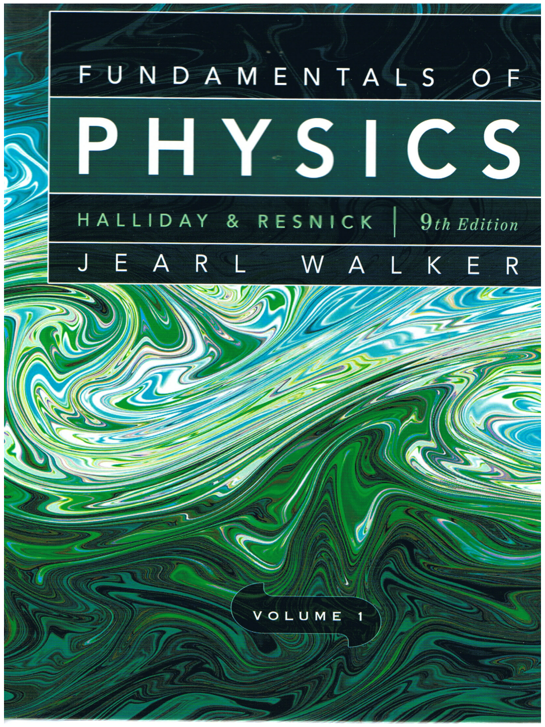
Chapter 1

Introduction

Introduction

- Why Study Physics?
- Scientific Method
- Physics Definitions
- Scientific Notation and Significant Figures
- Units and Conversions
- Problem Solving
- Mathematics
- Dimensional Analysis
- Graphs
- Vectors



Why Study Physics?

Physics is the foundation of every science (astronomy, biology, chemistry…).

Many pieces of technology and/or medical equipment and procedures are developed with the help of physicists.

Studying physics will help you develop good thinking skills, problem solving skills, and give you the background needed to differentiate between science and pseudoscience.

Scientific Classification

If its dead it's Biology

If it stinks it's Chemistry

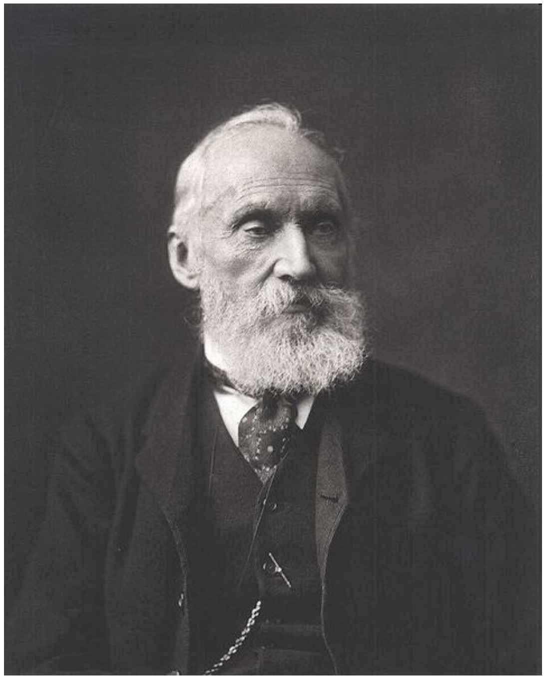
If it doesn't work it's Physics

Mathematics - The Language of Physics

"When you can measure what you are speaking about, and express it in numbers, you know something about it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts advanced to the stage of science."

Lord Kelvin

Lord Kelvin



William Thomson, 1st Baron Kelvin (or Lord Kelvin),

(26 June 1824 – 17 December 1907)

An Irish-born British mathematical physicist and engineer.

<u>Items Named for Kelvin</u>

Joule–Thomson effect
Thomson effect (thermoelectric)
Mirror galvanometer
Siphon recorder
Kelvin material
Kelvin water dropper
Kelvin wave
Kelvin–Helmholtz instability
Kelvin–Helmholtz mechanism
Kelvin–Helmholtz luminosity
Kelvin transform
Kelvin's circulation theorem
Kelvin bridge
Kelvin sensing
Kelvin equation
Magnetoresistance
Four-terminal sensing
Coining the term 'kinetic energy'

Lord Kelvin Quotes

"In science there is only physics; all the rest is stamp collecting."

"In physics, you don't have to go around making trouble for yourself - nature does it for you."

The Ones Lord Kelvin Got Wrong

- “Heavier-than-air flying machines are impossible.”
- "There is nothing new to be discovered in physics now, All that remains is more and more precise measurement.”
- "X-rays will prove to be a hoax.”
- "Radio has no future.”
- Writing to Niagara Falls Power Company: "Trust you will avoid the gigantic mistake of alternating current.”
- [The vector] "has never been of the slightest use to any creature."

Scientific Method

- Explain what we perceive in nature.
- At what level do we want to explain the phenomena
  - What do we include?
  - What do we leave out?
  - Only include the largest effects at first.
- Find the most appropriate <u>mathematical framework</u>

Scientific Method

The scientific method is a way to ask and answer scientific questions by making observations and doing experiments.

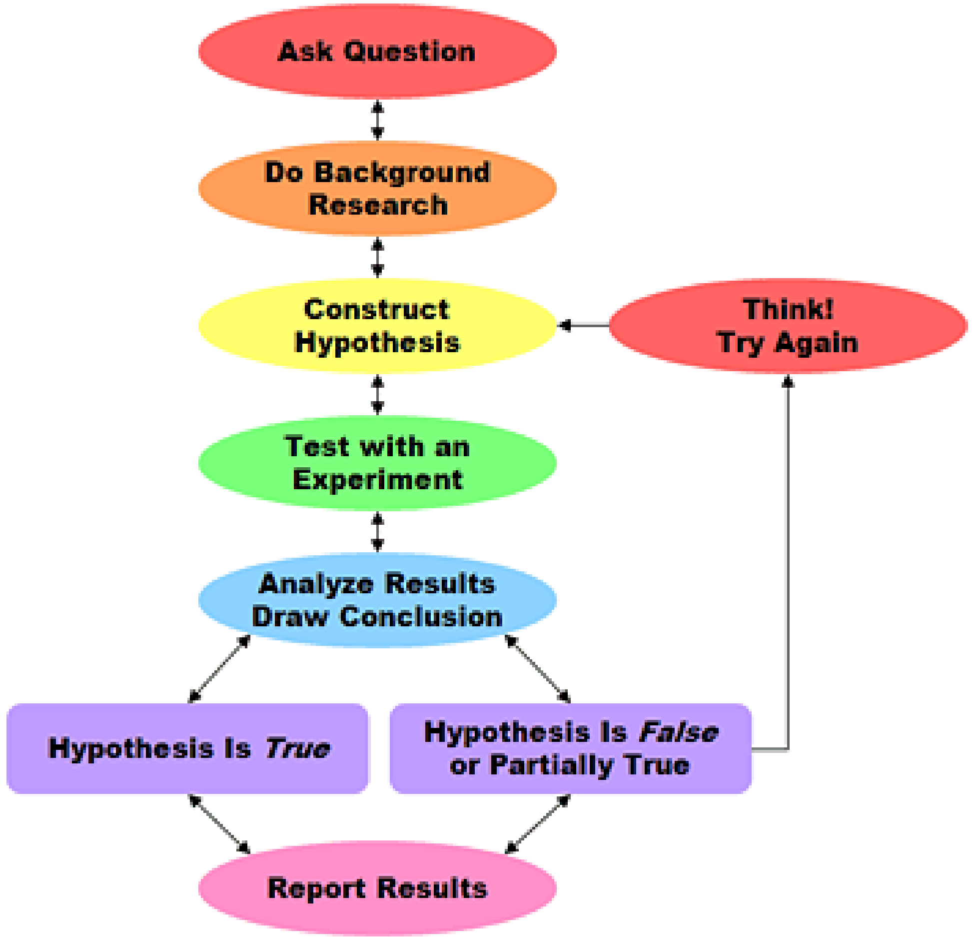
The steps of the scientific method are to:

- o Ask a Question
- o Do Background Research
- o Construct a Hypothesis
- o Test Your Hypothesis by Doing an Experiment
- o Analyze Your Data and Draw a Conclusion
- o Communicate Your Results

It is important for your experiment to be a fair test. A "fair test" occurs when you change only one factor (variable) and keep all other conditions the same.

http://www.sciencebuddies.org/mentoring/project_scientific_method.shtml

Scientific Method



http://www.sciencebuddies.org/mentoring/project_scientific_method.shtml

Scientific Method

As soon as a theory is established scientists start to investigate how far it can be stretched:

- smaller dimensions,
- larger dimensions,
- larger and smaller masses.

