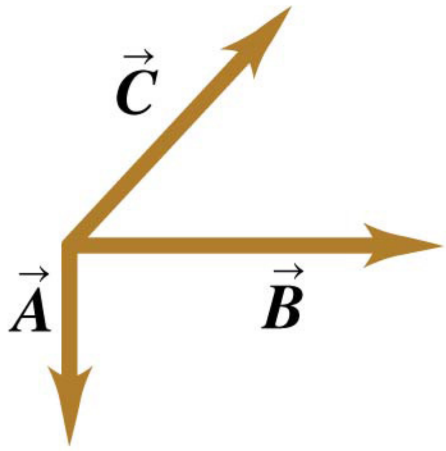
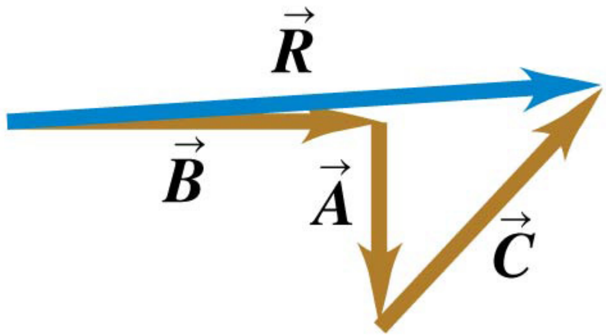
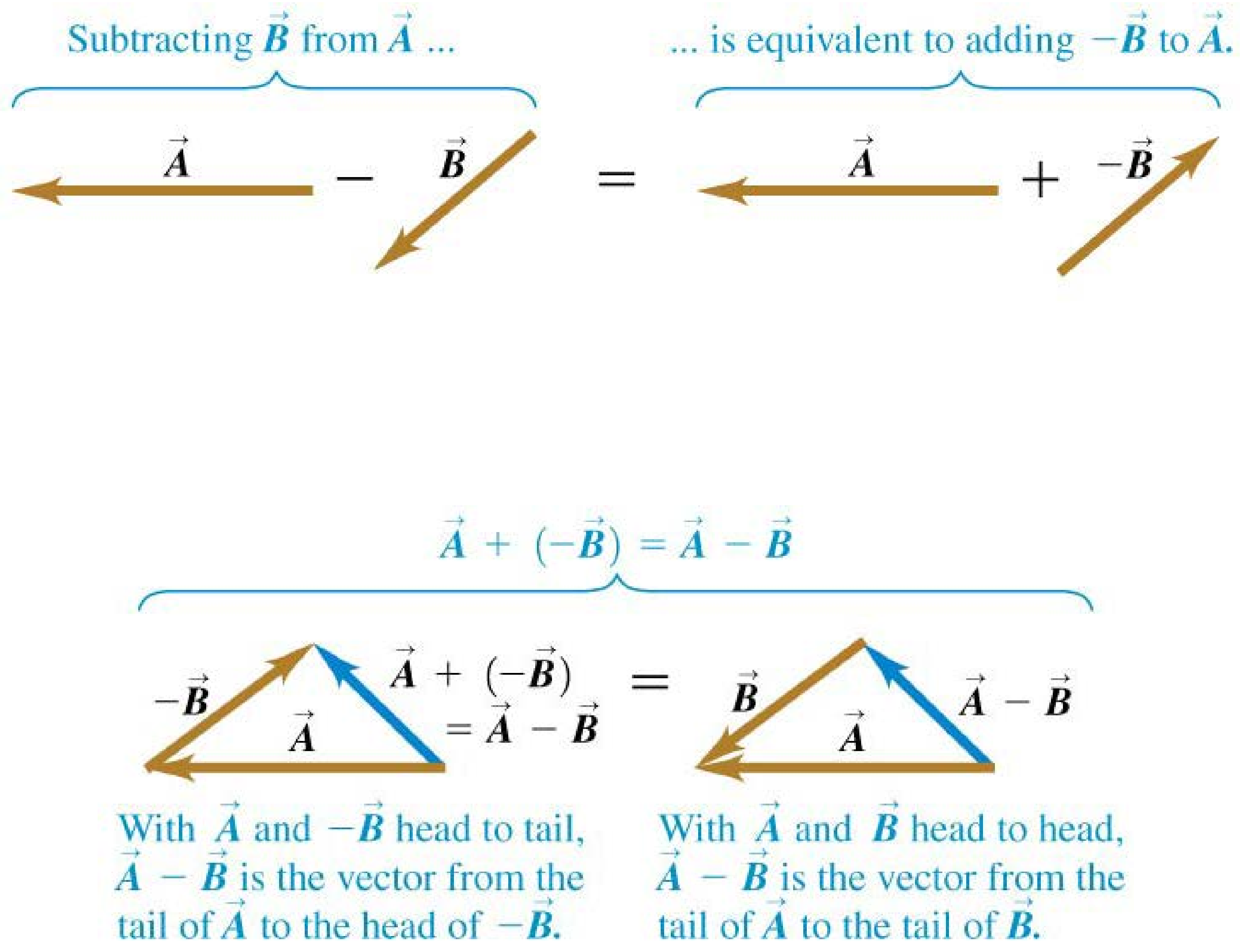


(e) ... or add $\vec{A}$, $\vec{B}$, and $\vec{C}$ in any other order and still get $\vec{R}$.

