
PHYSICS 111N

why physics ?

allow me to demonstrate via my morning :

→ got out of bed

*exerted a **force** on the bed, which exerted an equal and opposite force on me, **accelerating** me away from the bed*

MECHANICS

→ opened blinds, saw sun was up in a blue sky



*the Earth **orbits** the sun once a year, held in its orbit by the **force** of **gravitation**
the Earth **rotates** about its **axis** at a constant rate - **why** ?
can see at all because of **light** from the sun - how did the light make it to Earth ?
why does the light go through the window, but not the blinds ?
how does the sun produce the light ?
where did the sun come from ?
why is the sky blue ?*

OPTICS

NUCLEAR PHYSICS

ASTROPHYSICS

ATOMIC PHYSICS

→ in the kitchen, put on the coffee pot



*coffee gets **hot** - how ? **what does hot really mean** ?
electricity bill goes up - why ?
get milk from **refrigerator** - how is it kept cold ?
put milk in coffee - it mixes, but it never 'unmixes' - **why not** ?*

THERMODYNAMICS

→ turn on the radio

*signal somehow gets from Norfolk to Newport News - **how** ?
I listen to **sound** coming out of the radio - how does it get to me ?*

WAVES

ELECTROMAGNETISM

why physics ?

allow me to demonstrate via my morning :

→ make some toast *set off the smoke alarm - how does it detect smoke ?*



RADIOACTIVITY

→ filled a bath

*got into it and the water level went up - why & by how much ?
the rubber ducky floats, but the soap sinks - why ?*



FLUID DYNAMICS

→ got in my car

*how does the engine turn gasoline into motion - how efficiently ?
how does my GPS know where I am ?*



**THERMODYNAMICS
SPECIAL RELATIVITY**

→ stop at a red light *why is it red ? how does a light-emitting-diode work ?*



CONDENSED MATTER

and so on ...

physics

physics can be :

QUALITATIVE / CONCEPTUAL - “ball goes up, reaches an apex, falls back toward the ground, getting faster”

QUANTITATIVE - ball thrown upwards at 2.0 m/s from a height of 1.5 m above the ground, after 1.1 seconds it reaches the ground at a speed of 6.7 m/s .

we need to be able to deal with problems of both kinds

what this course is about :

- conceptual understanding of physics
- quantitative and abstract problem solving

and it is **NOT** about :

- memorizing a load of random facts

... “know a little, apply widely”

practicalities

in class reading tests & clicker participation	10%
weekly homework (problem solving practice)	25%
three midterm exams (lowest score dropped)	20%
lab grade	15%
final comprehensive exam	30%

through **MasteringPhysics**
... more on this later

getting help :

- in special homework sessions
- from Physics Learning Center staff
- from discussion with your peers

ENCOURAGED

- by copying anyone else's work
- by accessing solution manuals (incl. online)

CHEATING

homework

probably the most important part of the class

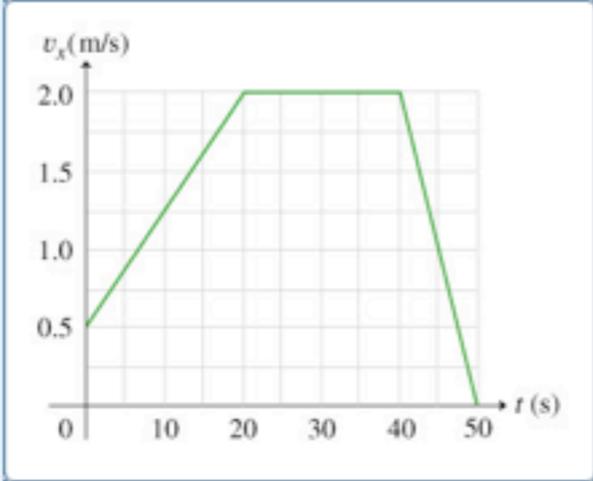
access the questions through **MasteringPhysics** - registration instructions on **blackboard**

Velocity vs. Time Graphs

This item is for practice only. Your work will not be saved and will not affect your grade.

We display a plot of velocity versus time for an object that travels along a straight line with a varying velocity. Refer to this plot to answer the following questions.

A common way to represent motion along a straight line is the v vs. t graph, the graph of (instantaneous) velocity as a function of time. In this plot, time t is the horizontal axis and velocity v is the vertical axis. Note that velocity and acceleration are vector quantities. In straight-line motion, however, these vectors have only a single nonzero component in the direction of motion. We will call this the velocity and the acceleration.



The graph shows velocity v_x (m/s) on the vertical axis and time t (s) on the horizontal axis. The vertical axis ranges from 0 to 2.0 with major ticks every 0.5. The horizontal axis ranges from 0 to 50 with major ticks every 10. The graph consists of three segments: a straight line from (0, 0.5) to (20, 2.0), a horizontal line from (20, 2.0) to (40, 2.0), and a straight line from (40, 2.0) to (50, 0).

Part A

What is the initial velocity of the particle, v_0 ?

Express your answer in meters per second.

$v_0 =$ m/s

Part B

What is the total distance Δx traveled by the particle?

Express your answer in meters.

$\Delta x =$ m

Part C

What is the average acceleration a_{av} of the particle over the first 20.0 seconds?

Express your answer in meters per second per second.

$a_{av} =$ m/s²

work through the question and insert the answer in the boxes
you get multiple attempts

on each homework the solutions to three or four questions are
to be written up and handed in for grading

some preliminaries - FREE CREDIT

a couple of short tests

→ a **physics pre-course test** to see what you know already

multiple choice, do it in class, full credit just for doing it

→ a **math pre-course test** to see how much math you have already

serves as the first homework, full credit just for doing it & handing in

big & small numbers - the 'scientific' notation

we need to get used to dealing with sometimes large and sometimes small numbers
scientific notation is perfect for this:

e.g. how much mass does a sample of six hundred-thousand-billion-billion atoms of carbon have if one carbon atom has a mass of twenty billion-billion-billionths of a kilogram

words for numbers - terrible!

conventional number representation:

$$600,000,000,000,000,000,000,000 \times 0.000,000,000,000,000,000,000,000,002 = ???????$$

lots of zeroes - terrible!

scientific notation:

$$\begin{aligned} &6 \times 10^{23} \times 20 \times 10^{-27} \text{ kg} \\ &= 120 \times 10^{23-27} \text{ kg} \\ &= 1.2 \times 10^2 \times 10^{-4} \\ &= 1.2 \times 10^{-2} \text{ kg} \\ &= 12 \text{ g} \end{aligned}$$

much more convenient !

big & small numbers - the 'scientific' notation

big numbers, e.g. $8 \times 10^4 = 8 \times 10 \times 10 \times 10 \times 10 = 80,000$

small numbers, e.g. $8 \times 10^{-4} = 8 / (10 \times 10 \times 10 \times 10) = 0.0008$

→ multiplication: e.g. $3 \times 10^4 \times 2 \times 10^3 = (3 \times 2) \times 10^{4+3} = 6 \times 10^7$

→ division: e.g. $3 \times 10^4 / 2 \times 10^3 = (3/2) \times 10^{4-3} = 1.5 \times 10^1 = 15$

→ addition & subtraction: easiest to make a common power of 10

$$\begin{aligned} \text{e.g. } & 2.04 \times 10^4 + 1.5 \times 10^3 \\ & = (2.04 \times 10) \times 10^3 + 1.5 \times 10^3 \\ & = 20.4 \times 10^3 + 1.5 \times 10^3 \\ & = (20.4 + 1.5) \times 10^3 \\ & = 21.9 \times 10^3 \end{aligned}$$

proportionality

traveling at 60 m.p.h for one hour you'll cover a distance of 60 miles

traveling at 60 m.p.h for two hours you'll cover a distance of 120 miles

the distance you travel at fixed speed is **proportional** to the time $d \propto t$

covering 20 miles at 30 m.p.h takes 40 minutes

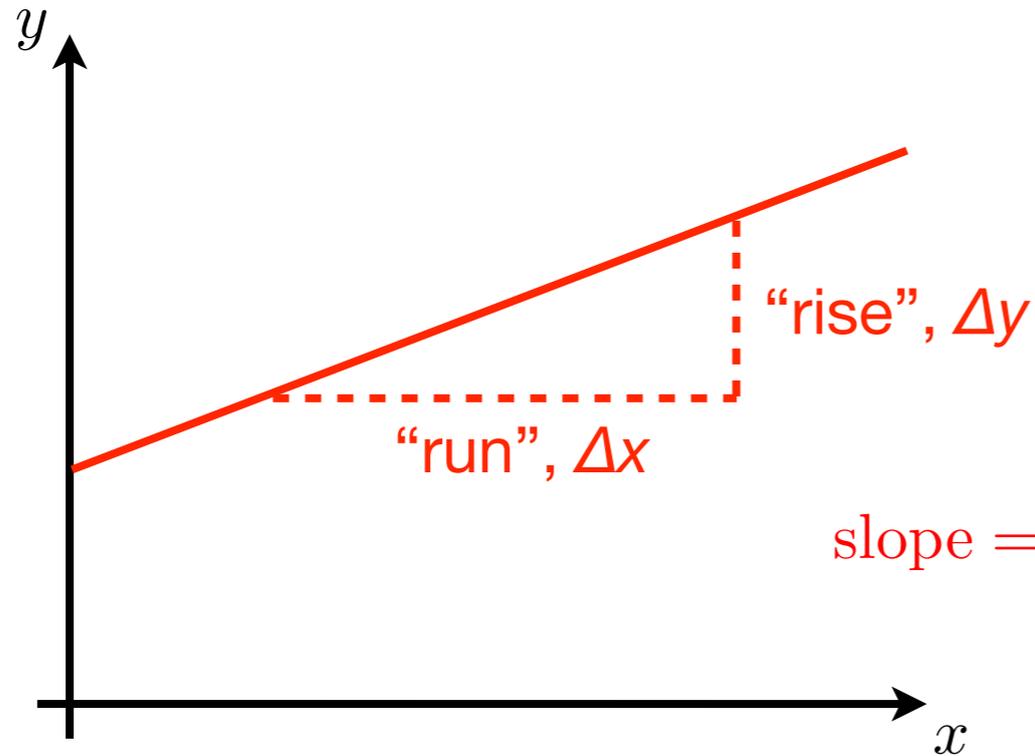
covering 20 miles at 60 m.p.h takes 20 minutes

the time taken to cover a fixed distance is **inversely proportional** to your speed

$$t \propto \frac{1}{s}$$

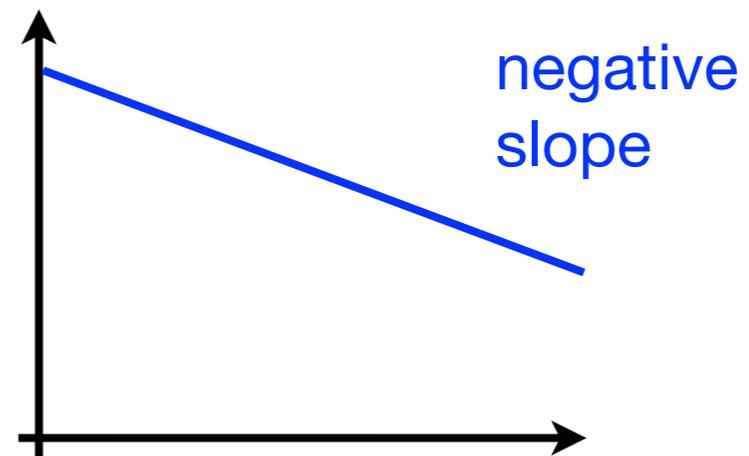
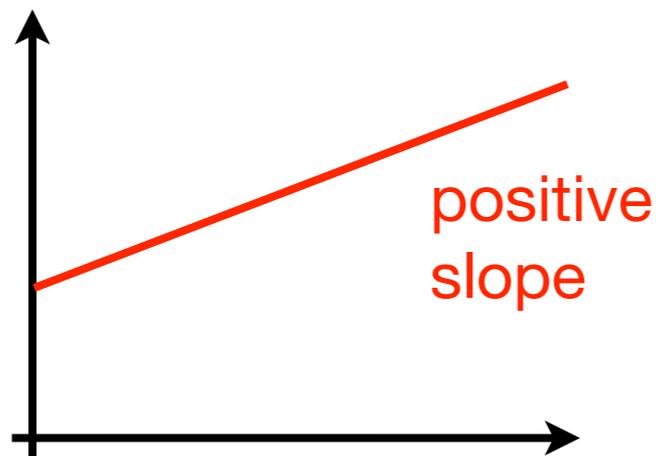
slope

computing the slope of a straight line :