Theories are accepted as correct according to the currently available data but are also tested on new data as it becomes available

New Hypothesis?

Since we ignored some of the smaller phenomena in creating our theory we should expect ***some disagreement*** when our experimental conditions take us into a region of experimental space where those ignored phenomena might be important.

In the beginning we might try to make ***small corrections*** to the theory so that we can remove some of the smaller areas of disagreement.

If the list of disagreements gets too long or one or more experiments produce large disagreements then our theory is in trouble.

The New Hypothesis

An improved theory is needed.

However, our earlier theory did explain some phenomena so any new theory will be required to reproduce those older results in the region where our theory was correct.

In other words our earlier theory will need to be a limiting case of any new theory that is proposed.

The New Hypothesis

Direction for a new theory

- Simple is better, few adjustable parameters
- Equations have an element of beauty
    - The most beautiful equation is the right one
    - However, beauty can be in the eye of the beholder.

Not All Follow the Method

Discoveries are not always that orderly but can benefit from luck, accidents and a prepared mind.

X-Rays were discovered when leaks in shielding exposed some nearby photographic plates.

Cosmic Background Radiation was discovered when trying to eliminate electrical noise in telephone transmission equipment.

Physics Definitions

Be aware that physicists have their own precise definitions of some words that are different from their common English language definitions.

Examples:

Speed and velocity are no longer synonymous;

Acceleration is a change of speed ***or*** direction.

A general solution to an equation applies ALL the time and not MOST of the time.

Scientific Notation

This is a shorthand way of writing very large and/or very small numbers.

.0000456 ==> 4.56×10^{-5} or 4.56E-05

1,236,000 ==> $1.236 \times 10^{+6}$ or 1.236E+06

Sometimes we will violate this convention if we find it convenient

Significant Figures

Significant figures answers the question of how many digits we can and should keep in our measurements and calculations.

1. Nonzero digits are always significant.
2. Final ending zeroes written to the right of the decimal are significant. (Example: 7.00.)
3. Zeroes that are placeholders are not significant. (Example: 700,000 versus 700,000.0.)
4. Zeroes written between digits are significant. (Example: 105,000; 150,000.)

Units

Some of the standard SI unit prefixes and their respective powers of 10.

Prefix	Power of 10	Prefix	Power of 10
tera (T)	10^{12}	centi (c)	10^{-2}
giga (G)	10^{9}	milli (m)	10^{-3}
mega (M)	10^{6}	micro (μ)	10^{-6}
kilo (k)	10^{3}	nano (n)	10^{-9}

The quantities in this column are based on an agreed upon standard.

Table 1.1 SI Base Units

Quantity	Unit Name	Symbol	Definition
Length	meter	m	The distance traveled by light in vacuum during a time interval of 1/299 792 458 s.
Mass	kilogram	kg	The mass of the international prototype of the kilogram.
Time	second	s	The duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.
Electric current	ampere	A	The constant current in two long, thin, straight, parallel conductors placed 1 m apart in vacuum that would produce a force on the conductors of 2×10^{-7} N per meter of length.
Temperature	kelvin	K	The fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
Amount of substance	mole	mol	The amount of substance that contains as many elementary entities as there are atoms in 0.012 kg of carbon-12.
Luminous intensity	candela*	cd	The luminous intensity, in a given direction, of a source that emits radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watts per steradian.

*Not used in this book

Levels of Understanding in Problem Solving

- Conceptually - Ability to see through the problem to see the nature of the solution.
- Mathematically - Ability to analyze the mathematical nature of the problem and to arrive at an algebraic solution.
- Numerical - Ability to calculate the numerical solution to a particular problem.

Problem Solving Techniques

- Read the problem thoroughly - what is the question(s).
- Diagram -Complete, properly labeled and large enough to be useful.
- List the given information
- What is unknown?
- State the starting principle or equation.
- Solve the problem algebraically. It is <u>easier</u> to catch mistakes.
- Calculate the end result. Don't forget units!
- Check your answer for reasonableness.

Problem Solving Requirements

You should be able to tell what the problem was without going back to the text.

The variables in your equations should match the labels in your diagram.

The problems should be self contained and detailed enough so that you can use them to study for the exams.

Mathematics Guide
Undergraduate Level

http://superstringtheory.com/math/index.html

The language of physics is mathematics. In order to study physics seriously, one needs to learn mathematics that took generations of brilliant people centuries to work out. Algebra, for example, was cutting-edge mathematics when it was being developed in Baghdad in the 9th century. But today it's just the first step along the journey.

Algebra

Algebra provides the first exposure to the use of variables and constants, and experience manipulating and solving linear equations of the form $y = ax + b$ and quadratic equations of the form $y = ax2+bx+c$.

Geometry

Geometry at this level is two-dimensional Euclidean geometry, Courses focus on learning to reason geometrically, to use concepts like symmetry, similarity and congruence, to understand the properties of geometric shapes in a flat, two-dimensional space.

Mathematics Guide
Undergraduate Level

http://superstringtheory.com/math/index.html

Trigonometry

Trigonometry begins with the study of right triangles and the Pythagorean theorem. The trigonometric functions sin, cos, tan and their inverses are introduced and clever identities between them are explored.

Calculus (single variable)

Calculus begins with the definition of an abstract functions of a single variable, and introduces the ordinary derivative of that function as the tangent to that curve at a given point along the curve. Integration is derived from looking at the area under a curve,which is then shown to be the inverse of differentiation.

Calculus (multivariable)

Multivariable calculus introduces functions of several variables f(x,y,z...), and students learn to take partial and total derivatives. The ideas of directional derivative, integration along a path and integration over a surface are developed in two and three dimensional Euclidean space.

Mathematics Guide
Undergraduate Level

http://superstringtheory.com/math/index.html

Analytic Geometry

Analytic geometry is the marriage of algebra with geometry. Geometric objects such as conic sections, planes and spheres are studied by the means of algebraic equations. Vectors in Cartesian, polar and spherical coordinates are introduced.

Linear Algebra

In linear algebra, students learn to solve systems of linear equations of the form ai1 x1 + ai2 x2 + ... + ain xn = ci and express them in terms of matrices and vectors. The properties of abstract matrices, such as inverse, determinant, characteristic equation, and of certain types of matrices, such as symmetric, antisymmetric, unitary or Hermitian, are explored.

Ordinary Differential Equations

This is where the physics begins! Much of physics is about deriving and solving differential equations. The most important differential equation to learn, and the one most studied in undergraduate physics, is the harmonic oscillator equation, ax'' + bx' + cx = f(t), where x' means the time derivative of x(t).

Mathematics Guide
Undergraduate Level

http://superstringtheory.com/math/index.html

Partial Differential Equations

For doing physics in more than one dimension, it becomes necessary to use partial derivatives and hence partial differential equations. The first partial differential equations students learn are the linear, separable ones that were derived and solved in the 18th and 19th centuries by people like Laplace, Green, Fourier, Legendre, and Bessel.

Methods of approximation

Most of the problems in physics can't be solved exactly in closed form. Therefore we have to learn technology for making clever approximations, such as power series expansions, saddle point integration, and small (or large) perturbations.

Probability and statistics

Probability became of major importance in physics when quantum mechanics entered the scene. A course on probability begins by studying coin flips, and the counting of distinguishable vs. indistinguishable objects. The concepts of mean and variance are developed and applied in the cases of Poisson and Gaussian statistics.

Dimensional Analysis

Dimensions are *basic types* of quantities that can be measured or computed. Examples are length, time, mass, electric current, and temperature.

Dimensional analysis was developed by the 19th century French mathematician Joseph Fourier, based on the idea that the physical laws like F = ma should be *independent* of the units employed to measure the physical variables.

A dimensional equation can have the dimensions reduced or eliminated through non-dimensionalization, which begins with **dimensional analysis**, and involves scaling quantities by *characteristic units* of a system or *natural units* of nature. This gives insight into the fundamental properties of the system.