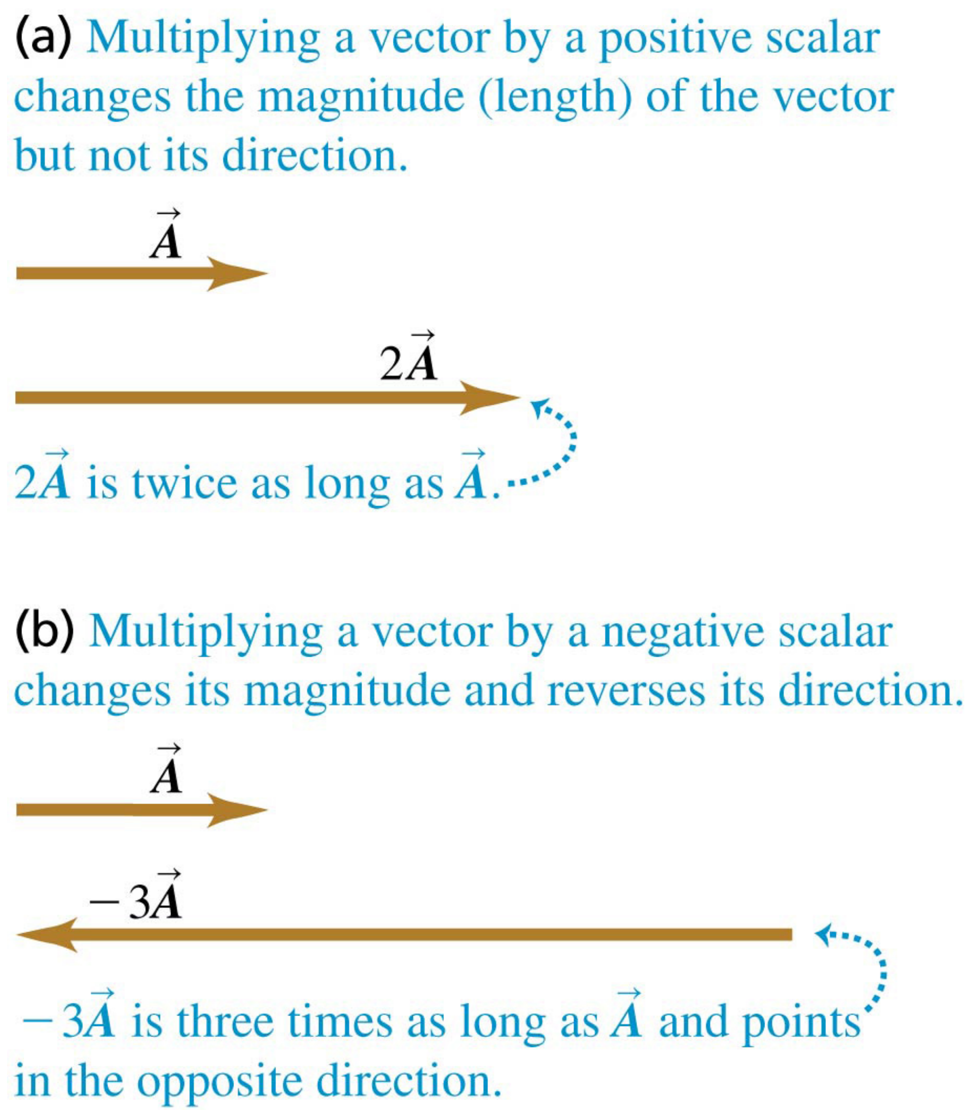


Subtracting vectors



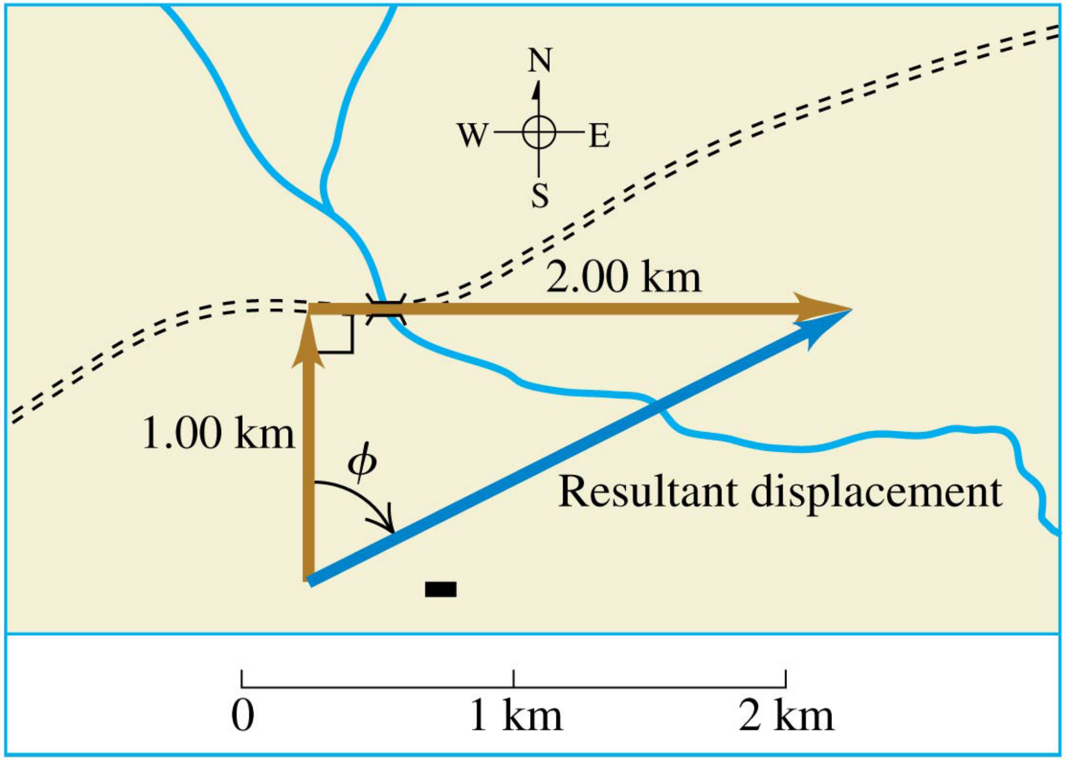
Multiplying a vector by a scalar

- If c is a scalar, the product $c\vec{A}$ has magnitude $|c|A$.
- The figure illustrates multiplication of a vector by (a) a positive scalar and (b) a negative scalar.



Addition of two vectors at right angles

- To add two vectors that are at right angles, first add the vectors graphically.
- Then use trigonometry to find the magnitude and direction of the sum.
- In the figure, a cross-country skier ends up 2.24 km from her starting point, in a direction of 63.4° east of north.