$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta y}{\Delta x}$$

doesn't matter where
you 'measure'



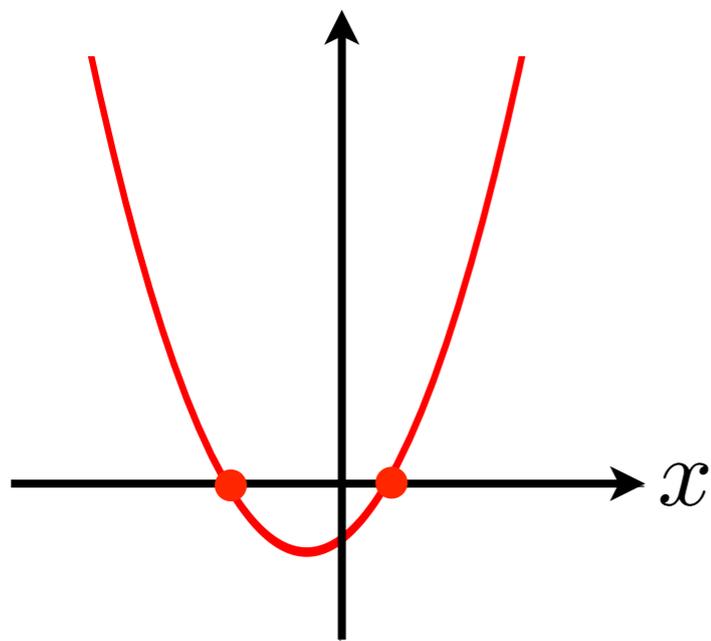
quadratic equations

occasionally we'll encounter expressions of the type $a x^2 + b x + c$

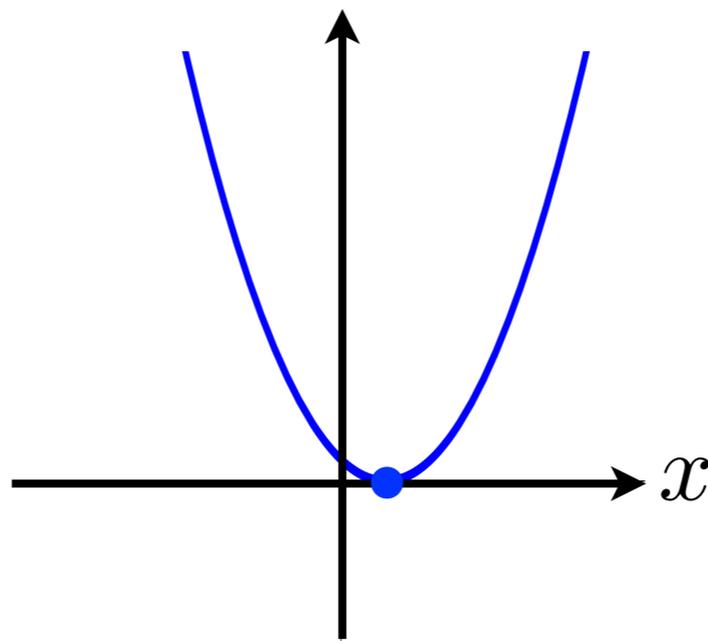
and we'll sometimes need to solve $0 = a x^2 + b x + c$

this equation will either have:

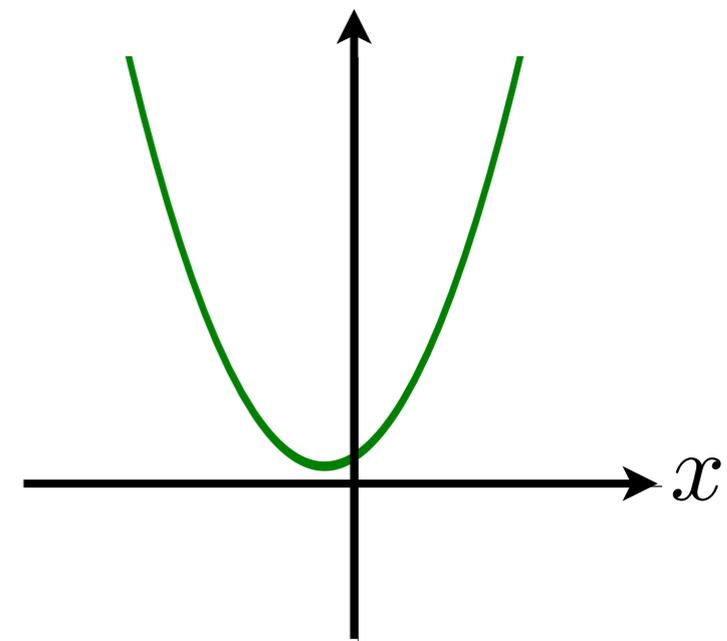
1. two solutions



2. one solution



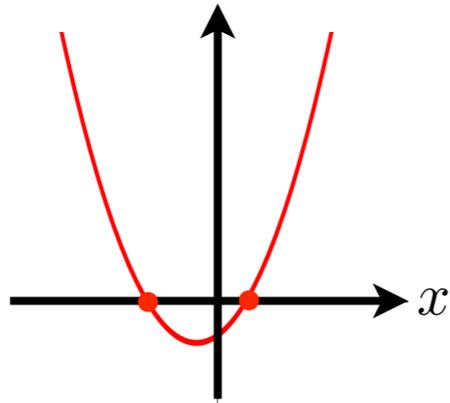
3. no solutions



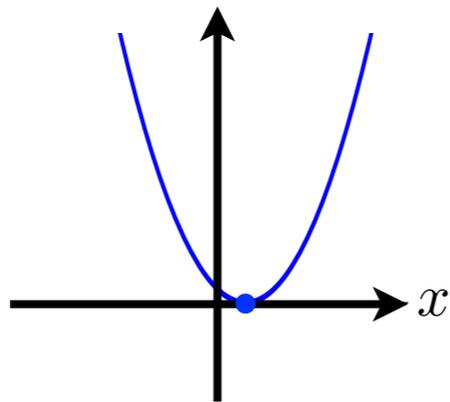
quadratic equations

$$0 = ax^2 + bx + c \quad \text{solutions are given by} \quad x = \frac{(-b \pm \sqrt{b^2 - 4ac})}{2a}$$

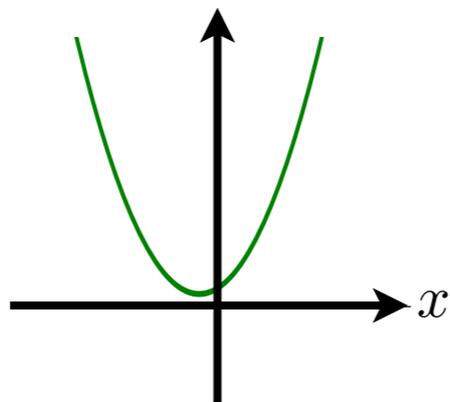
$$\rightarrow b^2 > 4ac$$



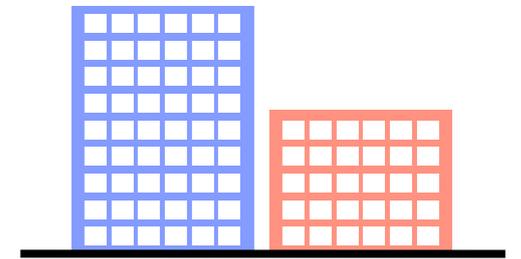
$$\rightarrow b^2 = 4ac$$



$$\rightarrow b^2 < 4ac$$



simultaneous equations - skyscrapers



Two skyscrapers are being built side-by-side.
Tower 1 already has ten floors built and the builders are adding more at a rate of 3 per week.
Tower 2 currently has no floors built, but the builders will build at 5 floors per week.

Q: after how many weeks do the towers have the same number of floors?

Solution:

Set up appropriate equations for the number of floors:

$$\text{Tower 1: } h_1 = 10 + 3t$$

$$\text{Tower 2: } h_2 = 5t$$

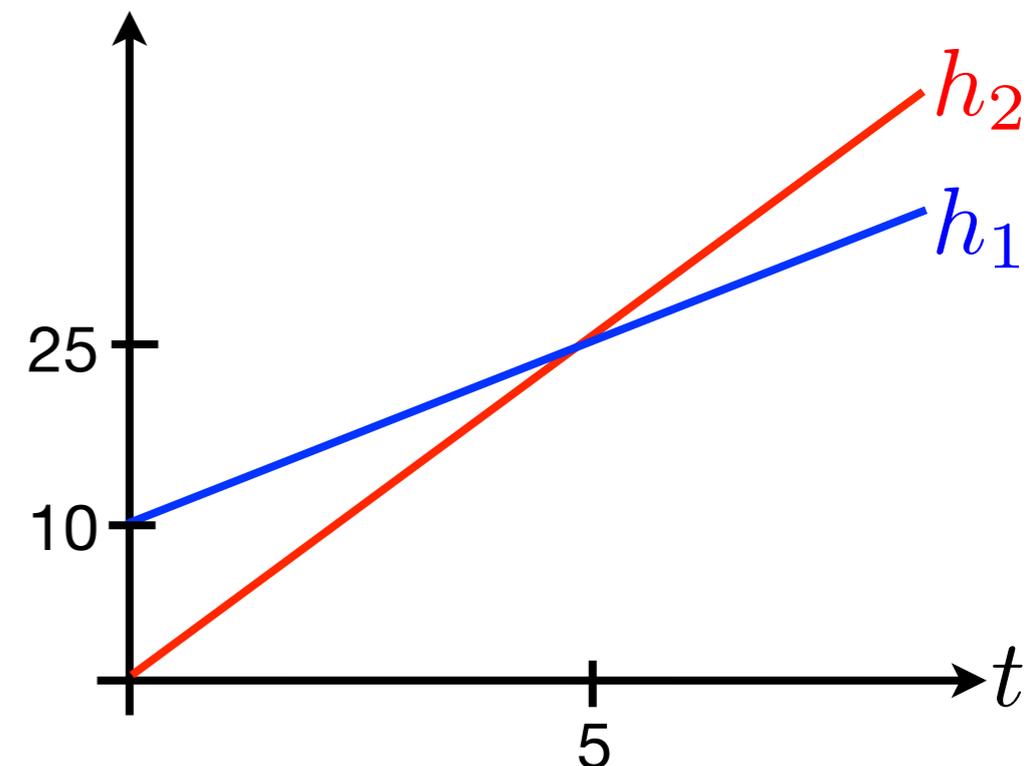
Solve for the case that $h_1 = h_2$:

$$10 + 3t = 5t$$

$$10 = 2t$$

$$t = 5$$

\Rightarrow after 5 weeks, both towers have 25 floors



simultaneous equations - the fruit cart



Fruit Cart Prices:
bag of apples - \$4
bunch of bananas - \$5

Wholesale Prices:
bag of apples - \$2
bunch of bananas - \$2

In a day the fruit cart took in \$65 having paid \$30 for the stock they sold.