Dimensional Analysis

More importantly, dimensional analysis is being used to find the *characteristic time* in the case of the pendulum. The characteristic time is the fundamental time scale over which "pendulum events" take place.

All intervals of time are considered small or large compared to this characteristic time.

NOTE: The pendulum is an example of a simple harmonic oscillator (SHO) if we restrict its angle of movement to less than 15^o.

The characteristic time associated with its motion is its period. The inverse of this period is the pendulum's frequency. Some SHO's have more than one frequency, the pendulum has only one.

Dimensional Analysis

Example: Use dimensional analysis to determine how the period of a pendulum depends on mass, the length of the pendulum, and the acceleration due to gravity (here the units are distance/time^2).

The period of a pendulum is how long it takes to complete 1 swing; the dimensions are time [T].

Mass of the pendulum [kg]

Length of the pendulum [m]

Acceleration of gravity [m/s^2]

The basic exercise is to find out how many combinations of these variables will yield a new variable with the unit of time (sec.)

Dimensional Analysis

Mass of the pendulum [kg]

Length of the pendulum [m]

Acceleration of gravity [m/s^2]

$$T = m^a L^b g^c$$

$$s = (kg)^a (m)^b (m/s^2)^c$$

$$s = (kg)^a m^b (m^c) s^{-2c}$$

$$s = (kg)^a m^{b+c} s^{-2c}$$

Comparing exponents on both sides of the equation yields these relationships

$a = 0$

$b + c = 0$

$-2c = 1$

Soln: $a = 0$; $b = 1/2$; $c = -1/2$

Dimensional Analysis

$$T = m^0 L^{0.5} g^{-0.5} = \sqrt{L/g}$$

Dimensional analysis can only determine the relationship up to within a multiplicative constant. The full equation is shown below.

$$T = 2\pi\sqrt{L/g}$$

Approximations

All of the problems that we will do this semester will be an approximation of reality. We will use models of how things work to compute our desired results.

Examples: For $\Theta << 1$

$$sin\Theta \approx \Theta$$

$$cos\Theta \approx 1$$

The more effects we include, the more correct our results will be.

And the more complex will be our formulas!

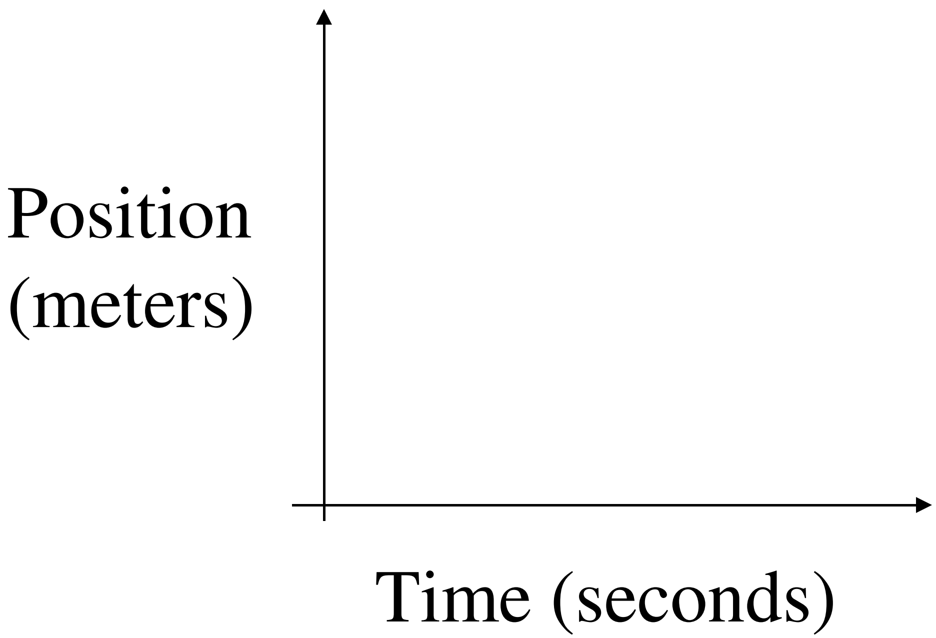
Graphs

Experimenters vary one quantity (the independent variable) and measure another quantity (the dependent variable).

Dependent variable here

Independent variable here

Be sure to label the axes with both the quantity and its unit. For example: Position versus Time



Example: A nurse recorded the values shown in the table for a patient's temperature. Plot a graph of temperature versus time and find

(a) the patient's temperature at noon,

(b) the slope of the graph, and

(c) would you expect the graph to follow the same trend over the next 12 hours? Explain.

The given data:

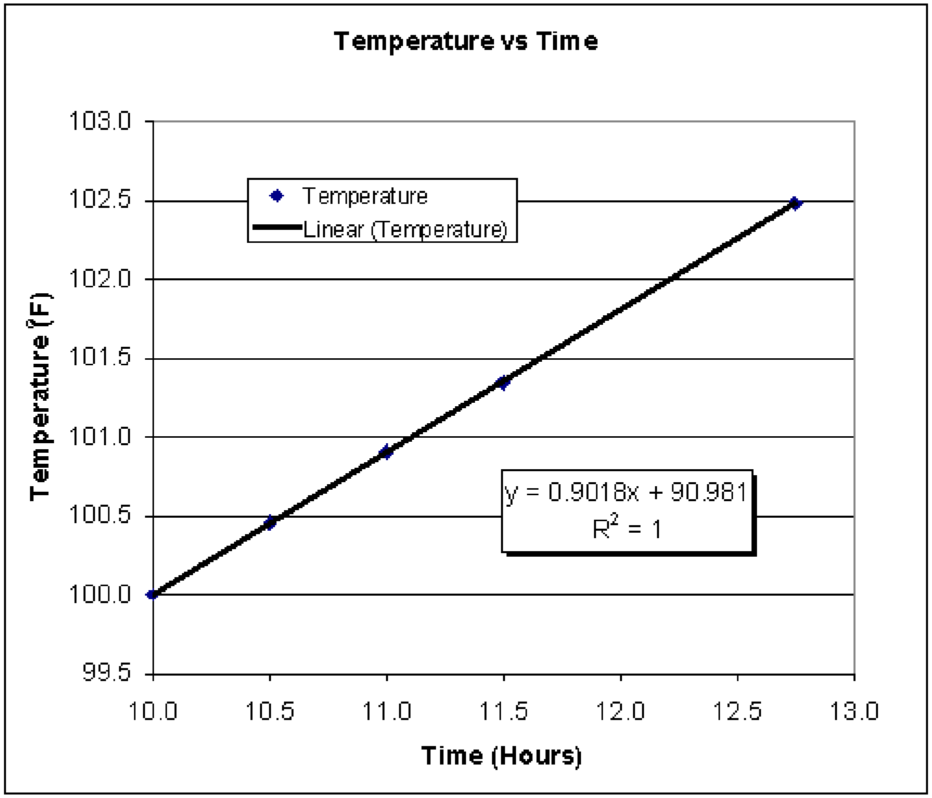
Time	Decimal time	Temp (°F)
10:00 AM	10.0	100.00
10:30 AM	10.5	100.45
11:00 AM	11.0	100.90
11:30 AM	11.5	101.35
12:45 PM	12.75	102.48

Graphing Example from Excel

Time	Decimal Time	Temp (°F)
10:00	10.00	100.00
10:30	10.50	100.45
11:00	11.00	100.90
11:30	11.50	101.35
12:45	12.75	102.48