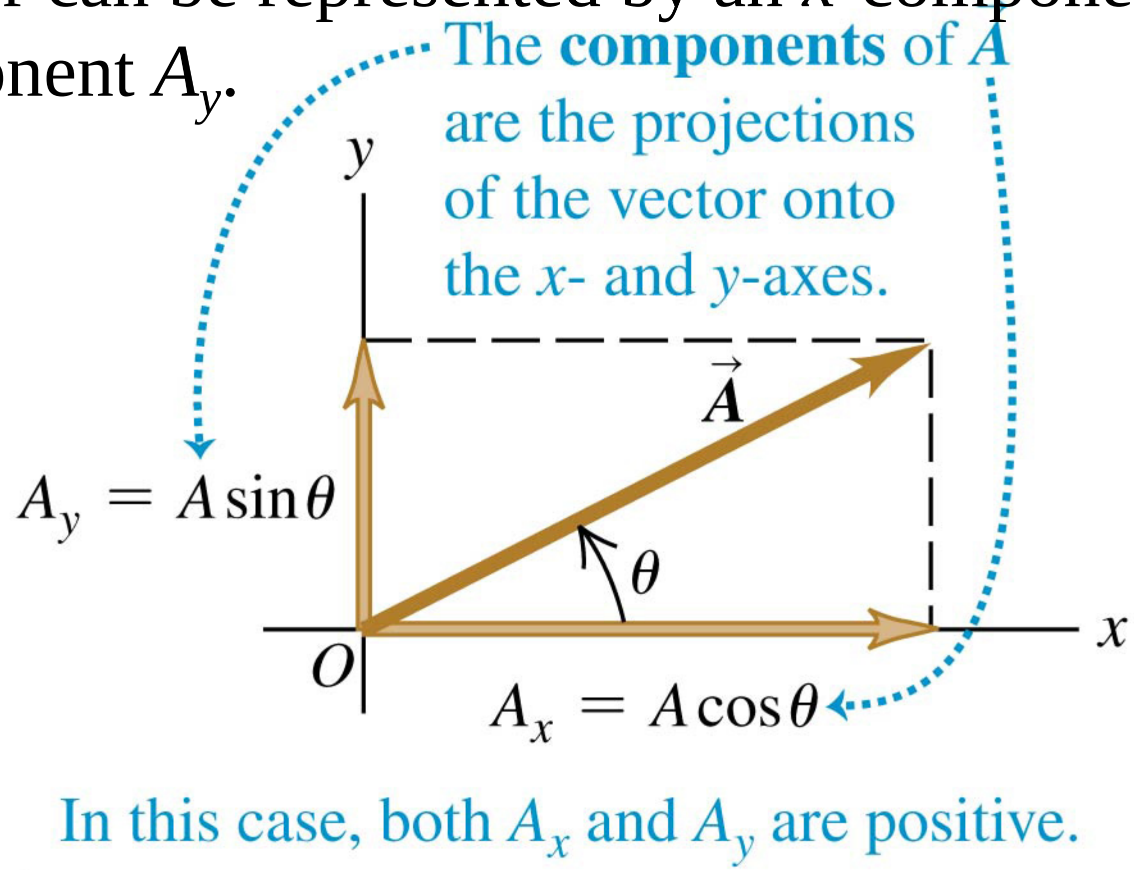


- Refresh your sin, cos, tan

Components of a vector

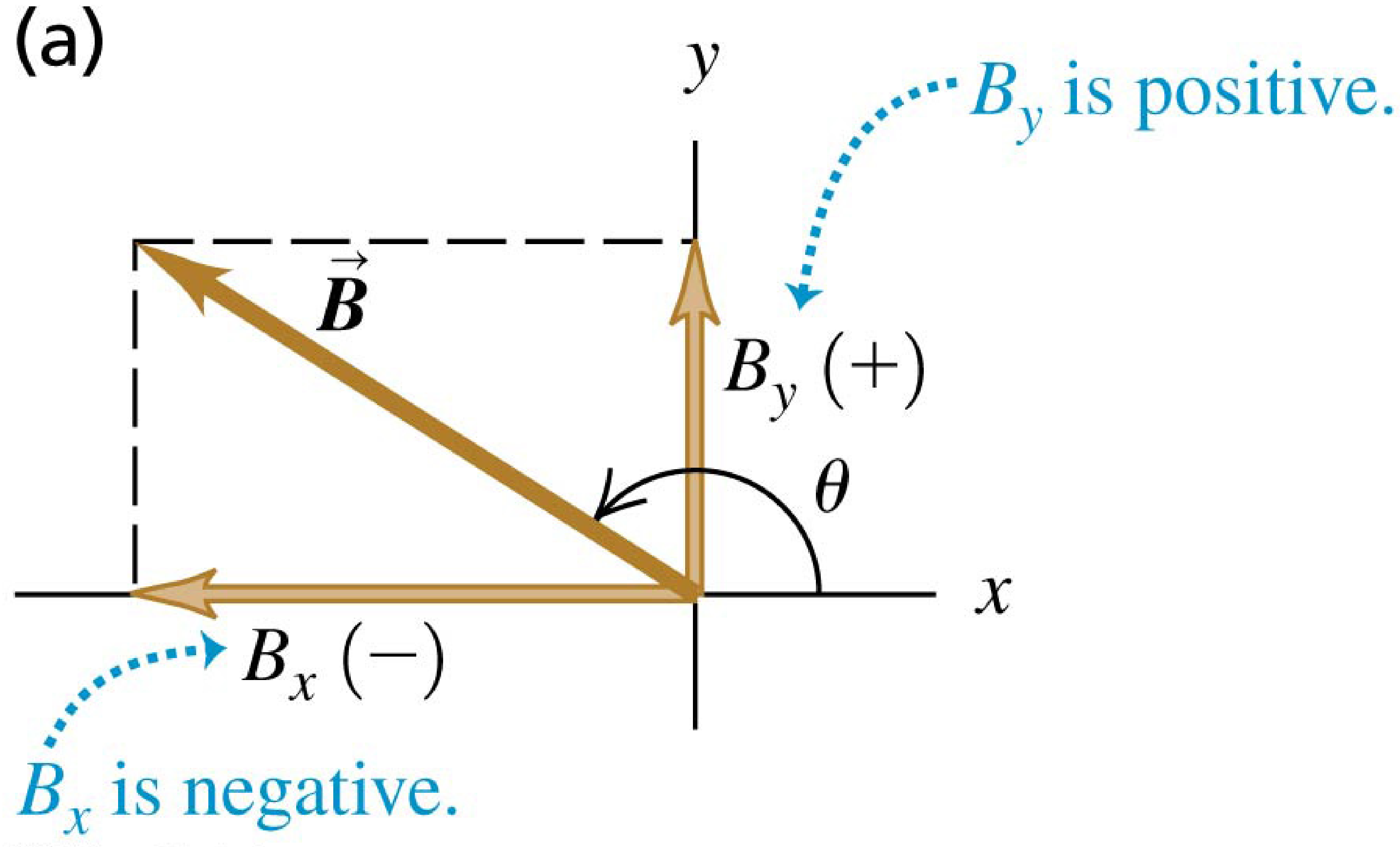
- Adding vectors graphically provides limited accuracy. Vector components provide a general method for adding vectors.

- Any vector can be represented by an x-component A_x and a y-component A_y.



Positive and negative components

- The components of a vector may be positive or negative numbers, as shown in the figures.



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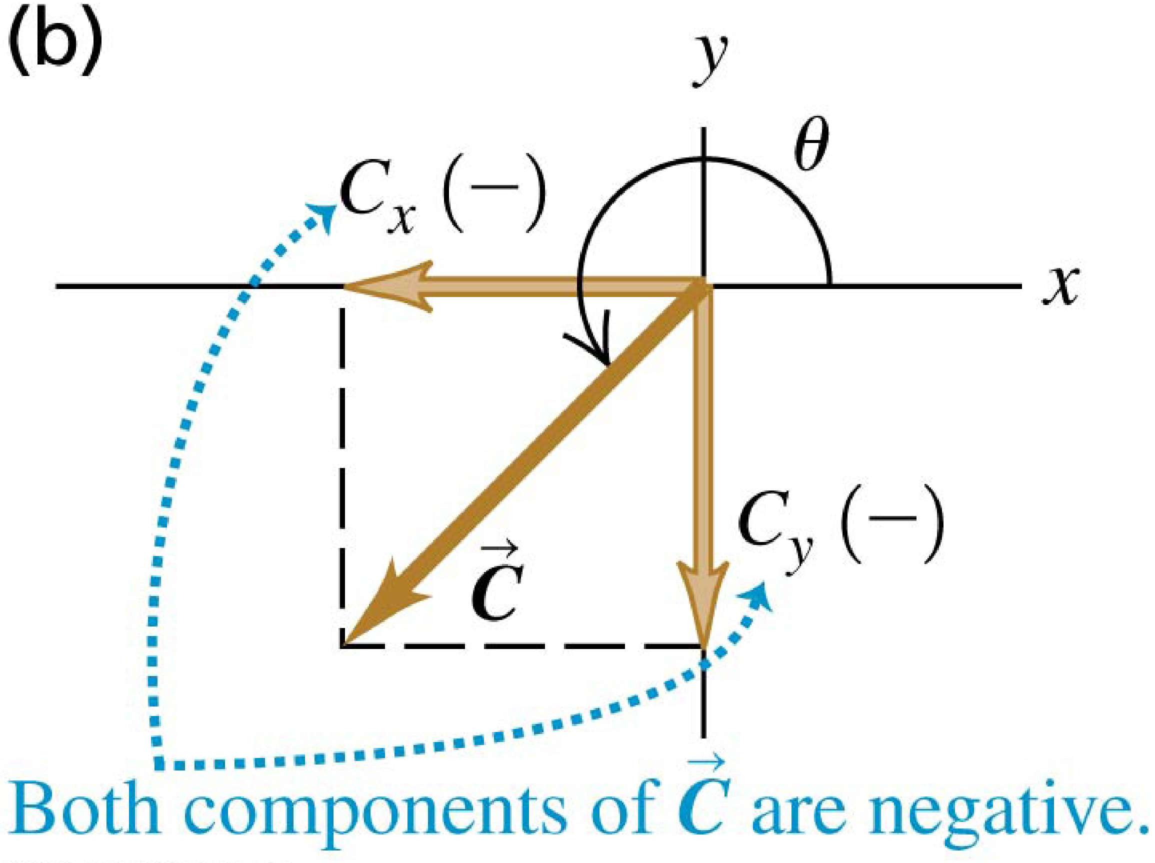
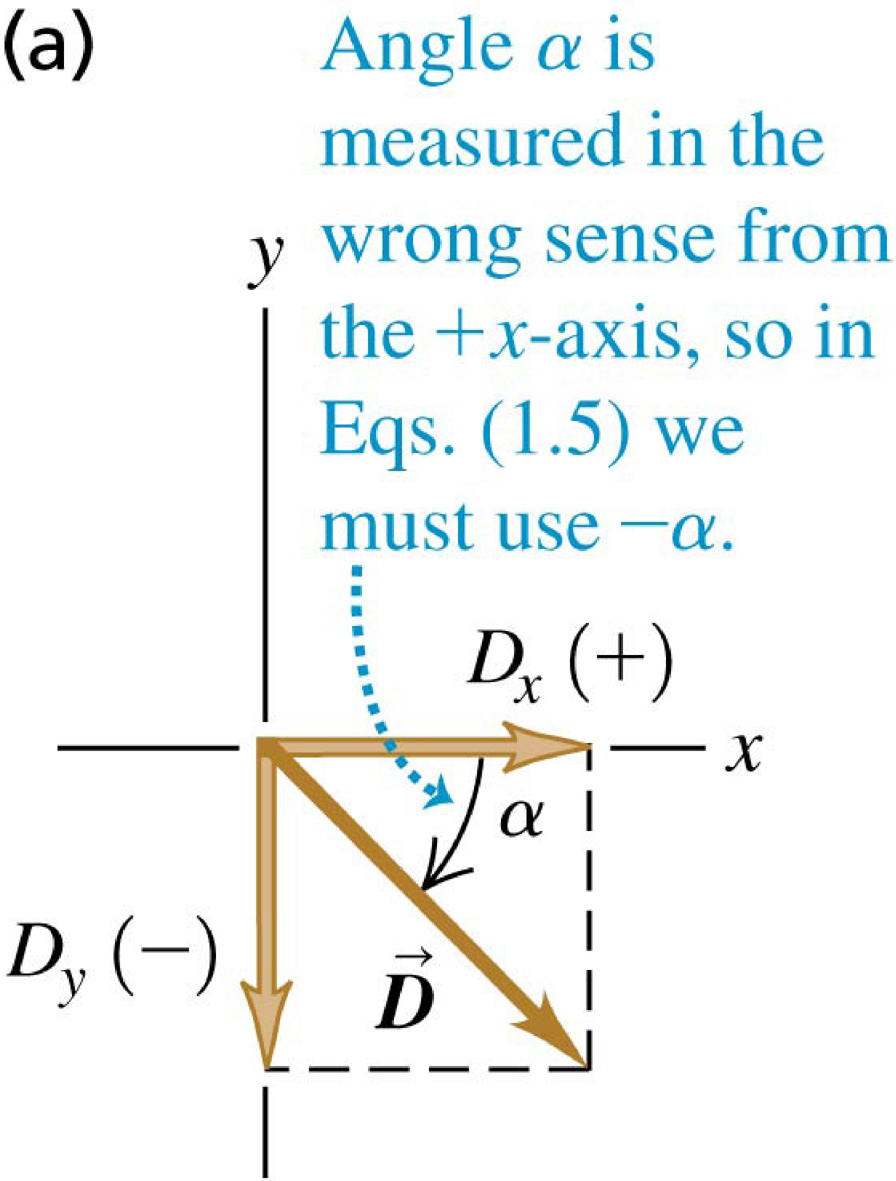