Q: How many bags of apples and bunches of bananas were sold ?

Solution:

Set up appropriate equations for money in and money spent:

$$\text{money taken in: } 65 = 4a + 5b$$

$$\text{money spent: } 30 = 2a + 2b$$

Solve the equations for the unknown a and b :

e.g. eliminate a from the equations:

$$15 = a + b$$

$$a = 15 - b$$

$$4a = 60 - 4b$$

$$65 = 60 - 4b + 5b$$

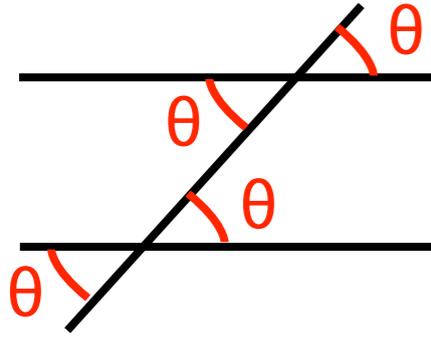
$$5 = b$$

$$\text{\& plug-in to find } a: a = 15 - 5 = 10$$

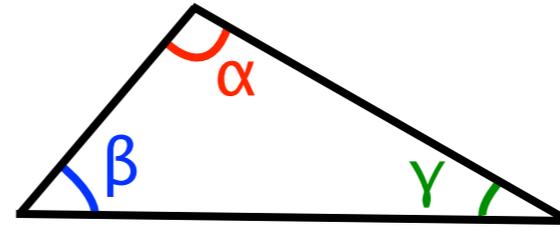
\Rightarrow 10 bags of apples & 5 bunches of bananas

geometry

identifying equal angles

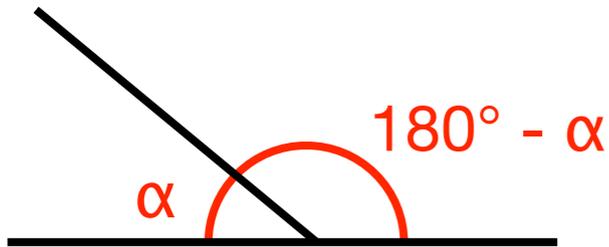


triangles

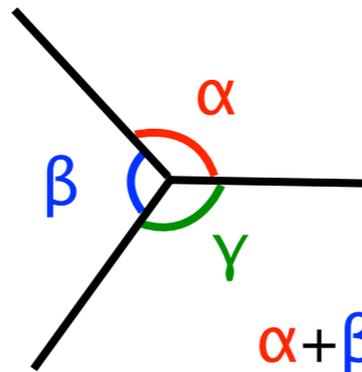


$$\alpha + \beta + \gamma = 180^\circ$$

angles on a line



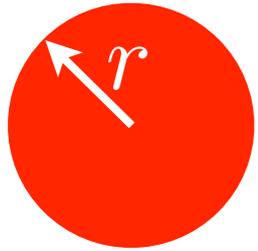
angles around a point



$$\alpha + \beta + \gamma = 360^\circ$$

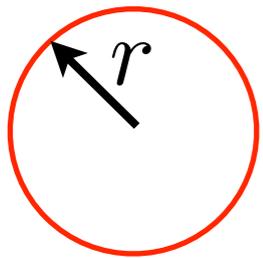
geometry

circle



area

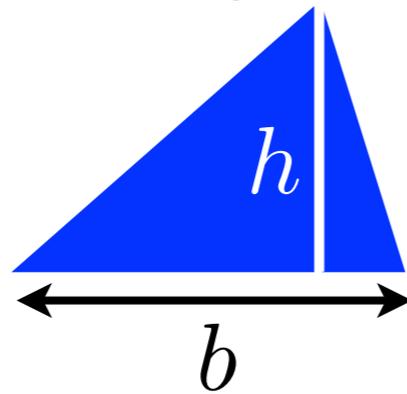
$$A = \pi r^2$$



circumference

$$C = 2\pi r$$

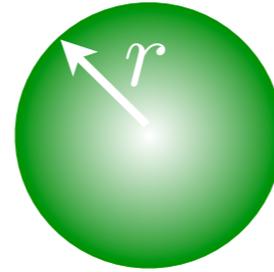
triangle



area

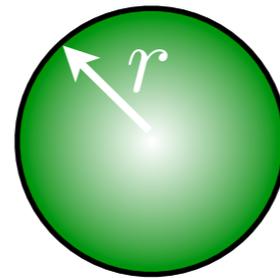
$$A = \frac{1}{2}bh$$

sphere



volume

$$V = \frac{4}{3}\pi r^3$$

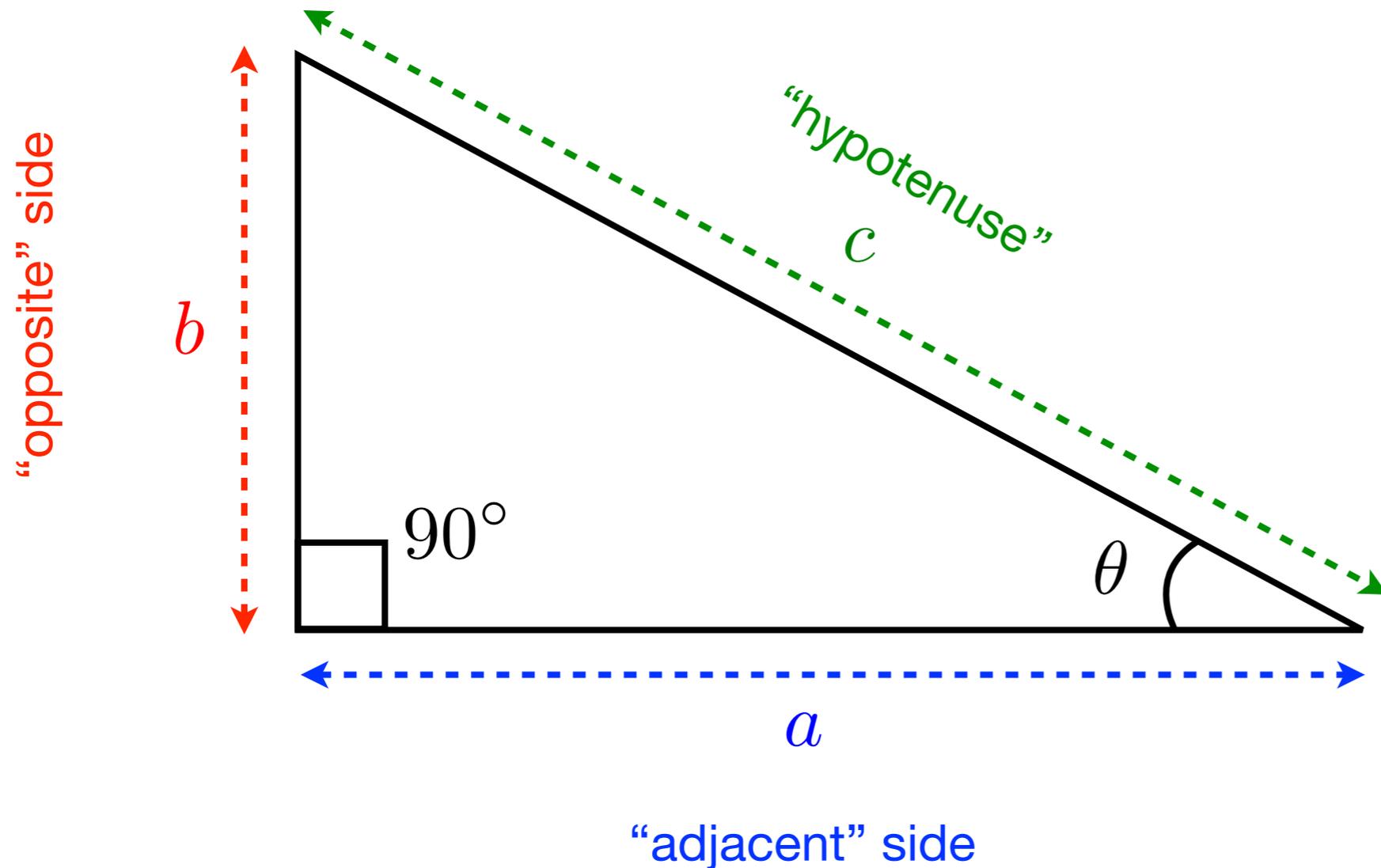


surface area

$$A = 4\pi r^2$$

trigonometry

triangles with a right angle (90°)



$$a = c \cos \theta$$

$$b = c \sin \theta$$

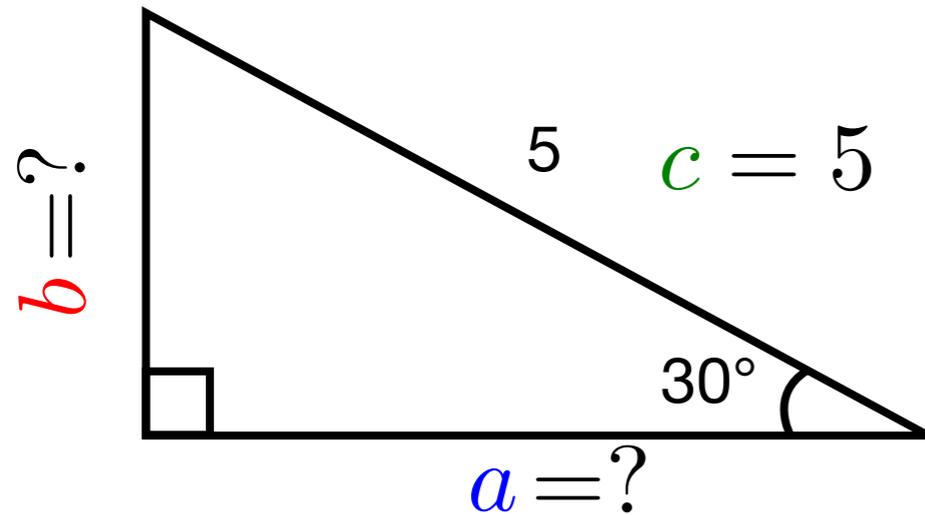
$$\frac{b}{a} = \tan \theta$$

Pythagoras' theorem

$$a^2 + b^2 = c^2$$

using trigonometry (with your calculator)