	Slope	Y-Intercept
Average	0.9018	90.9810
Std Dev	0.0006	0.0073

Statistics from the worksheet
Function LINEST



X-Y Scatter Chart

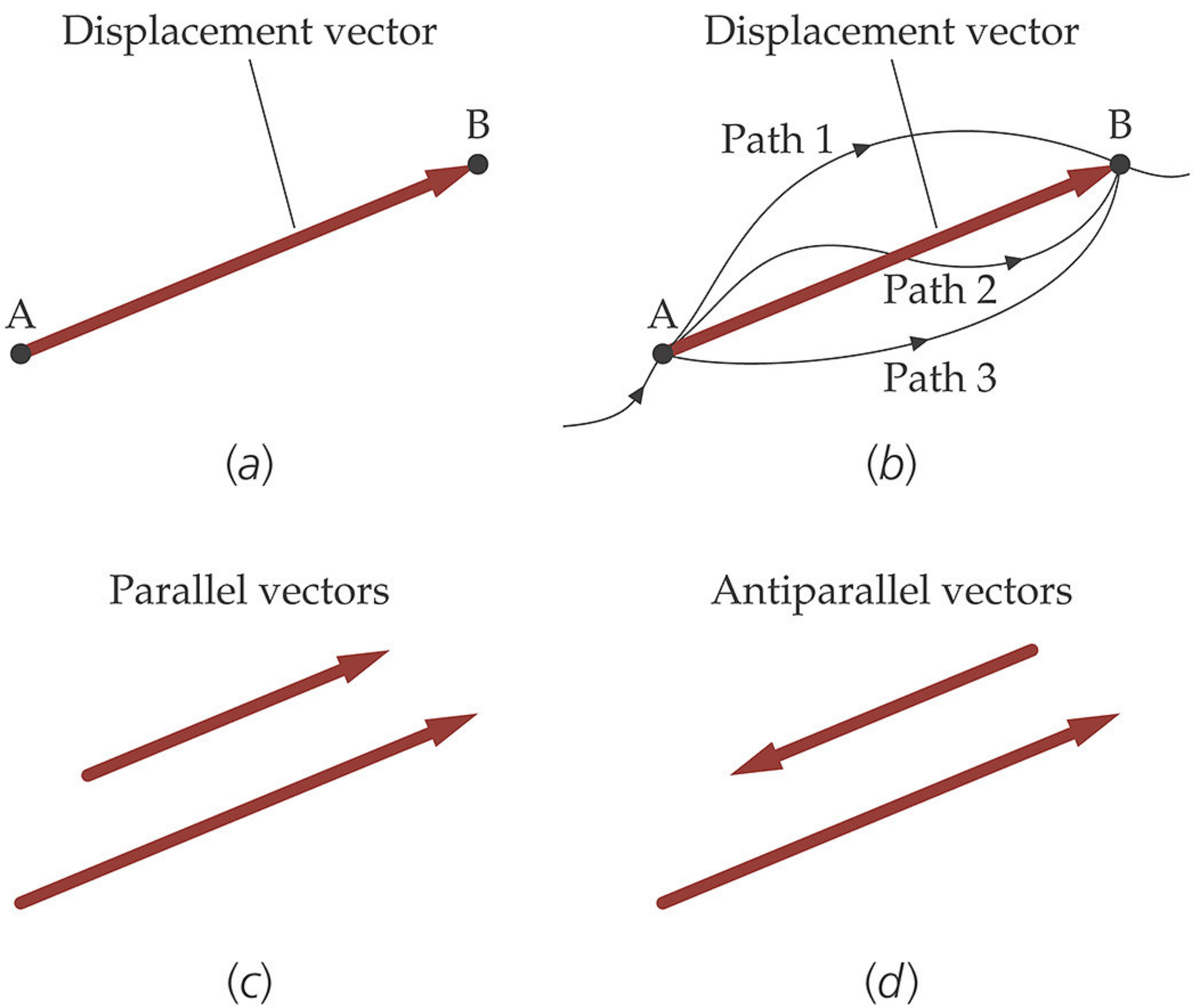
(a) Reading from the graph: 101.8 °F.

(b) $$\text{slope} = \frac{T_2 - T_1}{t_2 - t_1} = \frac{101.8\ °\text{F} - 100.0\ °\text{F}}{12.0\ \text{hr} - 10.0\ \text{hr}} = 0.9\ °\text{F/hour}$$

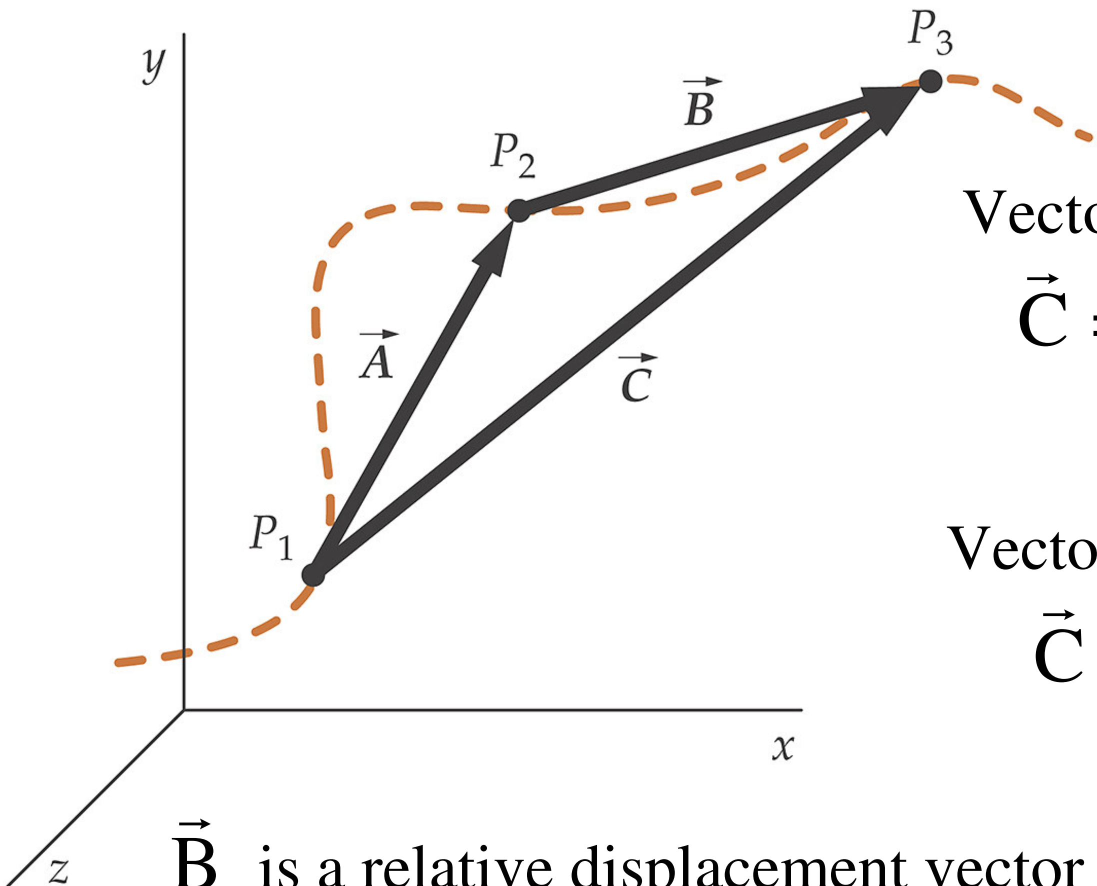
(c) No.