Finding components

- We can calculate the components of a vector from its magnitude and direction.



Finding components

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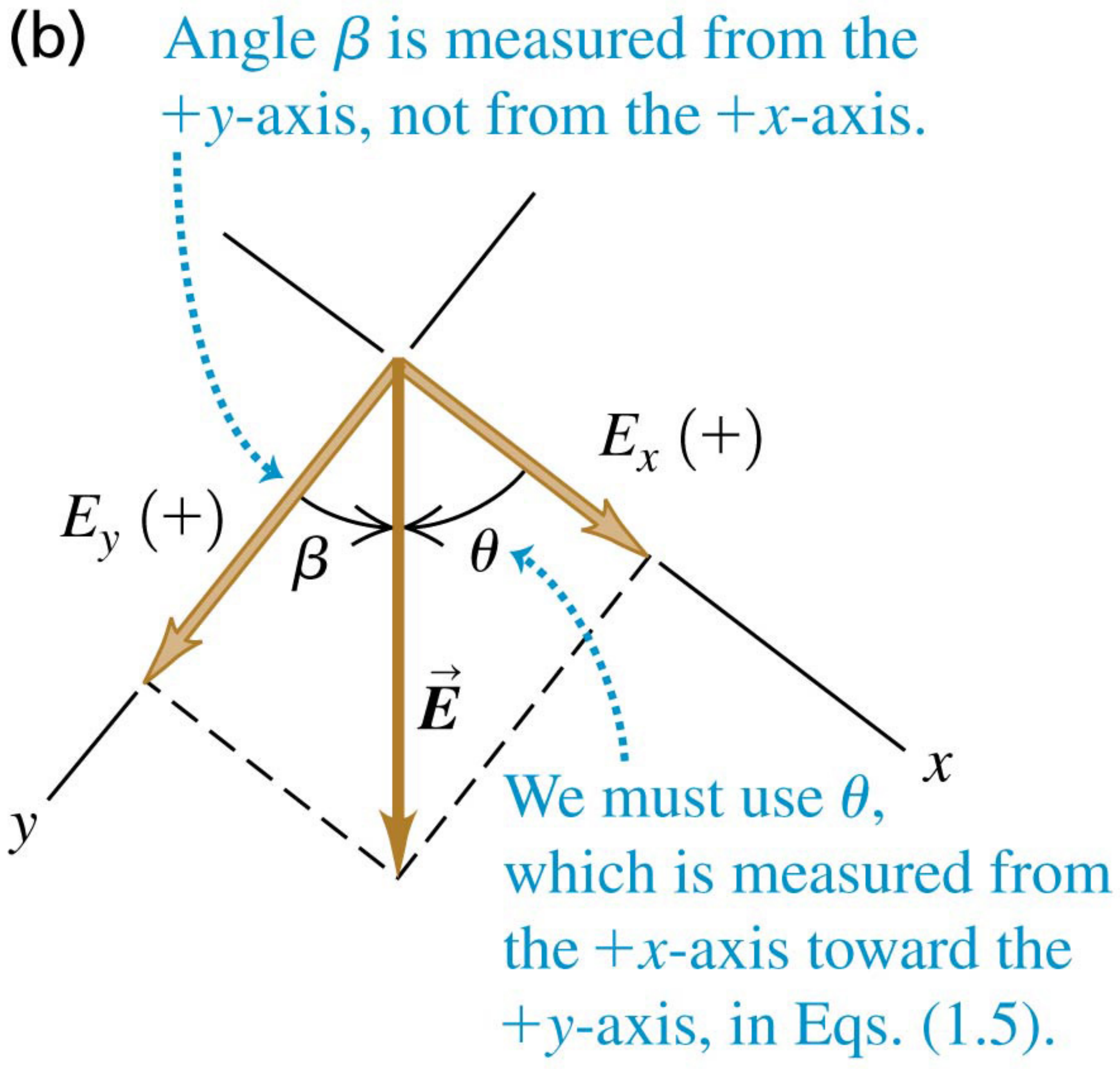
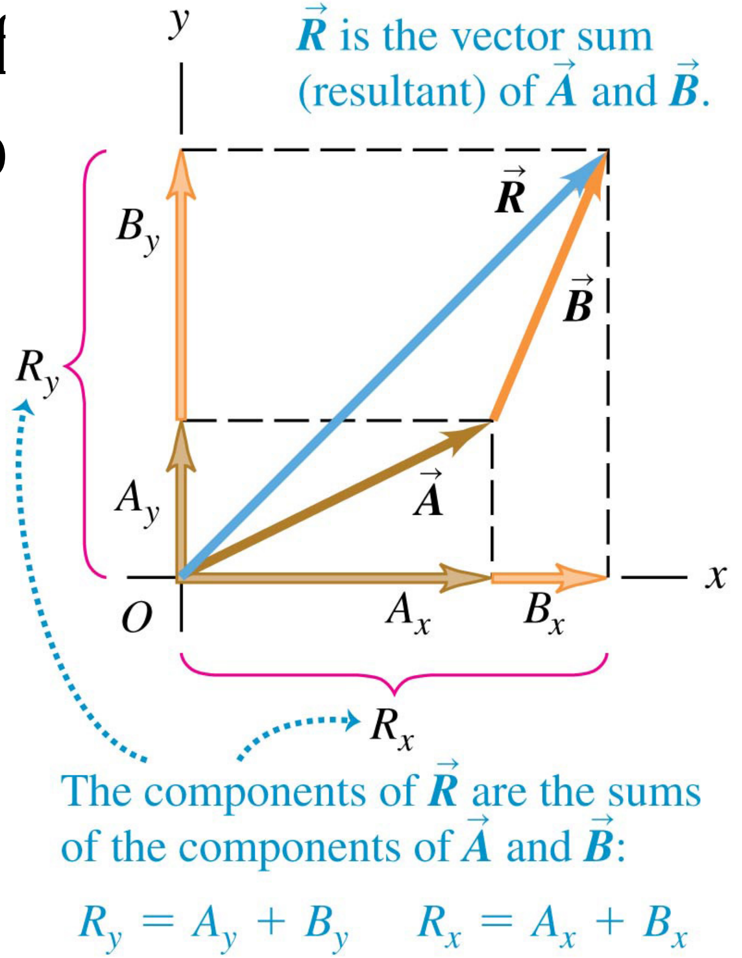


Calculations using components

- We can use the components of a vector to find its magnitude and direction: $A = \sqrt{A_x^2 + A_y^2}$ and $\tan\theta = \frac{A_y}{A_x}$
- We can use the components of a set of vectors to find the components of their sum:

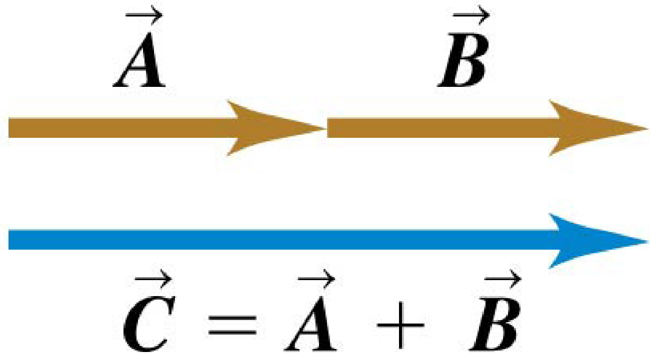
$$R_x = A_x + B_x + C_x + \cdots, \quad R_y = A_y + B_y + C_y + \cdots$$

- Refer to *Problem-Solving Strategy 1.3.*



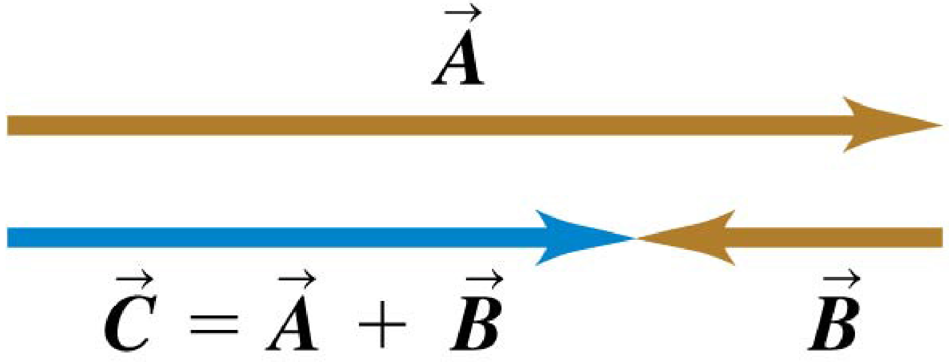
Adding two vectors graphically

(a) Only when vectors $\vec{A}$ and $\vec{B}$ are parallel does the magnitude of their vector sum $\vec{C}$ equal the sum of their magnitudes: $C = A + B$.



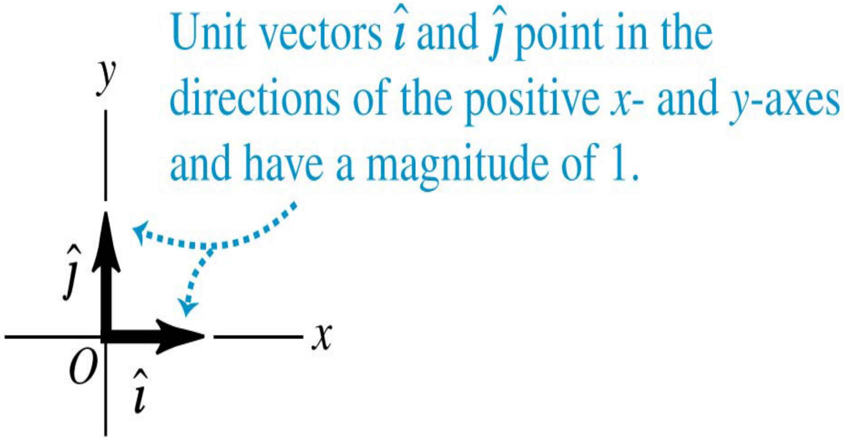
Adding two vectors graphically

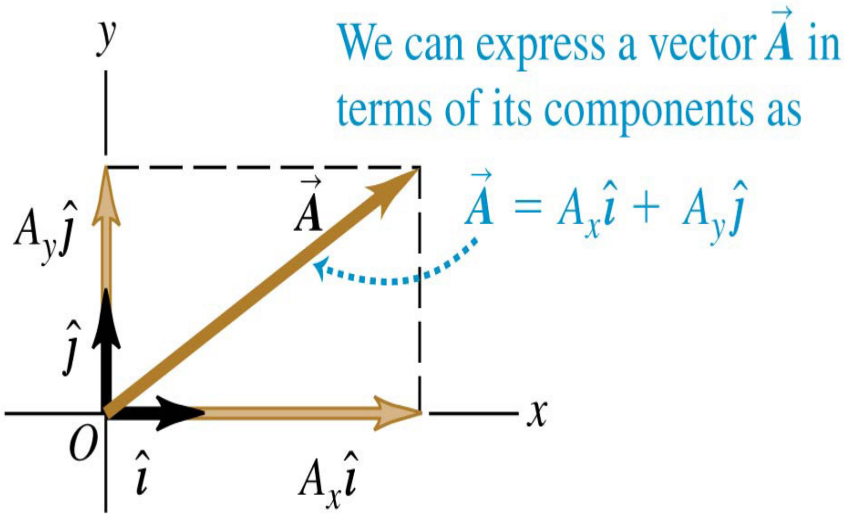
(b) When $\vec{A}$ and $\vec{B}$ are antiparallel, the magnitude of their vector sum $\vec{C}$ equals the *difference* of their magnitudes: $C = |A - B|$.



Unit vectors

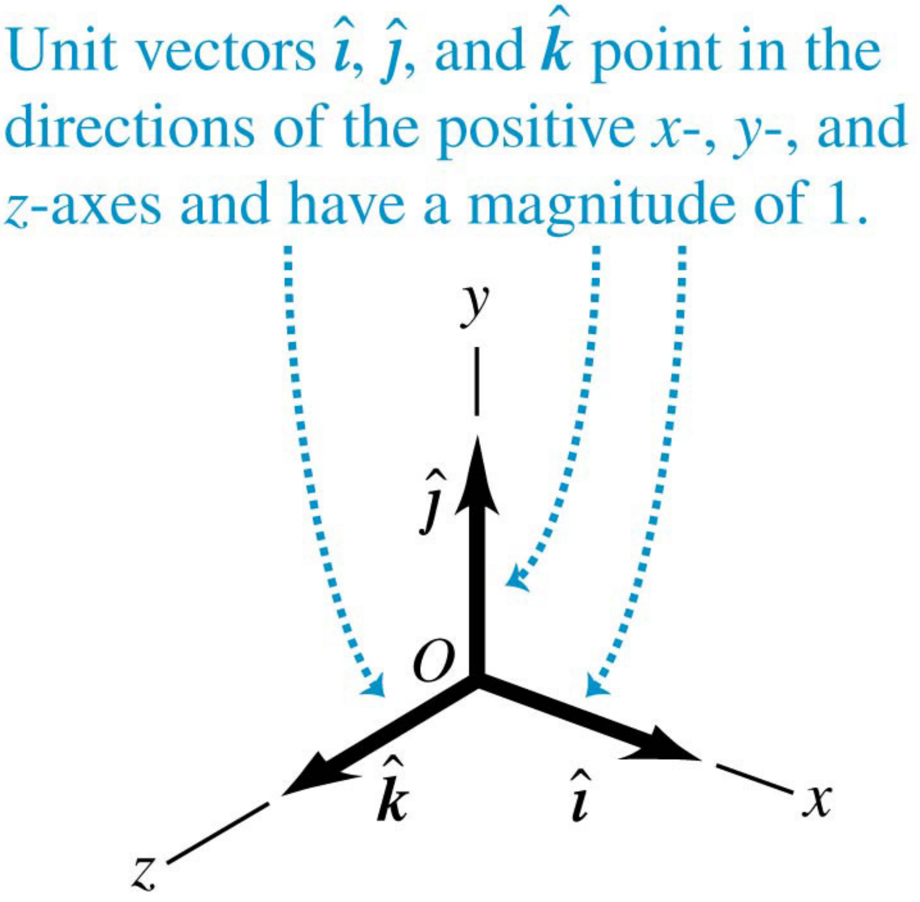
- A **unit vector** has a magnitude of 1 with no units.