suppose we're given



and asked to find the lengths of the other two sides

$$a = 5 \cos 30^\circ = 5 \times 0.866 = 4.33$$

$$b = 5 \sin 30^\circ = 5 \times 0.5 = 2.5$$

$$a = c \cos \theta$$

$$b = c \sin \theta$$

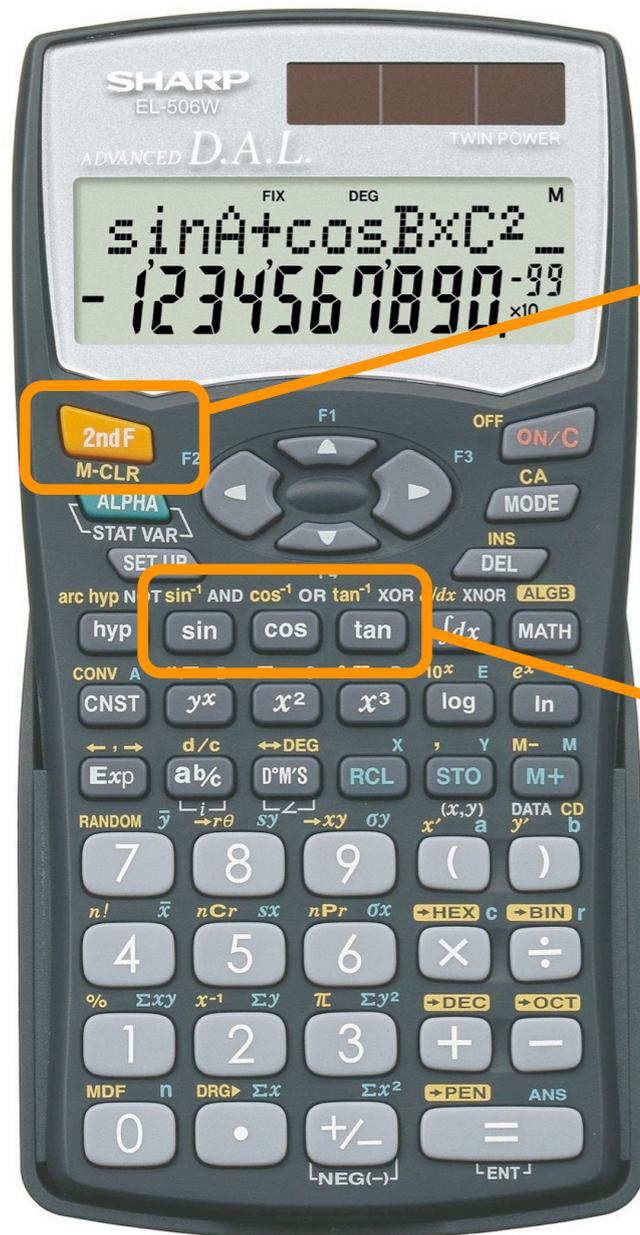
$$\frac{b}{a} = \tan \theta$$

$$a^2 + b^2 = c^2$$

using trigonometry (with your calculator)

inverse functions, e.g. $\theta = \cos^{-1} \left(\frac{a}{c} \right)$

might be hidden
on your calculator



$$a = c \cos \theta$$

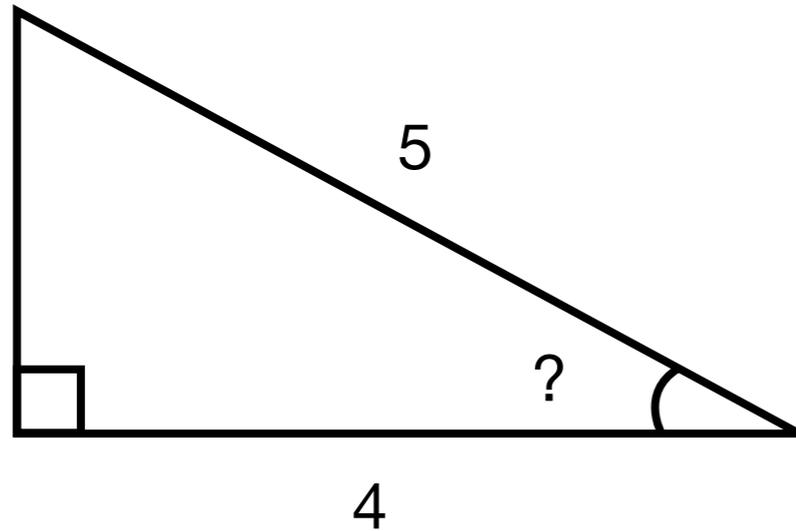
$$b = c \sin \theta$$

$$\frac{b}{a} = \tan \theta$$

$$a^2 + b^2 = c^2$$

using trigonometry (with your calculator)

suppose we're given



and asked to find the marked angle

$$a = 4$$

$$b = ?$$

$$c = 5$$

$$\theta = ?$$

$$a = c \cos \theta$$

$$\cos \theta = \frac{a}{c}$$

$$\theta = \cos^{-1} \left(\frac{a}{c} \right)$$

$$a = c \cos \theta$$

$$b = c \sin \theta$$

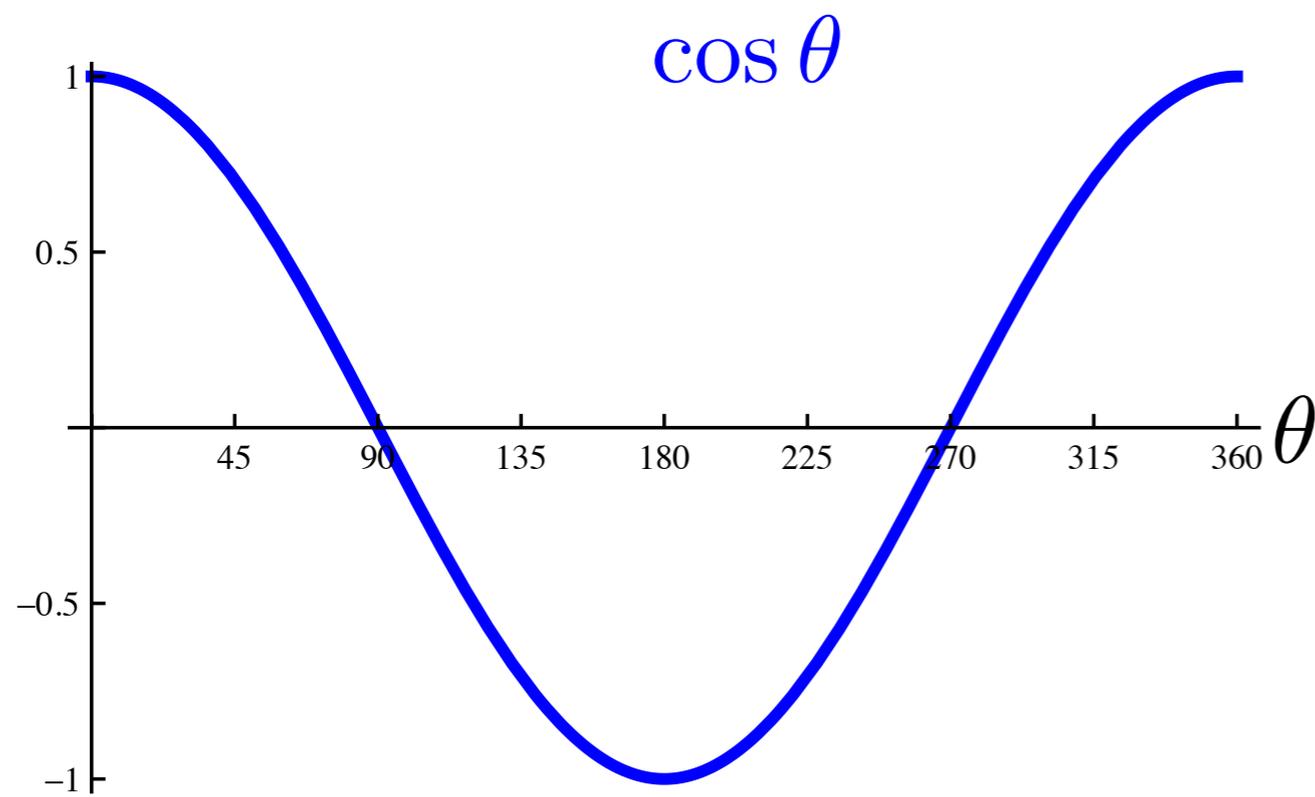
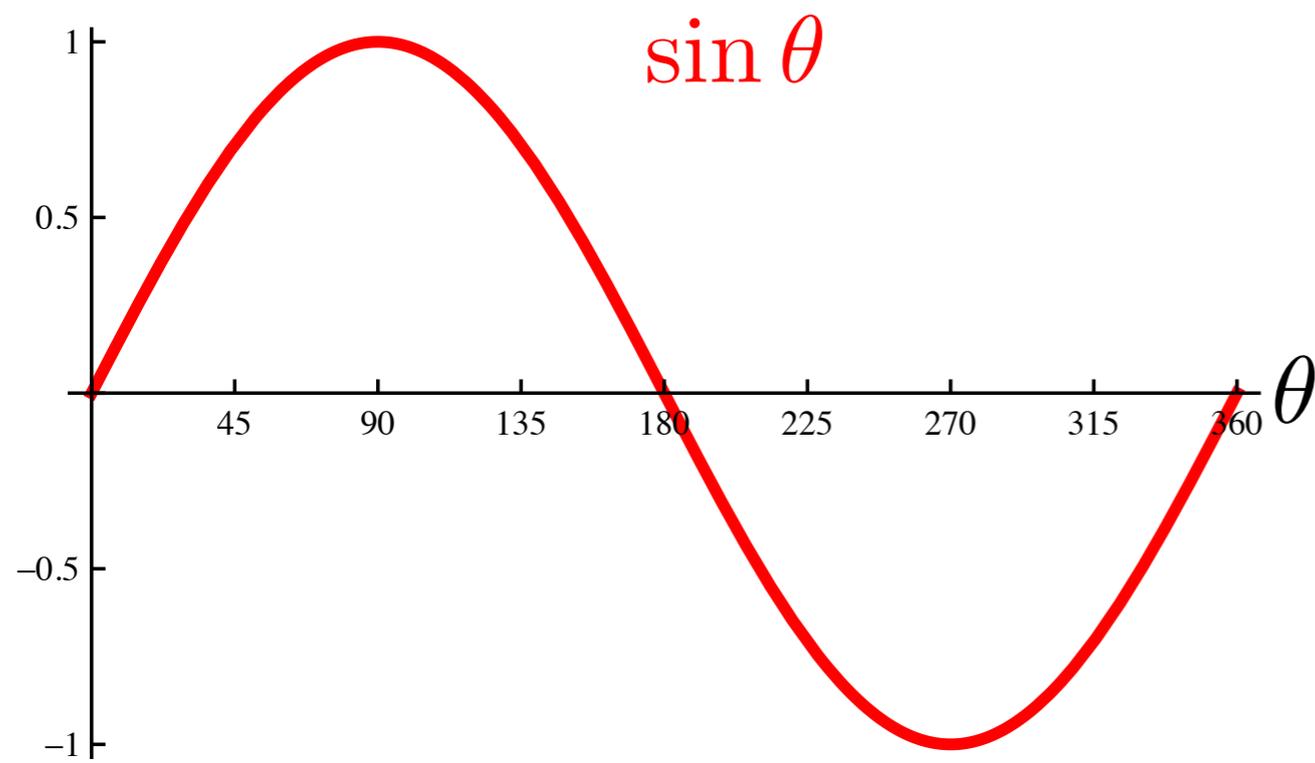
$$\frac{b}{a} = \tan \theta$$