Working with Vectors

Types of Vectors



Relative Displacement Vectors



Vector Addition

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

Vector Subtraction

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

$\vec{B}$ is a relative displacement vector of point P_3 relative to P_2

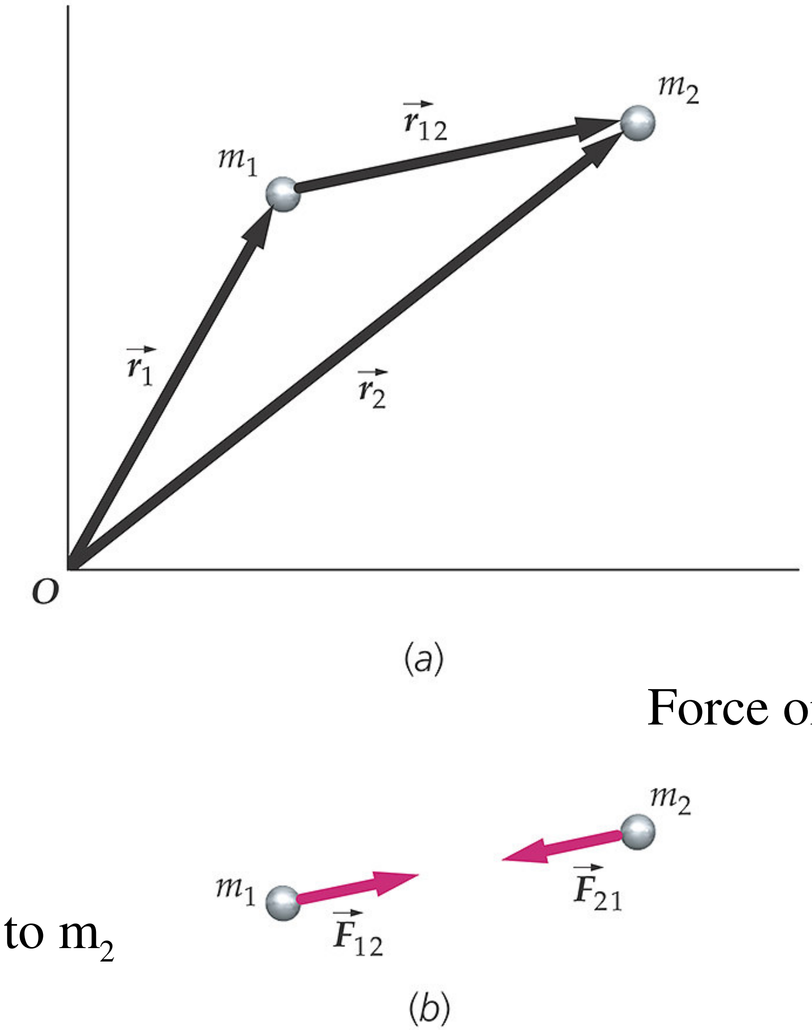
Relative Displacement Vectors

Relative vector via subtraction

$$\vec{r}_{12} = \vec{r}_2 - \vec{r}_1$$

Relative vector via addition

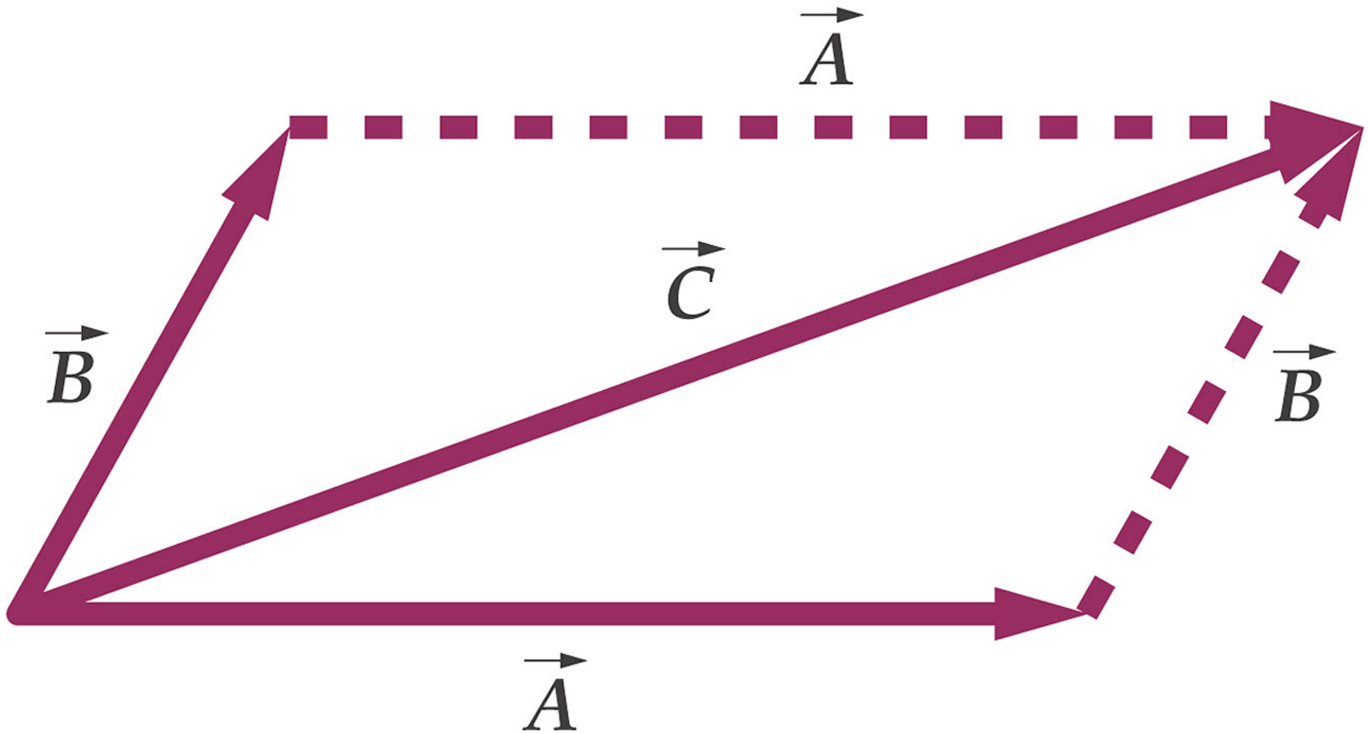
$$\vec{r}_1 + \vec{r}_{12} = \vec{r}_2$$