Unit vectors

- A **unit vector** has a magnitude of 1 with no units.
- The unit vector $\hat{\boldsymbol{i}}$ points in the +*x*-direction, $\hat{\boldsymbol{j}}$ points in the +*y*-direction, and $\hat{\boldsymbol{k}}$ points in the +*z*-direction.
- Any vector can be expressed in terms of its components as $\vec{\boldsymbol{A}} = A_x\hat{\boldsymbol{i}} + A_y\hat{\boldsymbol{j}} + A_z\hat{\boldsymbol{k}}.$



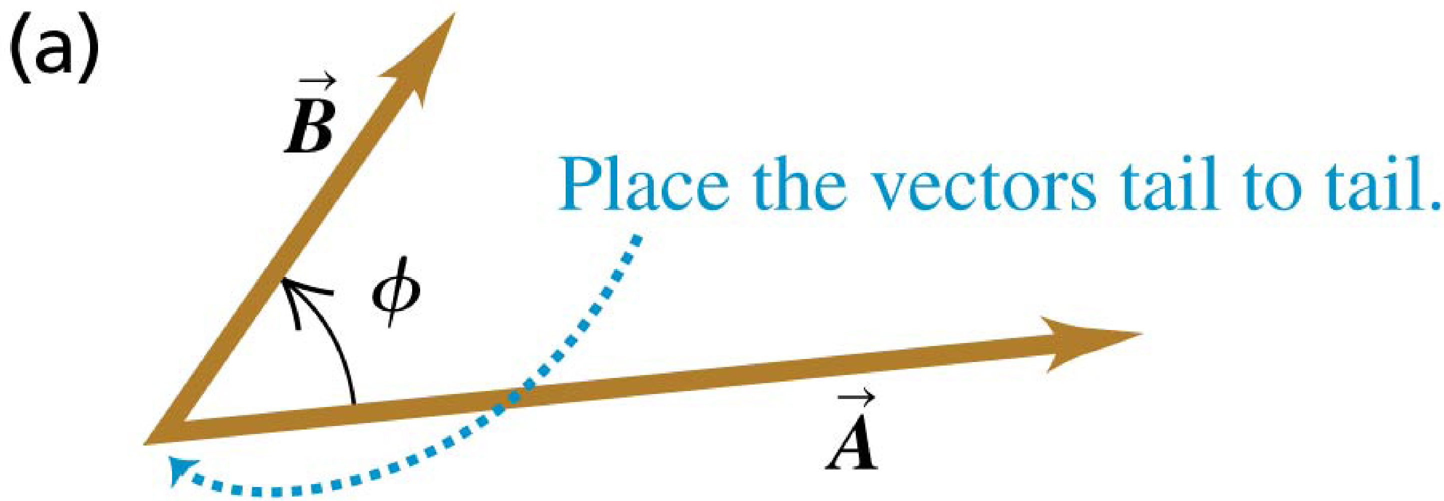
The scalar (dot) product

Scalar (dot) product of vectors $\vec{A}$ and $\vec{B}$

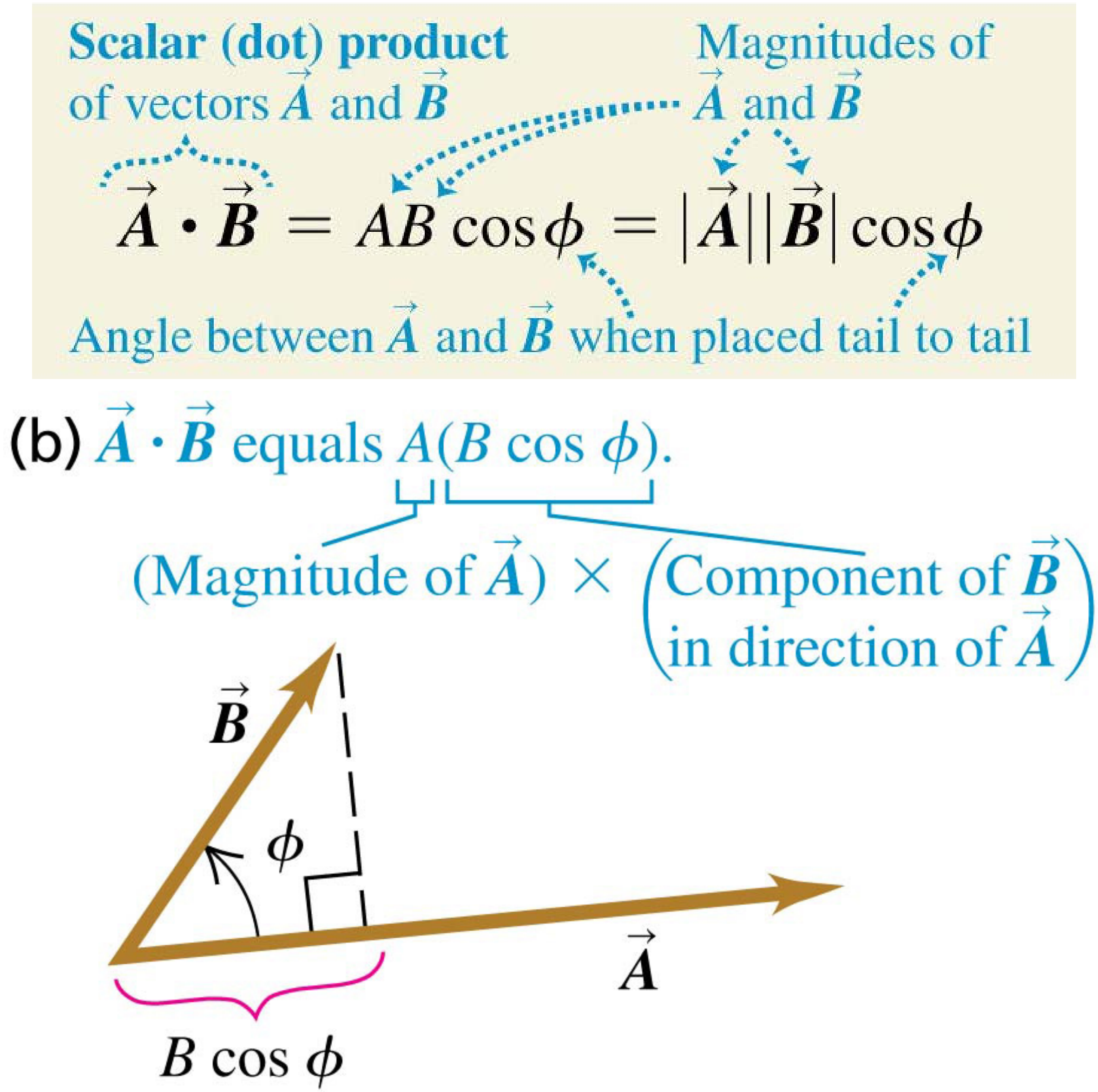
Magnitudes of $\vec{A}$ and $\vec{B}$

$$\vec{A} \cdot \vec{B} = AB\cos\phi = |\vec{A}||\vec{B}|\cos\phi$$

Angle between $\vec{A}$ and $\vec{B}$ when placed tail to tail



The scalar (dot) product



The scalar (dot) product: commutative!