$$a^2 + b^2 = c^2$$

$$\theta = \cos^{-1} (0.8)$$

$$\theta = \underline{\underline{36.9^\circ}}$$

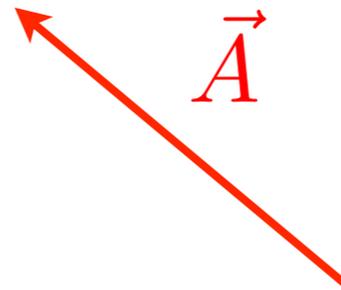
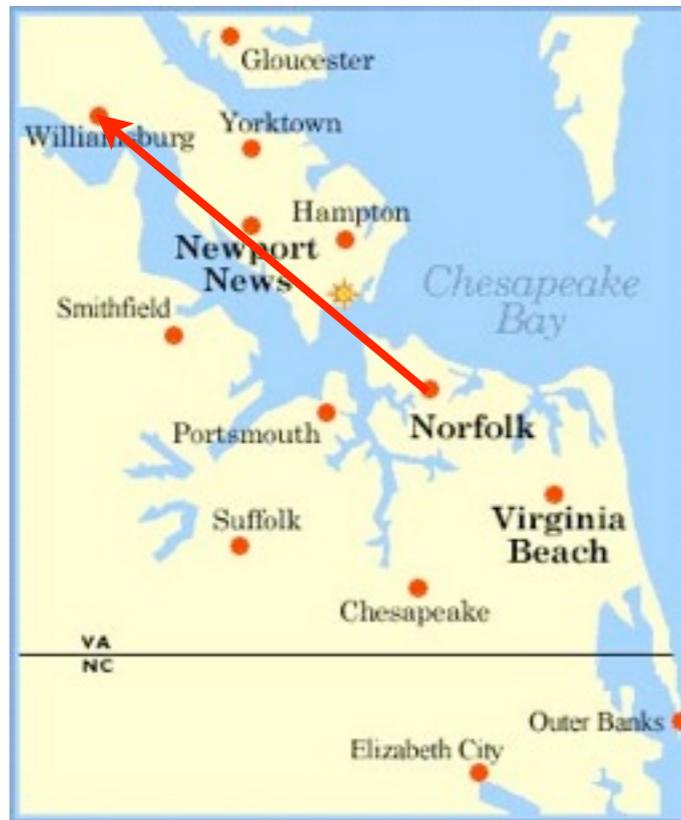
trig functions



vectors

a vector is a quantity with *magnitude* and *direction*

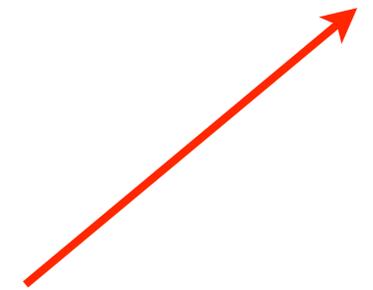
e.g. a *displacement*



smaller magnitude



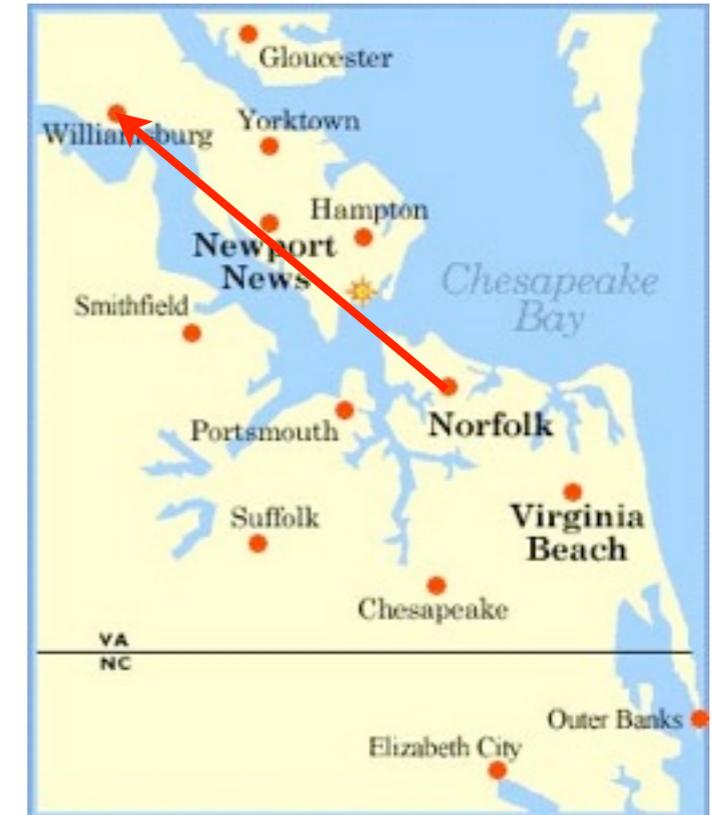
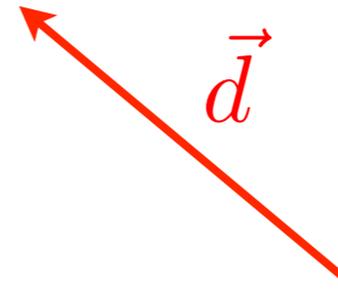
different direction



vectors - magnitude & direction

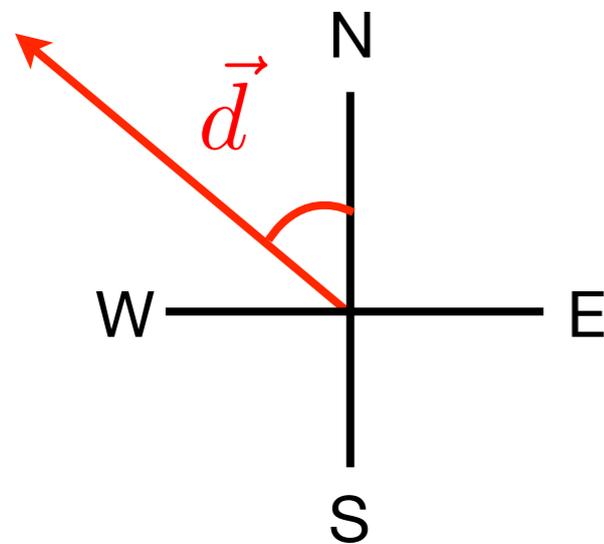
the magnitude is just the “length” of the vector

$$d = |\vec{d}| = 37 \text{ miles}$$



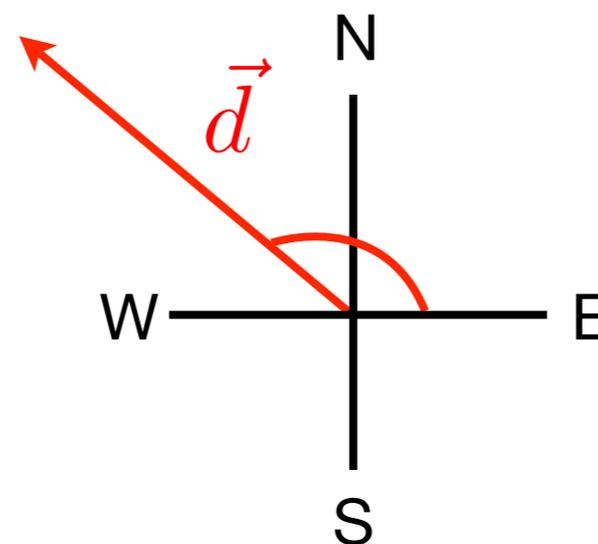
there are several ways we could express the direction

e.g.



50° west of north

e.g.

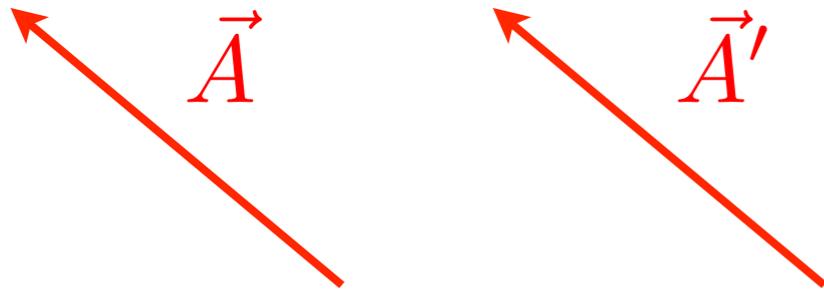


140° counter-clockwise from E

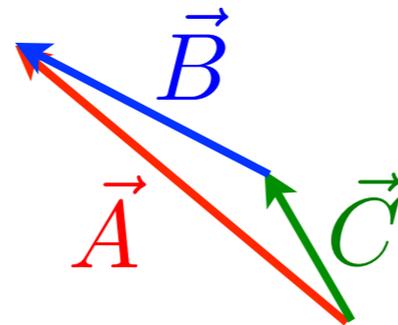
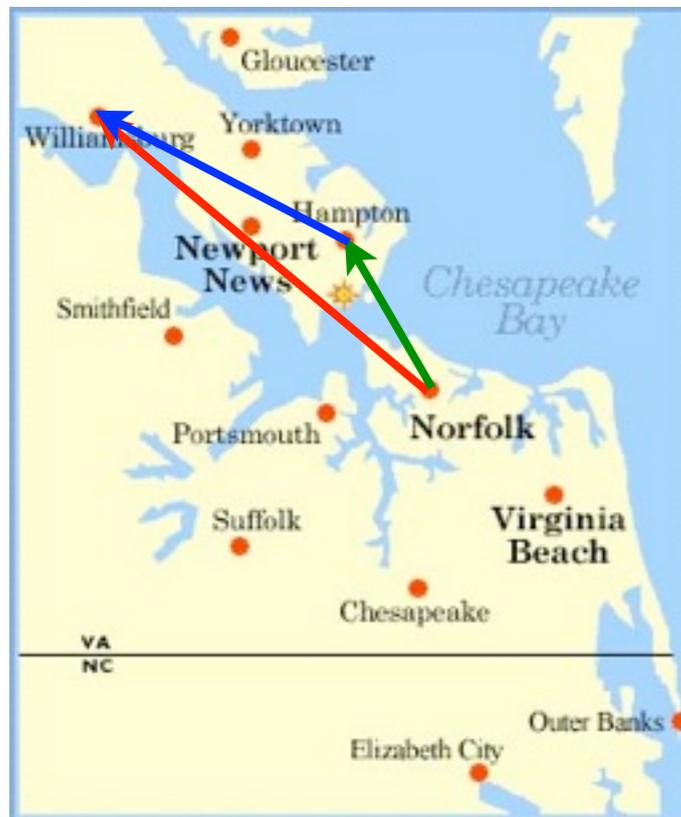
adding vectors

two vectors are equal if they have the same magnitude *and* direction

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



vectors can be added - suppose you go to Williamsburg via Hampton



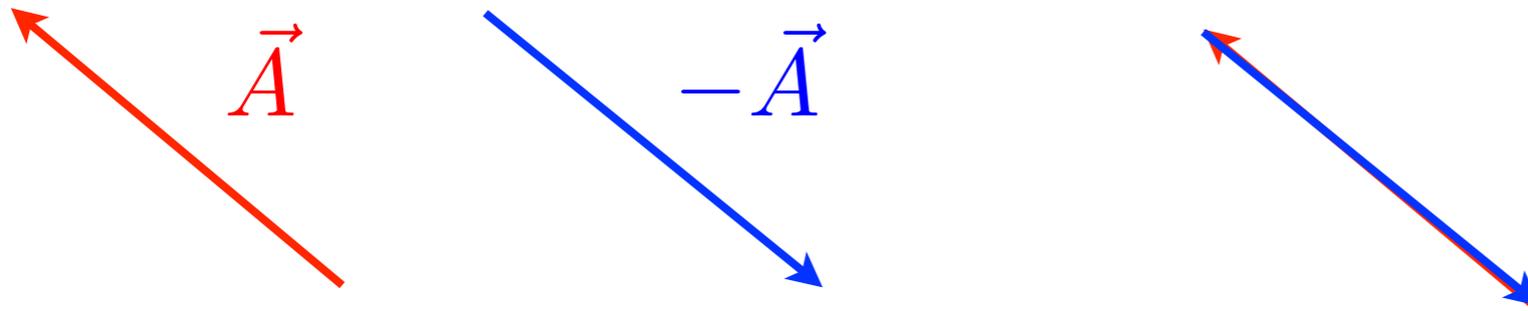
$$\vec{A} = \vec{B} + \vec{C}$$

the negative of a vector

what does $-\vec{A}$ mean ?