Force on m_2 due to m_1

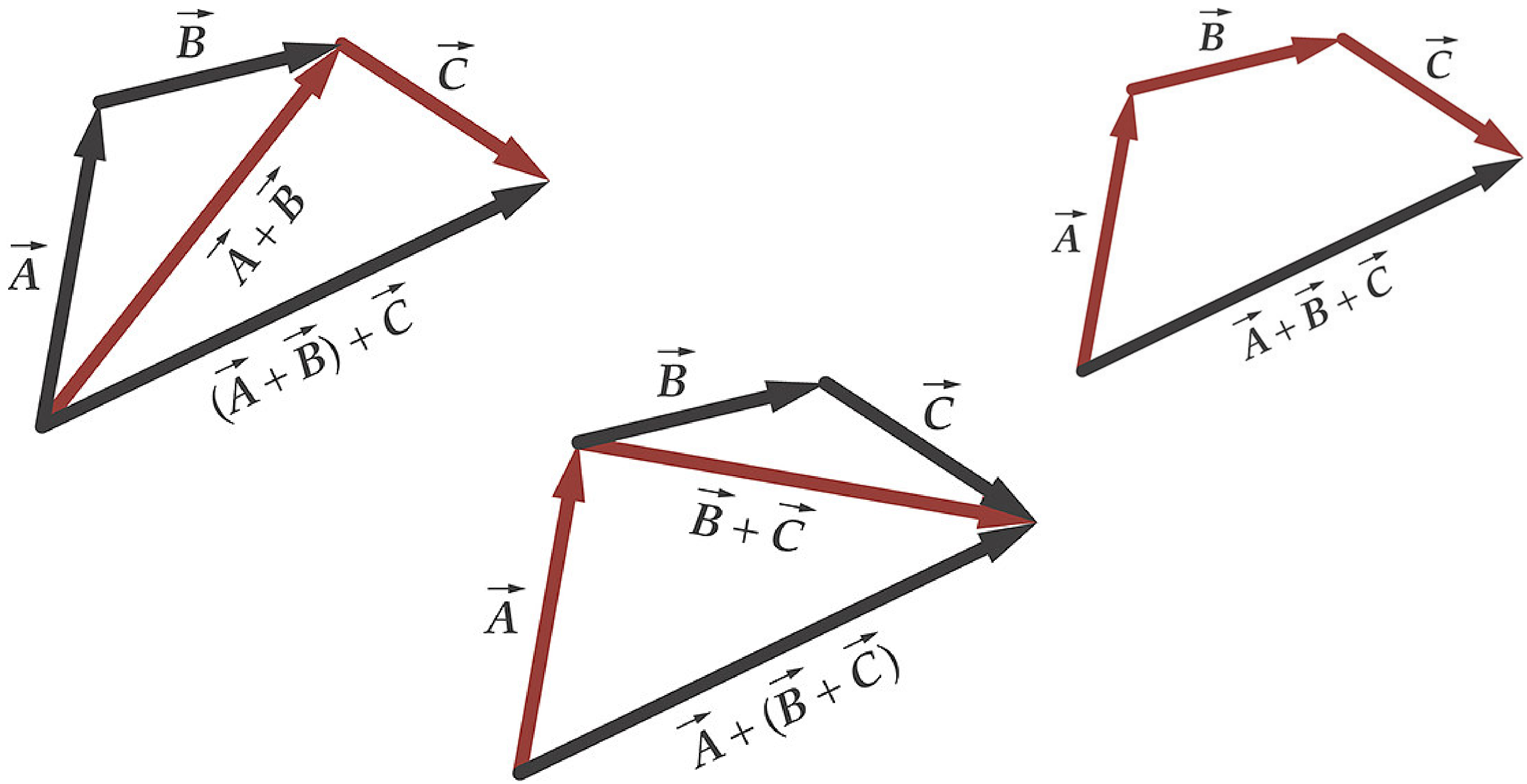
Force on m_1 due to m_2

Vector Addition via Parallelogram

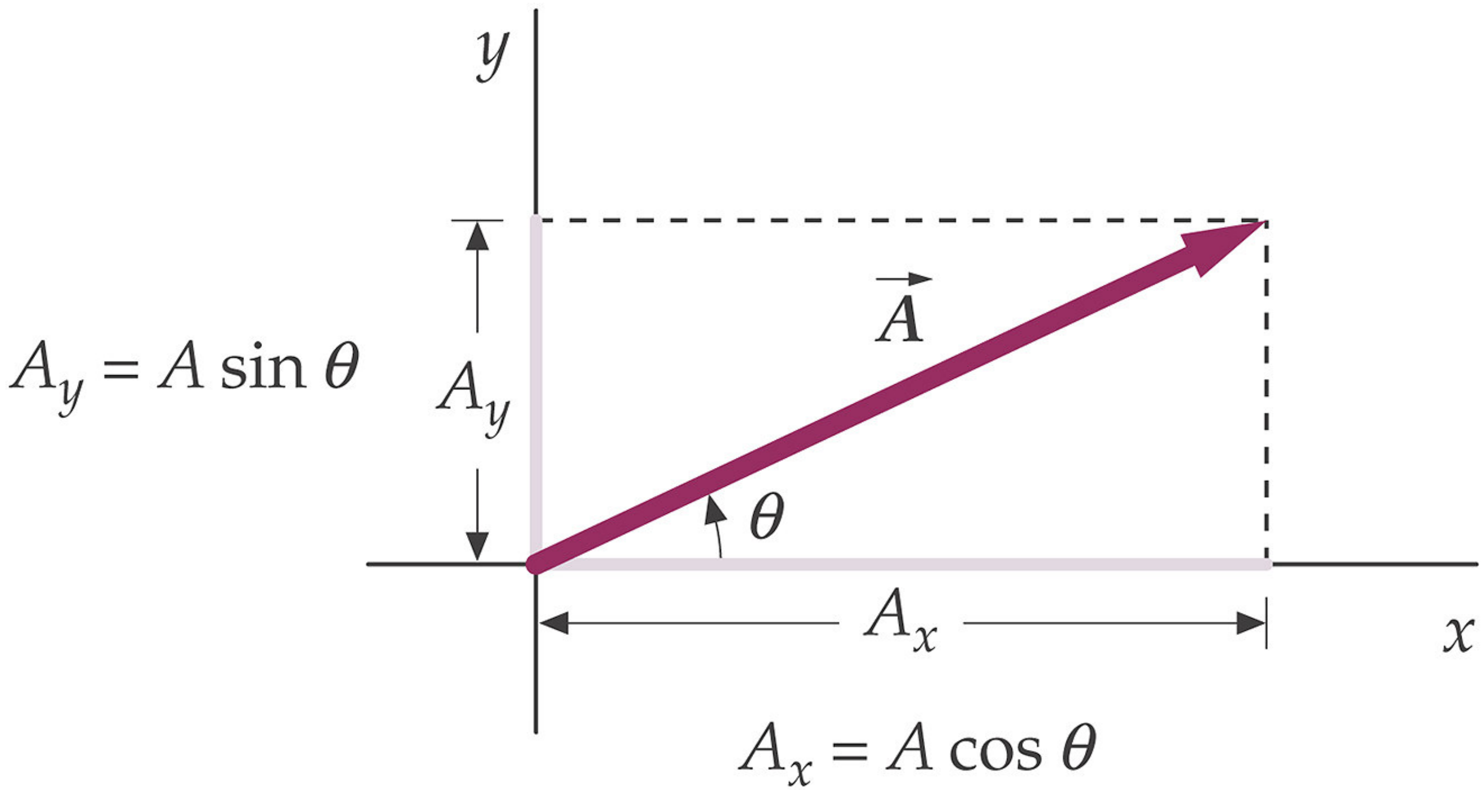


$$\vec{A} + \vec{B} = \vec{B} + \vec{A} = \vec{C}$$

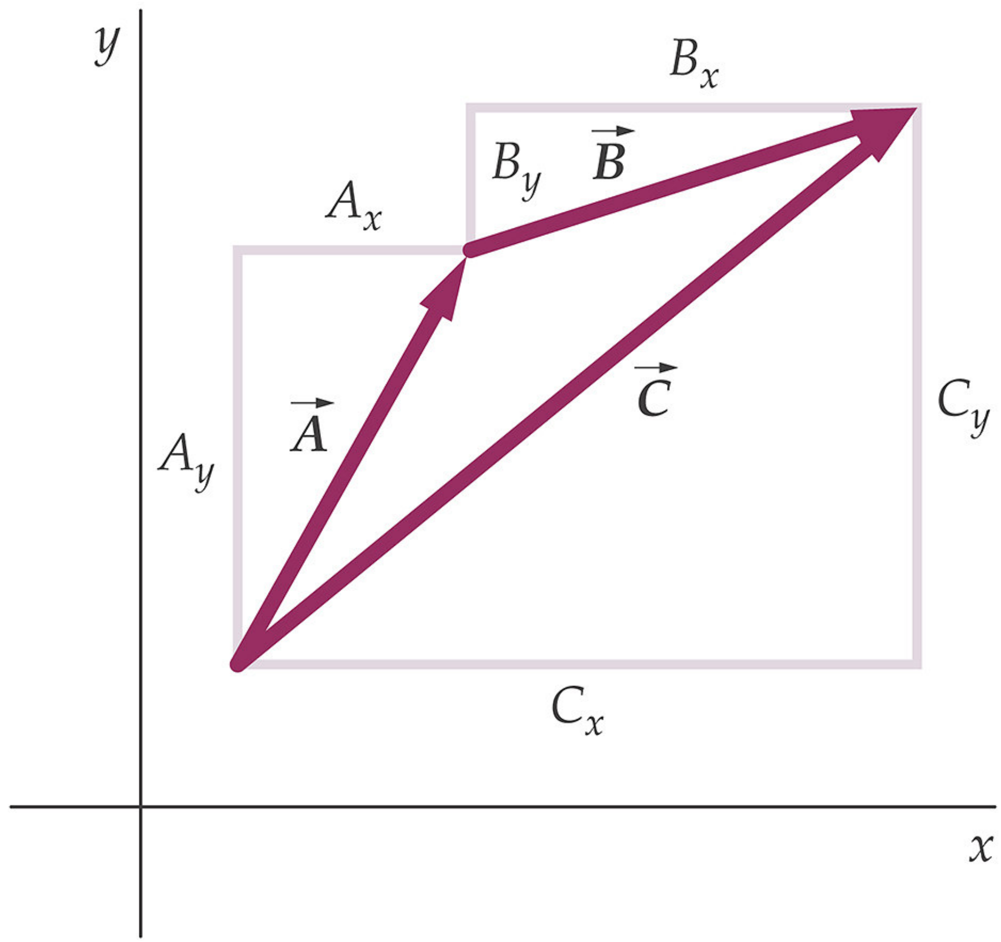
Vector Addition - Any Order



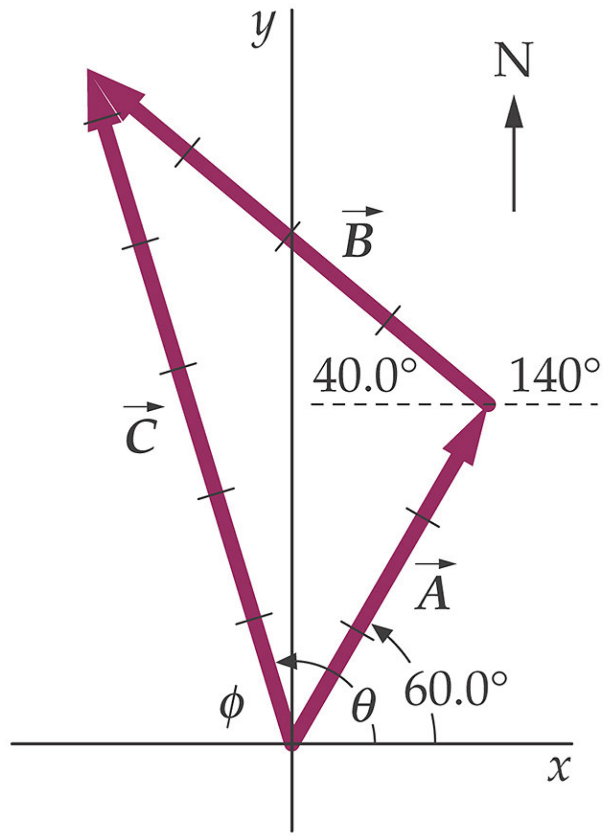
Vector Components



Vector Components

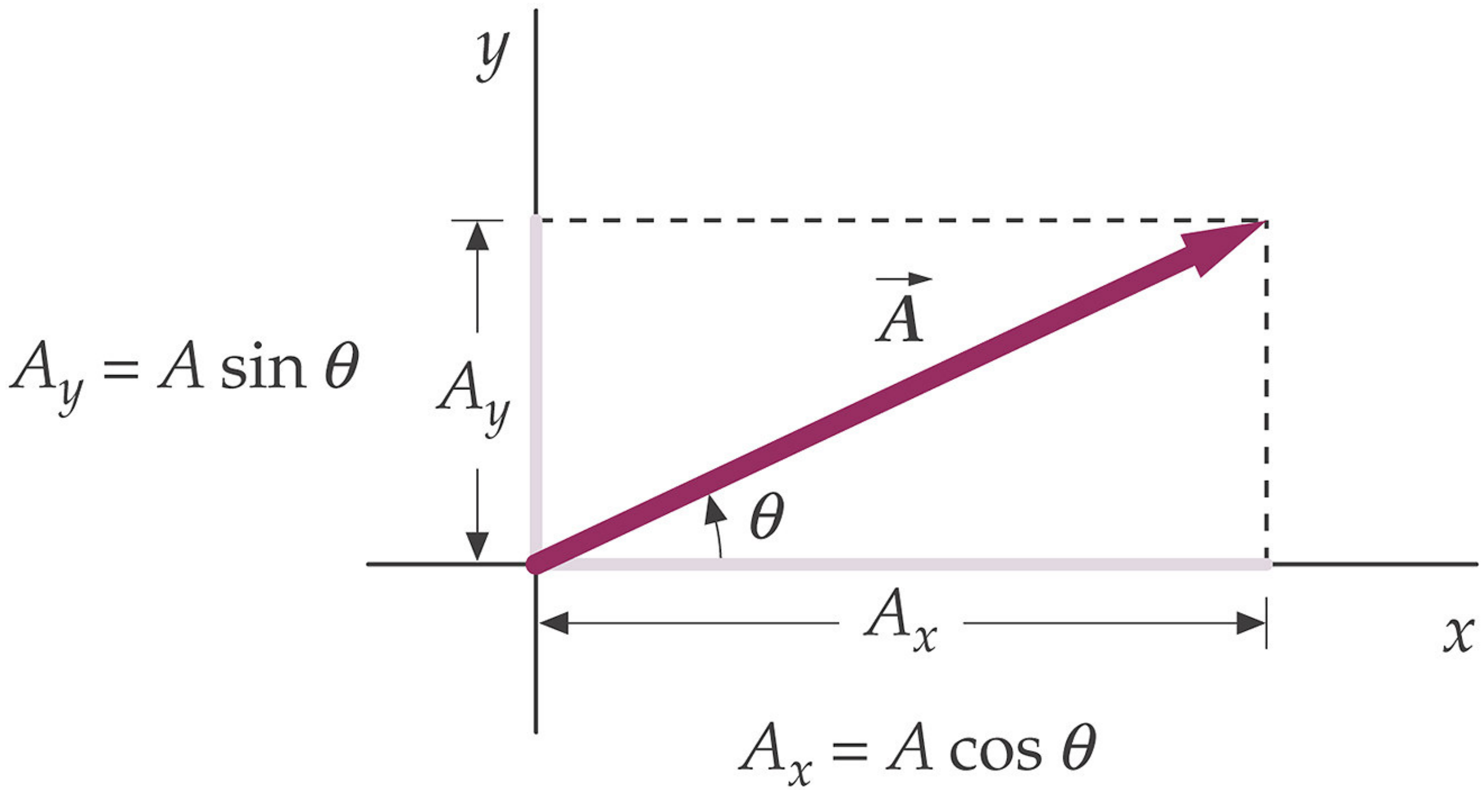


Graphical Method of Vector Addition

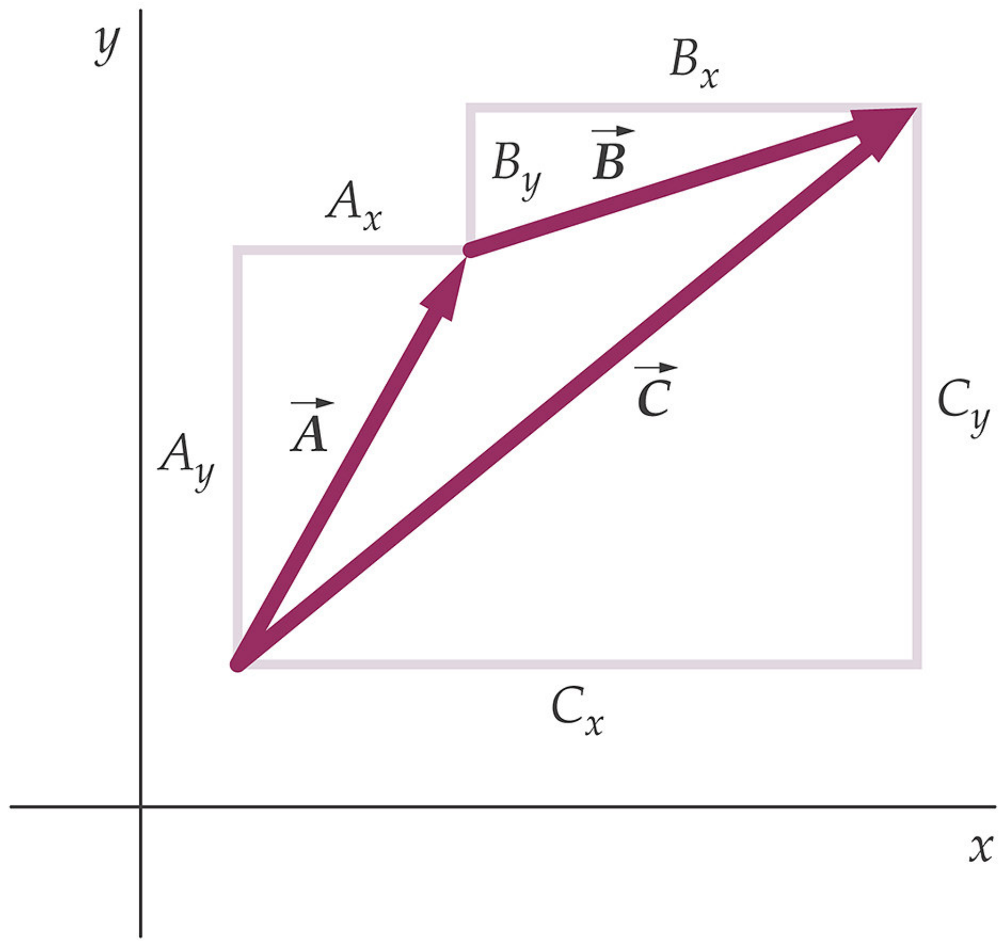


Ruler and protractor only

Vector Components



Vector Components



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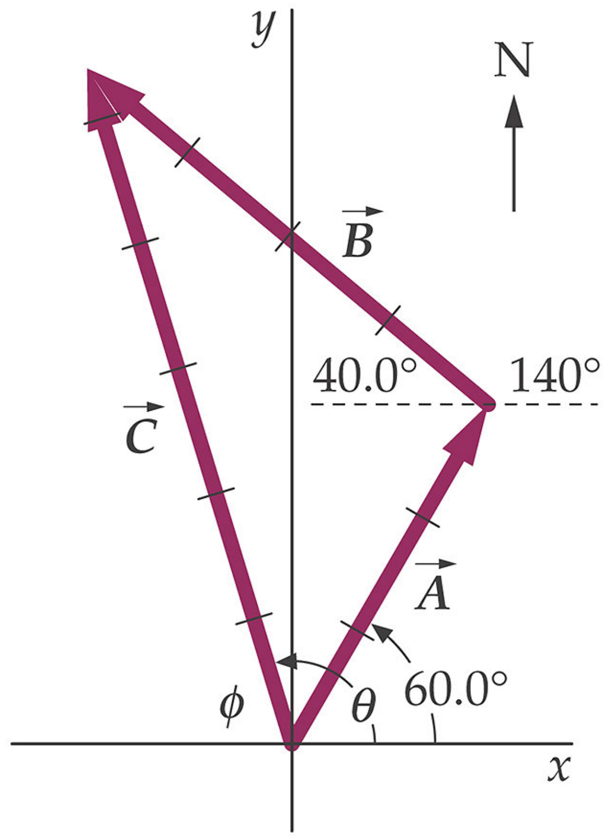
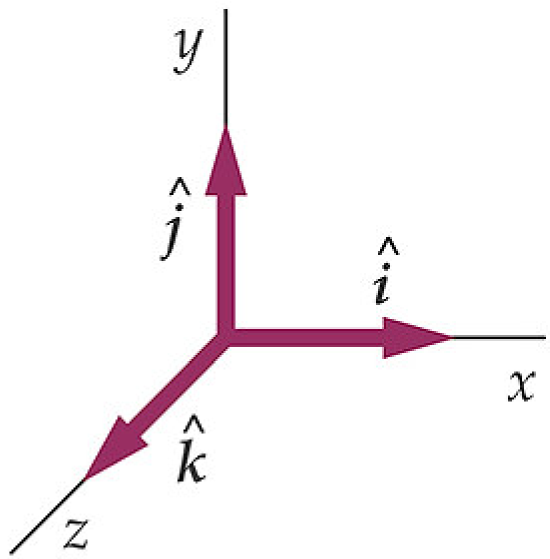
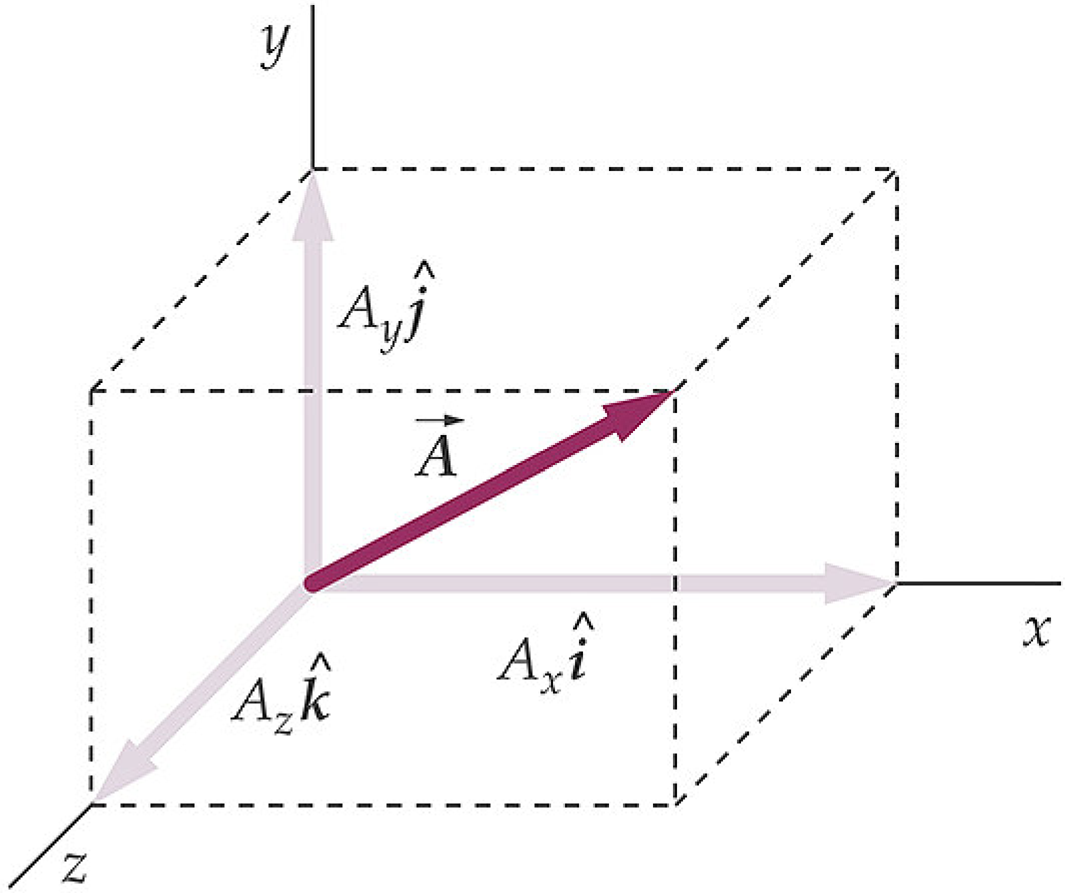


Unit Vectors in Rectangular Coordinates



(a)

Vector Components in Rectangular Coordinates



(b)

Vectors with Rectangular Unit Vectors

$$\vec{A} = A_x\,\hat{i} + A_y\,\hat{j} + A_z\,\hat{k}$$

$$\vec{B} = B_x\,\hat{i} + B_y\,\hat{j} + B_z\,\hat{k}$$

Dot Product - Scalar

The dot product multiplies the portion of A that is *parallel* to B with B

$$\hat{i} \bullet \hat{i} = 1$$

$$\hat{i} \bullet \hat{j} = 0$$