Scalar (dot) product of vectors $\vec{A}$ and $\vec{B}$

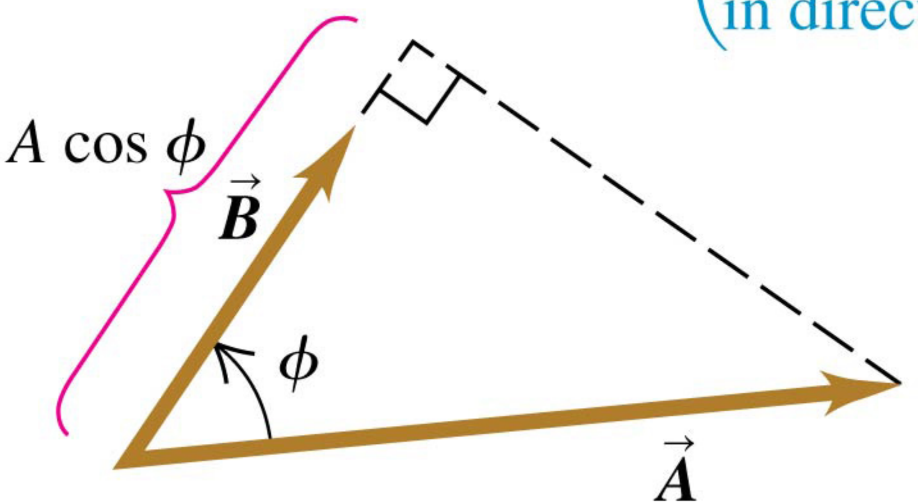
Magnitudes of $\vec{A}$ and $\vec{B}$

$$\vec{A} \cdot \vec{B} = AB\cos\phi = |\vec{A}||\vec{B}|\cos\phi$$

Angle between $\vec{A}$ and $\vec{B}$ when placed tail to tail

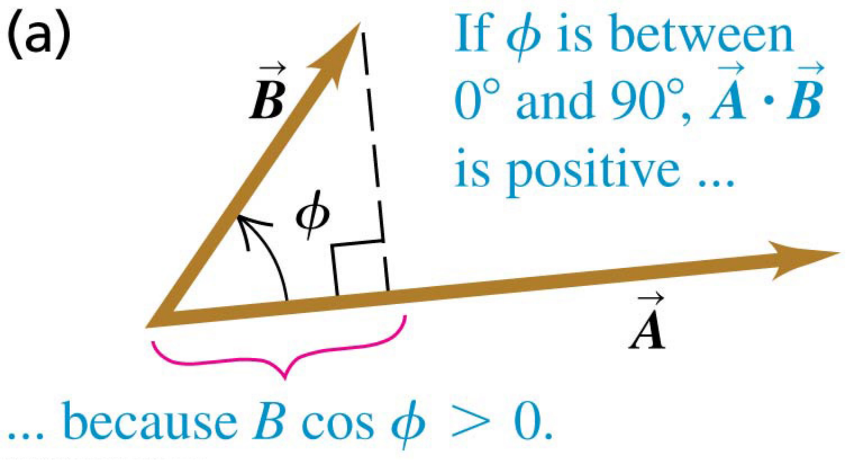
(c) $\vec{A} \cdot \vec{B}$ also equals $B(A\cos\phi)$.

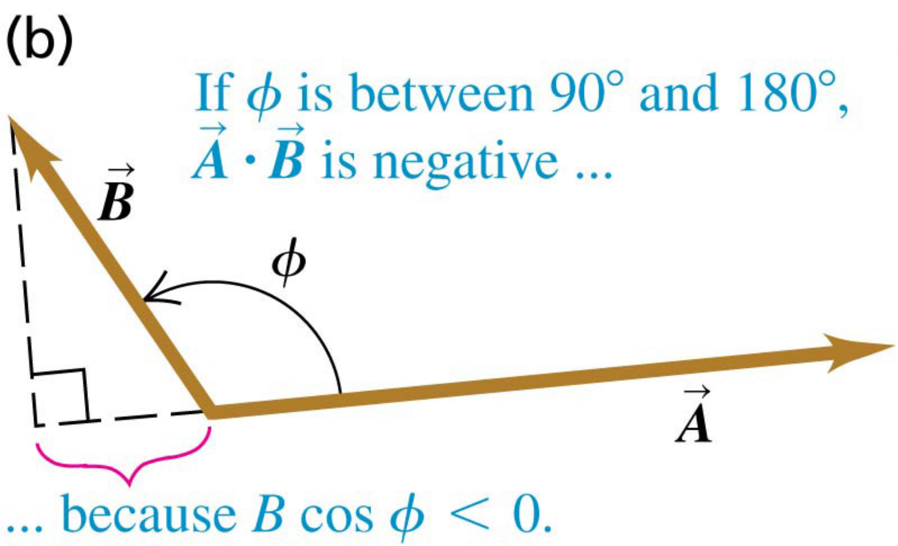
(Magnitude of $\vec{B}$) $\times$ (Component of $\vec{A}$ in direction of $\vec{B}$)

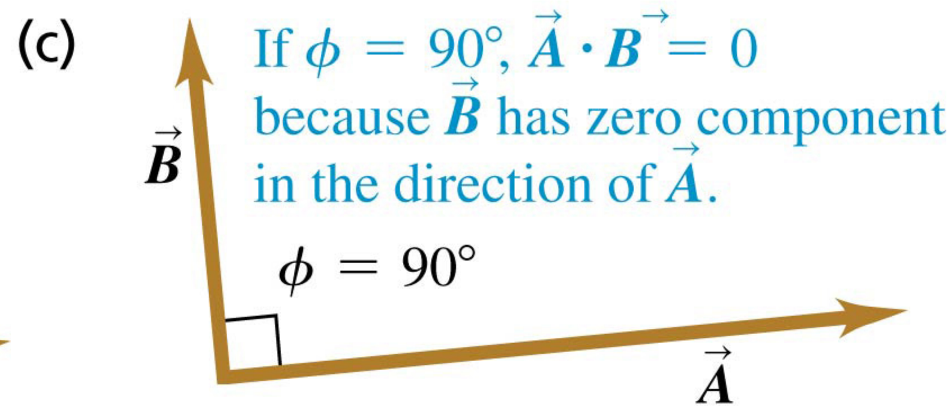


The scalar product: results in a scalar quantity

The scalar product can be positive, negative, or zero, depending on the angle between $\vec{A}$ and $\vec{B}$

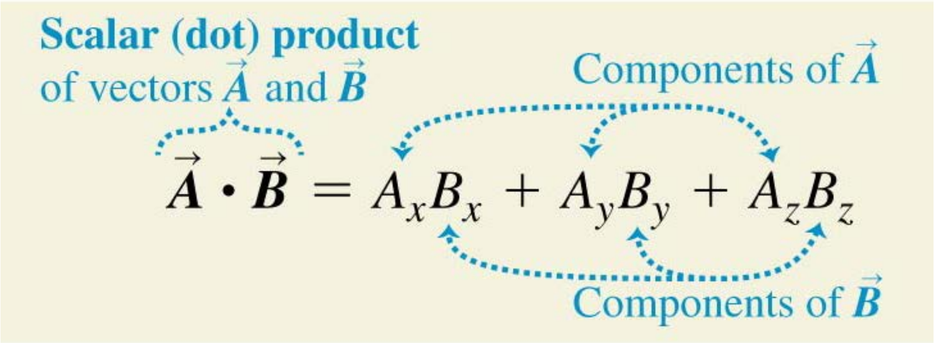






Calculating a scalar product using components

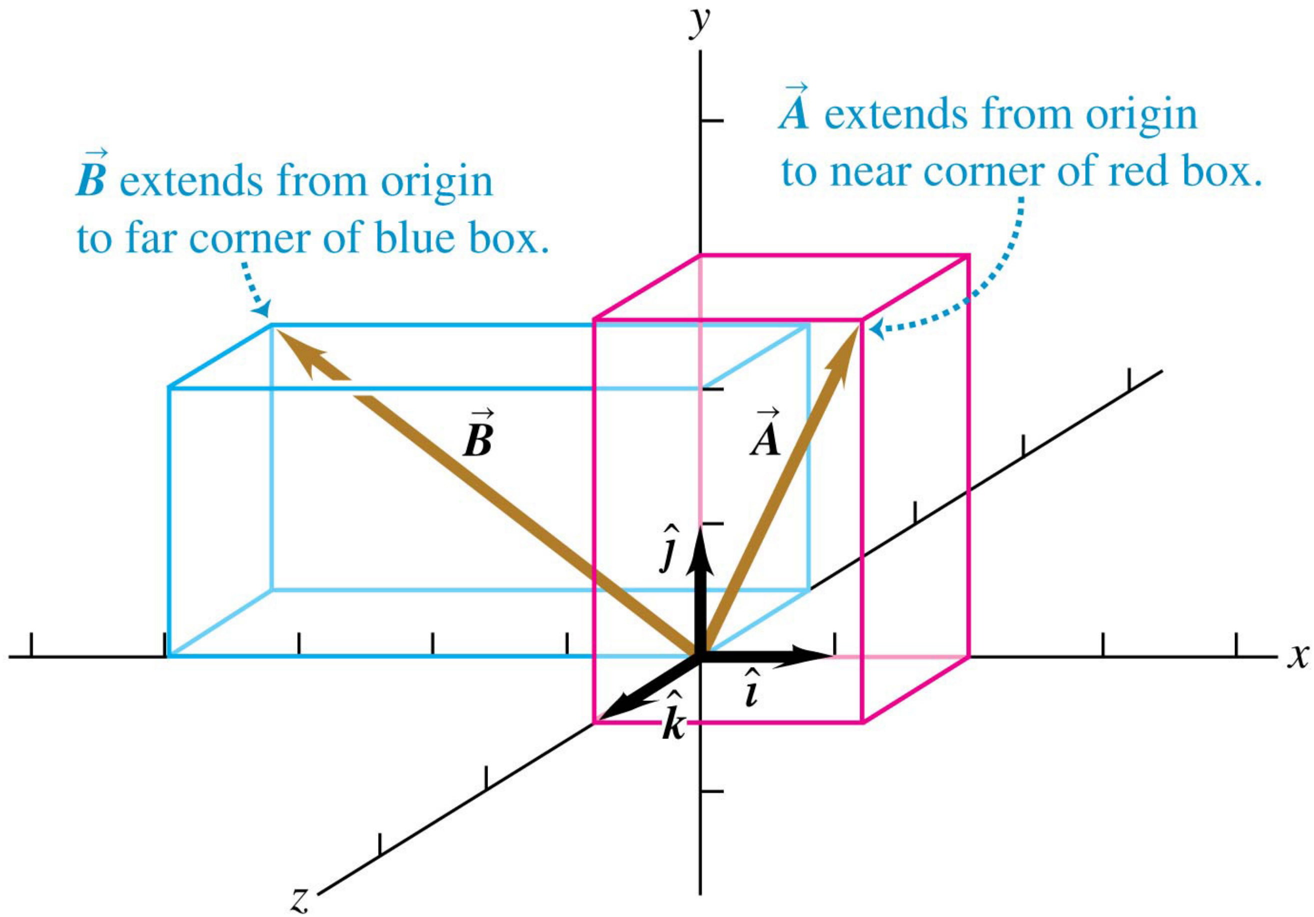
- In terms of components:



- The scalar product of two vectors is the sum of the products of their respective components.

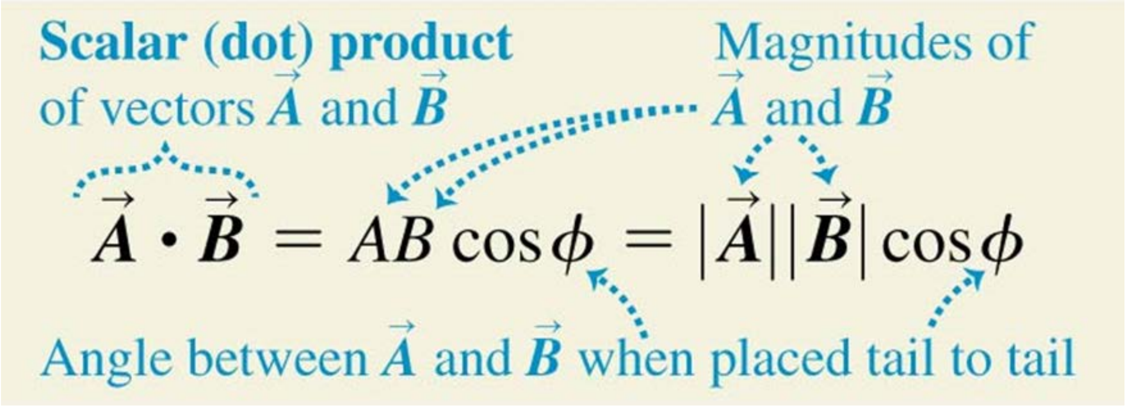
Finding an angle using the scalar product

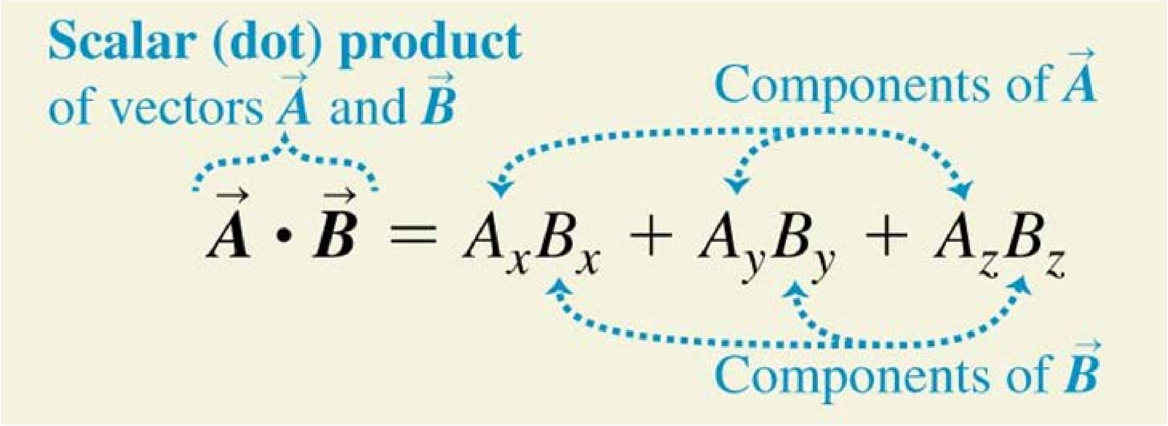
- Example 1.10 shows how to use components to find the angle between two vectors.



Finding an angle using the scalar product

- Example 1.10: knowing the magnitudes of both vectors and their components allows the angle between them to be determined.





The vector (cross) product

If the vector product ("cross product") of two vectors is $\vec{C} = \vec{A} \times \vec{B}$

Magnitude of **vector (cross) product** of vectors $\vec{B}$ and $\vec{A}$

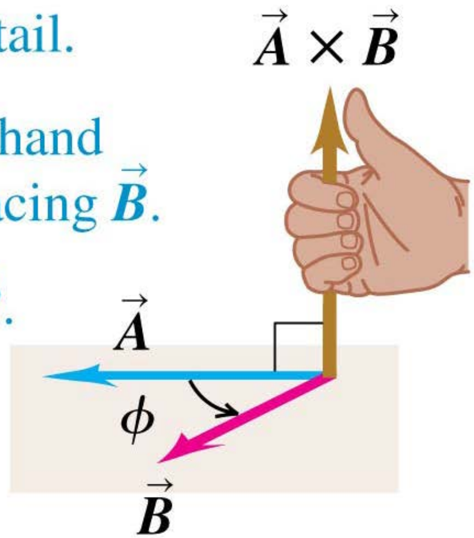
$$C = AB \sin\phi$$

Magnitudes of $\vec{A}$ and $\vec{B}$

Angle between $\vec{A}$ and $\vec{B}$ when placed tail to tail

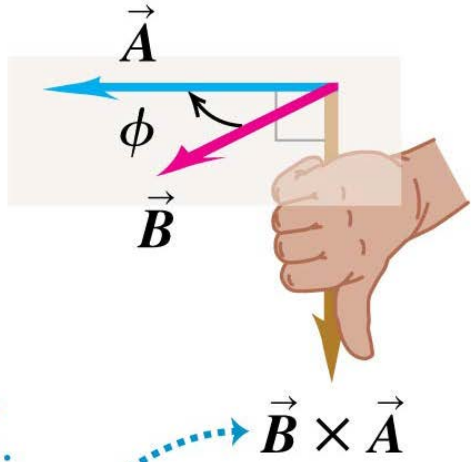
The direction of the vector product can be found using the right-hand rule:

1. Place $\vec{A}$ and $\vec{B}$ tail to tail.
2. Point fingers of right hand along $\vec{A}$, with palm facing $\vec{B}$.
3. Curl fingers toward $\vec{B}$.
4. Thumb points in direction of $\vec{A} \times \vec{B}$.



The vector product is anticommutative

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



1. Place $\vec{B}$ and $\vec{A}$ tail to tail.
2. Point fingers of right hand along $\vec{B}$, with palm facing $\vec{A}$.
3. Curl fingers toward $\vec{A}$.
4. Thumb points in direction of $\vec{B} \times \vec{A}$.
5. $\vec{B} \times \vec{A}$ has same magnitude as $\vec{A} \times \vec{B}$ but points in opposite direction.

Calculating the vector product

- Use $AB\sin\phi$ to find the magnitude and the right-hand rule to find the direction.
- The components of the vectors can also be used to determine the magnitude of the new vector (Equ 1.24).
- $C_x = A_y B_z - A_z B_y$
- $C_y = A_z B_x - A_x B_z$
- $C_z = A_x B_y - A_y B_x$