imagine adding it to \vec{A} : $\vec{A} + (-\vec{A}) = \vec{A} - \vec{A}$ but (thing) - (thing) = zero !

$$\vec{A} - \vec{A} = \vec{0}$$

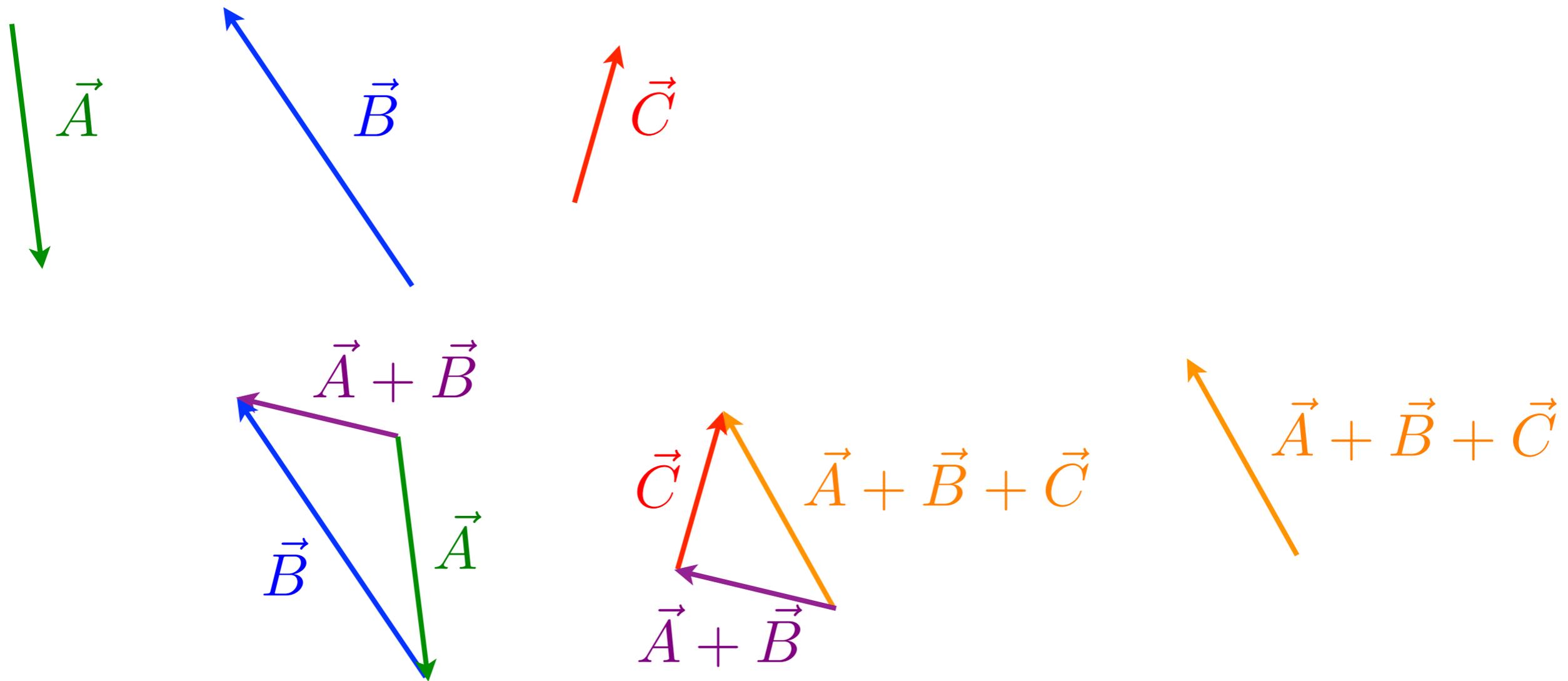


adding vectors

what about adding more than two vectors ?

just choose any pair, combine them and you have one fewer

keep going until you have two left then combine them to make a final vector

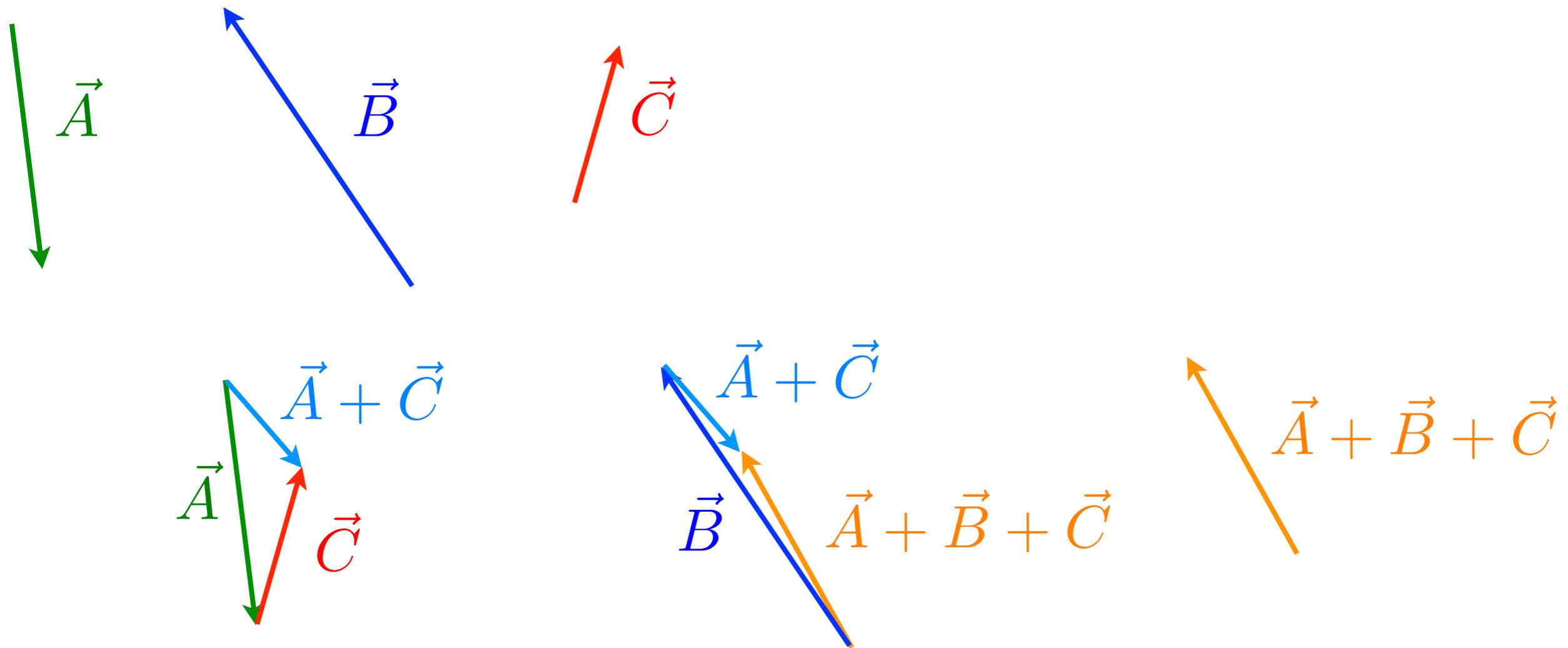


adding vectors

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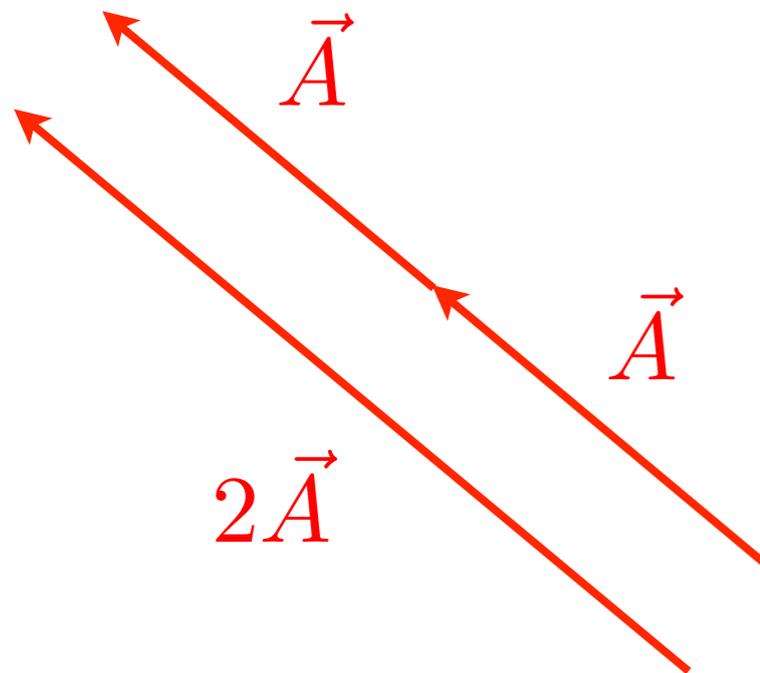
keep going until you have two left then combine them to make a final vector



multiplying vectors ?

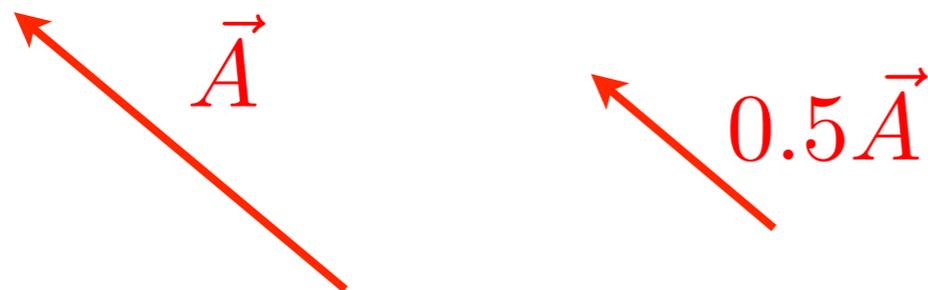
what does $2\vec{A}$ mean ?

suppose we treat it as $2\vec{A} = \vec{A} + \vec{A}$



so it's a vector in the same direction
but with double the magnitude

multiplying by a number scales the magnitude, so e.g.