$$\hat{i} \bullet \hat{k} = 0$$

	$\hat{i}$	$\hat{j}$	$\hat{k}$
$\hat{i}$	1	0	0
$\hat{j}$	0	1	0
$\hat{k}$	0	0	1

Dot Product - Scalar

In 2 dimensions

$$\vec{A} \bullet \vec{B} = A\,B\cos(\Theta)$$

In any number of dimensions

$$\vec{A} \bullet \vec{B} = A_x B_x + A_y B_y + A_z B_z$$

The dot product multiplies the portion of A that is *parallel* to B with B

Cross Product - Vector

The cross product multpilies the portion of A that is *perpendicular* to B with B

$$\hat{i} \times \hat{i} = 0$$

$$\hat{i} \times \hat{j} = \hat{k}$$

$$\hat{i} \times \hat{k} = -\hat{j}$$

	$\hat{i}$	$\hat{j}$	$\hat{k}$
$\hat{i}$	0	$\hat{k}$	$-\hat{j}$
$\hat{j}$	$-\hat{k}$	0	$\hat{i}$
$\hat{k}$	$\hat{j}$	$-\hat{i}$	0

Cross Product - Vector

In 2 dimensions

$$\left|\vec{A} \times \vec{B}\right| = A\ B \sin(\Theta)$$

In any number of dimensions

$$\begin{bmatrix} \hat{i} & \hat{j} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{bmatrix} \begin{aligned} &= (A_y B_z - A_z B_y)\,\hat{i} \\ &+ (A_x B_z - A_z B_x)\,\hat{j} \\ &+ (A_x B_y - A_x B_y)\,\hat{k} \end{aligned}$$

Appendix

More Lord Kelvin Quotes

"Quaternions came from Hamilton after his really good work had been done; and though beautifully ingenious, have been an unmixed evil to those who have touched them in any way, including Maxwell.”

[The vector] "has never been of the slightest use to any creature."

Mathematics is the Language of Physics

Sometimes we are able to find an area of mathematics that previously had no physical applications but it turns out to perfectly describe a new physical phenomena.

- Matrices and the Heisenberg formulation of Quantum Mechanics. QM describes matter at the atomic scale. The matrix elements were probability amplitudes for the transitions between quantum states.
- Quaternions (generalizations of complex numbers) were long thought to be curious but not useful in and of themselves. So, they were stripped of their useful vector objects (Dot Product and Cross Product) and the rest of the carcass was left behind. In recent years Video Game Programmers have rediscovered them and have found Quaternions to be very useful and efficient in describing rotations.

Sometimes an area of mathematics is developed to serve the needs of some new physical phenomena. A lack of a mathematical framework will seriously retard progress in any area of science.