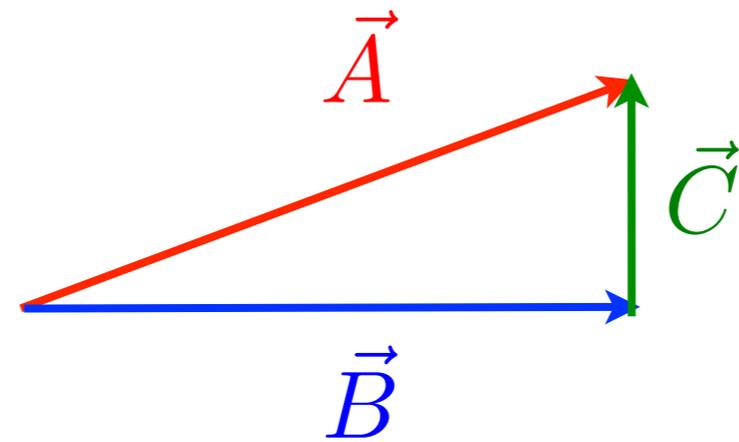
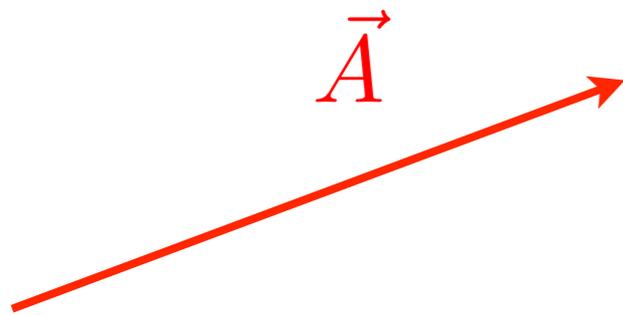


components of vectors

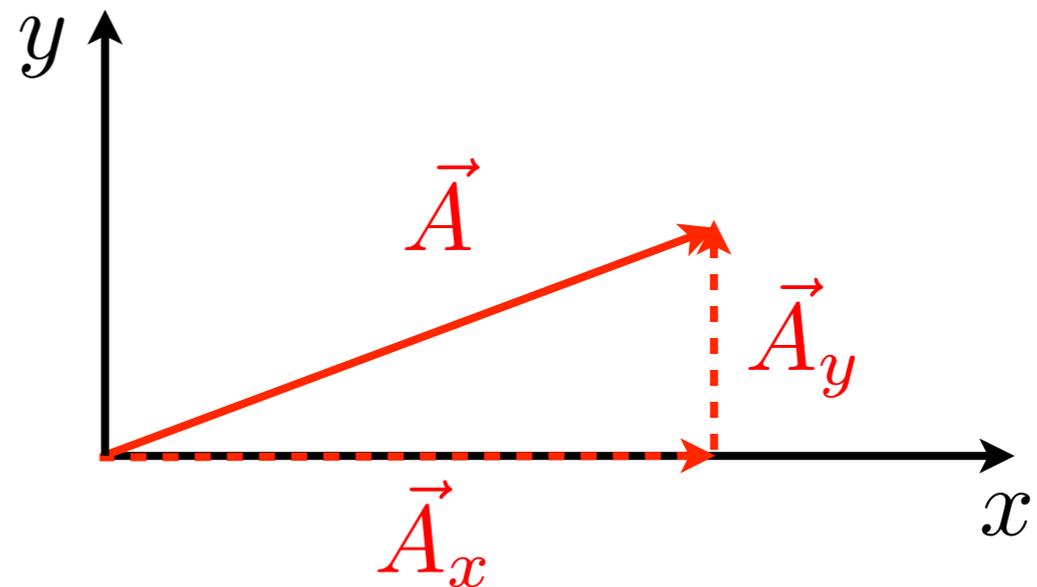
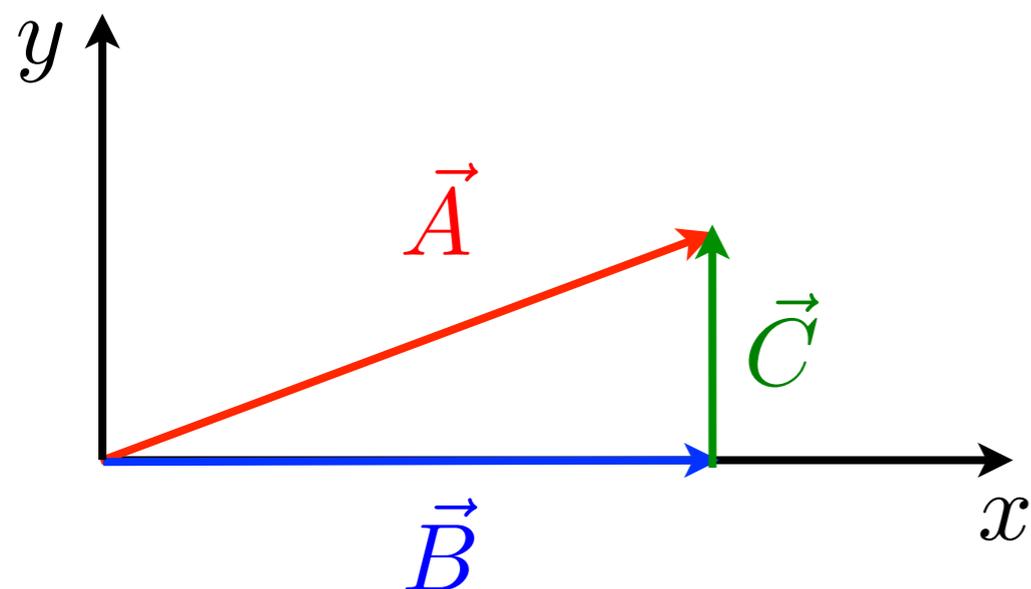
this graphical method is limited - we don't want to have to draw scale diagrams !

is there a mathematical technique to add vectors ?

yes! but we need to develop *components* first



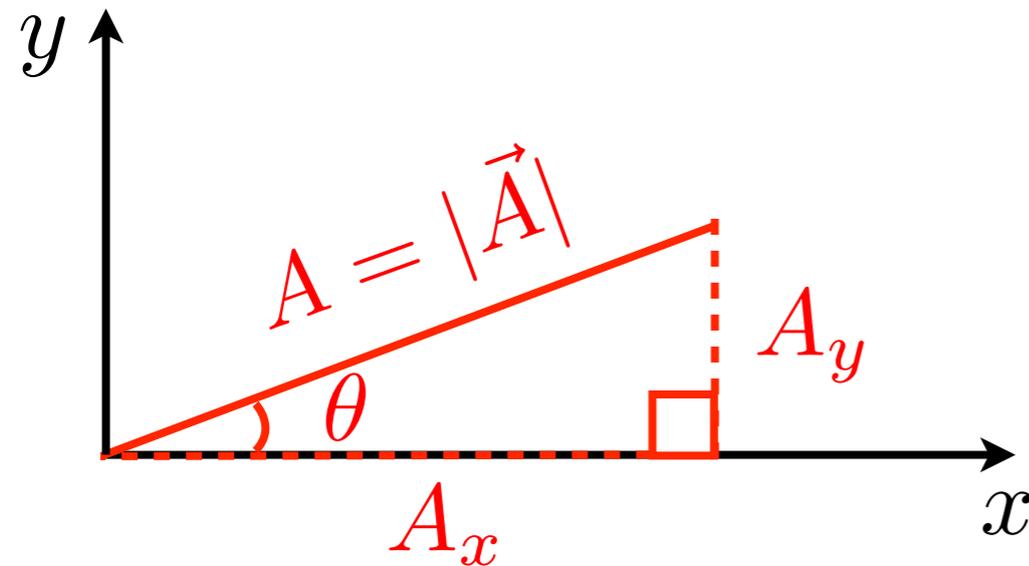
$$\vec{A} = \vec{B} + \vec{C}$$



components of vectors

but notice that this is just a right-angled triangle !

TRIGONOMETRY



$$A^2 = A_x^2 + A_y^2$$

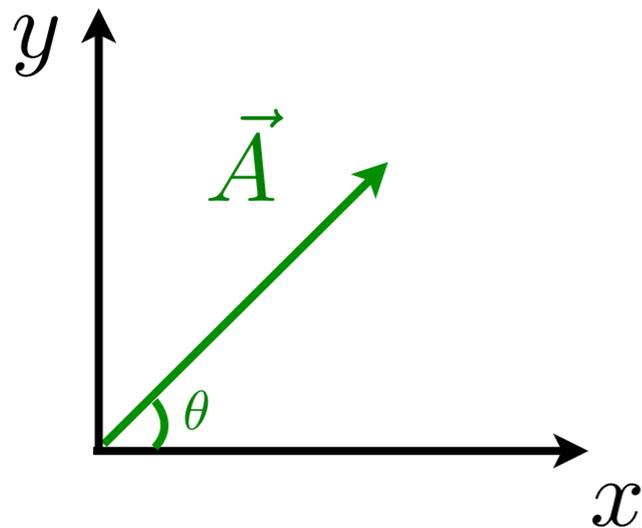
pythagoras

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

$$A_x = A \cos \theta$$

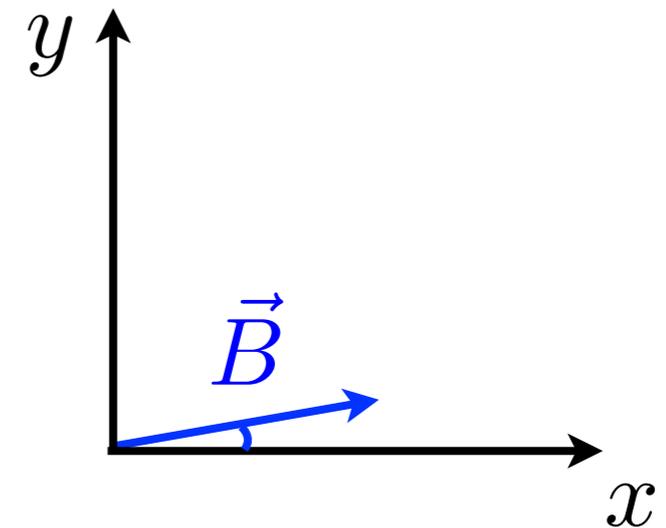
$$A_y = A \sin \theta$$

components of vectors



$$|\vec{A}| = 3$$
$$\theta = 45^\circ$$

$$\begin{array}{l} A_x = 3 \cos 45^\circ \\ = 3 \times 0.707 \\ = 2.121 \end{array} \quad \left| \quad \begin{array}{l} A_y = 3 \sin 45^\circ \\ = 3 \times 0.707 \\ = 2.121 \end{array} \right.$$

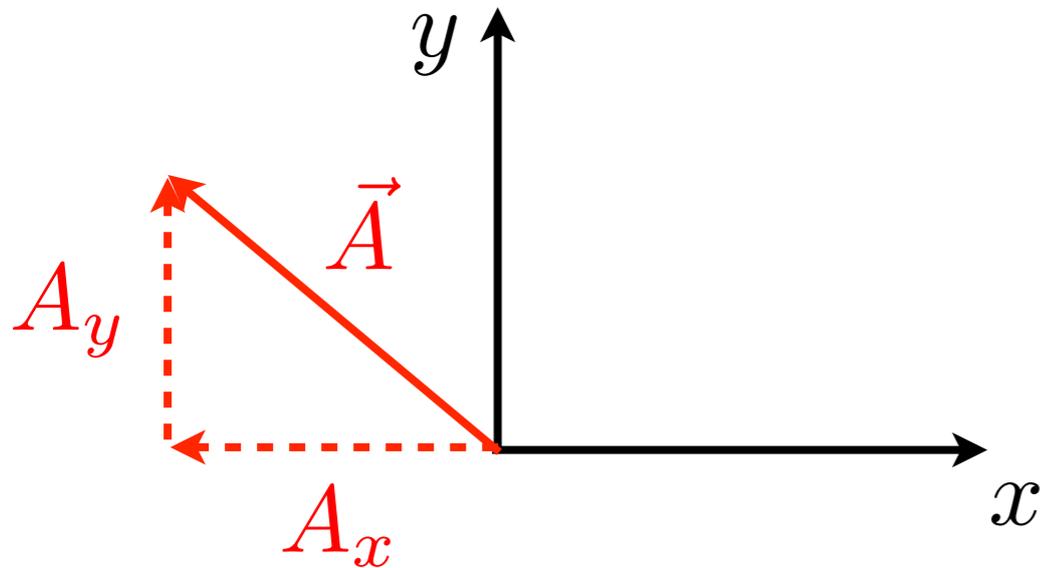


$$|\vec{B}| = 2$$
$$\theta = 10^\circ$$

$$\begin{array}{l} B_x = 2 \cos 10^\circ \\ = 2 \times 0.985 \\ = 1.970 \end{array} \quad \left| \quad \begin{array}{l} B_y = 2 \sin 10^\circ \\ = 2 \times 0.174 \\ = 0.347 \end{array} \right.$$

components of vectors

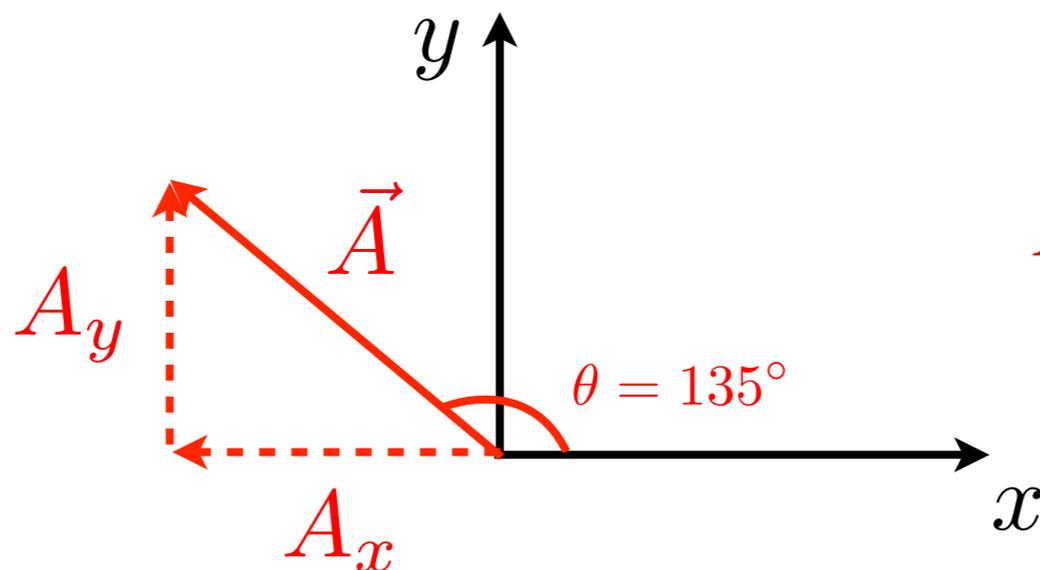
careful, components might be negative



A_x will be negative here (going to negative x)

A_y is still positive (going to positive y)

be careful “doing the trig”



use the angle counter-clockwise from the x -axis and the signs will be right automatically

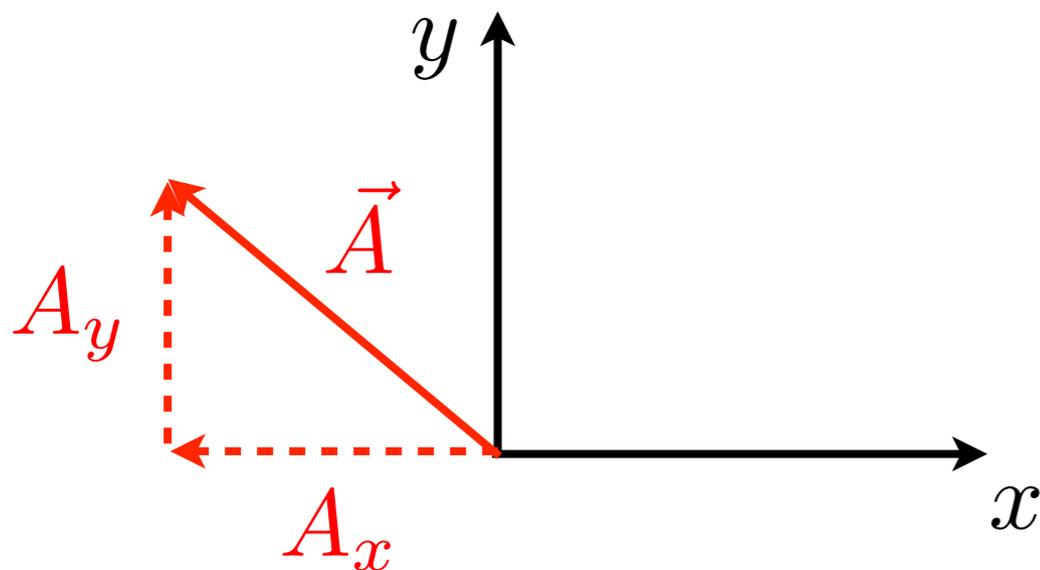
$$|\vec{A}| = 3$$

$$\begin{aligned} A_x &= 3 \cos 135^\circ \\ &= 3 \times (-0.707) \\ &= -2.121 \end{aligned}$$

$$\begin{aligned} A_y &= 3 \sin 135^\circ \\ &= 3 \times 0.707 \\ &= 2.121 \end{aligned}$$

components of vectors

careful, components might be negative

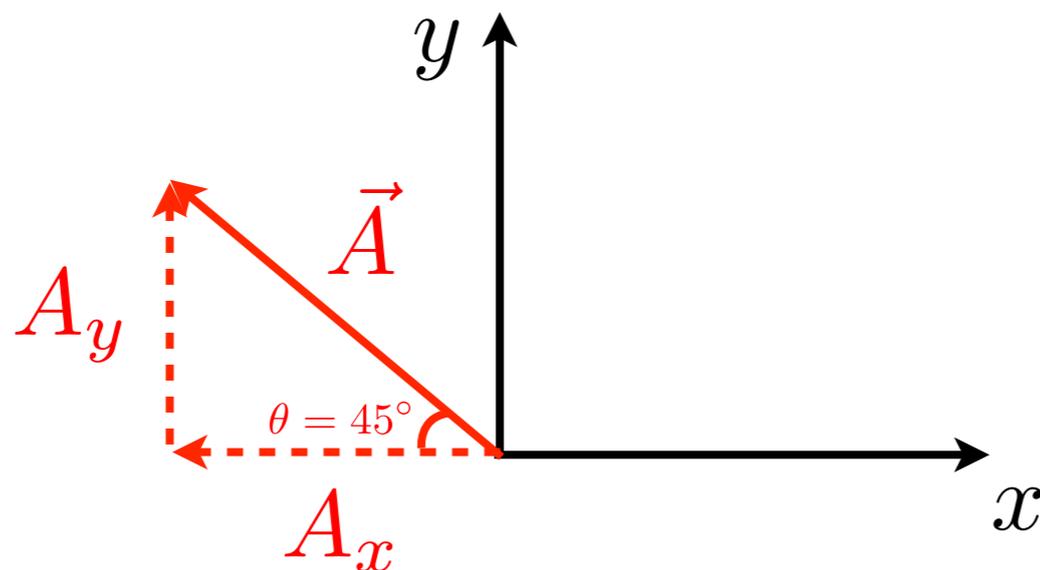


A_x will be negative here (going to negative x)

A_y is still positive (going to positive y)

be careful “doing the trig”

use any other angle and you better be careful to put the right signs “by hand”

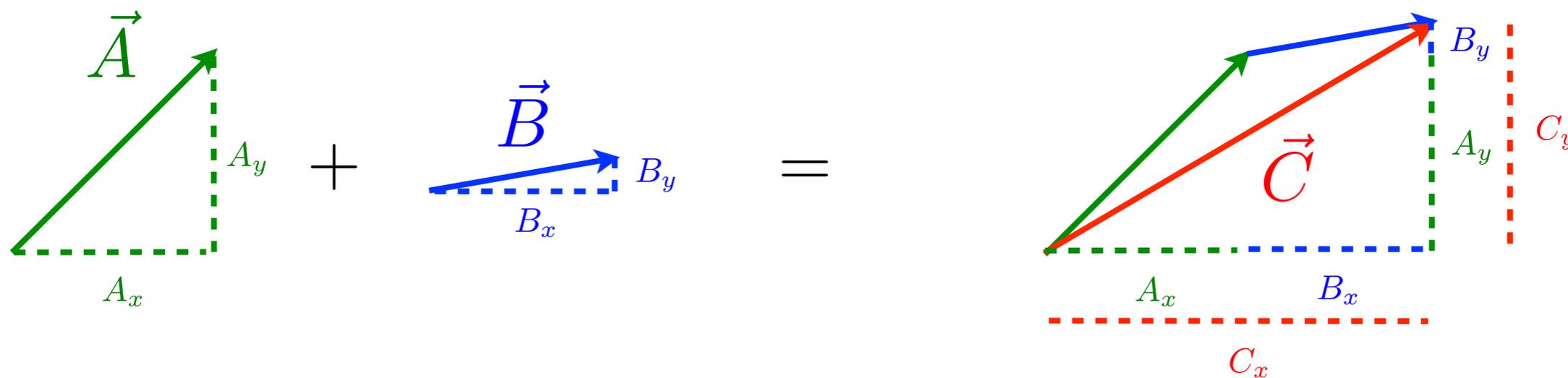
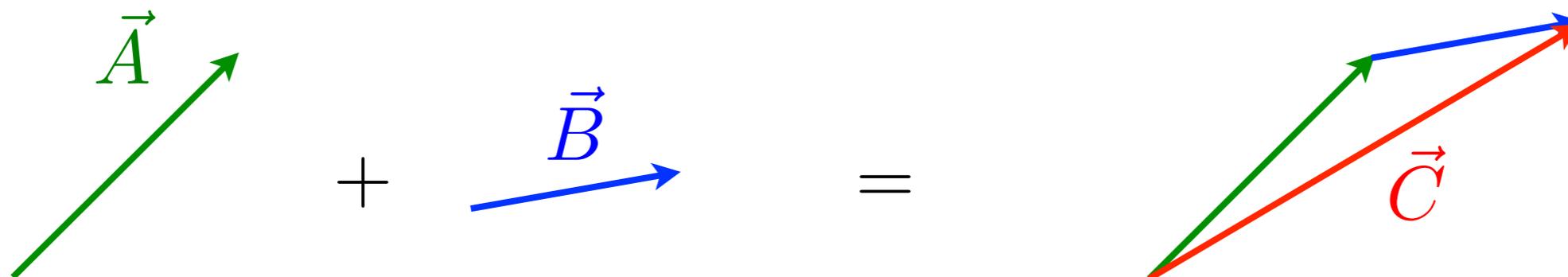


$$|\vec{A}| = 3$$

$$\begin{aligned} A_x &= 3 \cos 45^\circ \\ &= 3 \times 0.707 \\ &= \underline{\underline{-2.121}} \end{aligned}$$

$$\begin{aligned} A_y &= 3 \sin 45^\circ \\ &= 3 \times 0.707 \\ &= 2.121 \end{aligned}$$

adding vectors via components



$$C_x = A_x + B_x$$

$$C_y = A_y + B_y$$

units & dimensions

most quantities we measure have **dimensions** and we need to choose **units**

e.g. lengths: meters, feet, miles, cubits ...

the closest thing to standardized scientific units is **SI** (*Système international d'unités*):

- length in meters (m)
- mass in kilograms (kg)
- time in seconds (s)
- ...

smaller & larger scale units
can be made using prefixes:

tera-	$\times 10^{12}$	T
giga-	$\times 10^9$	G
mega-	$\times 10^6$	M
kilo-	$\times 10^3$	k
<hr/>		
centi-	$\times 10^{-2}$	c
milli-	$\times 10^{-3}$	m
micro-	$\times 10^{-6}$	μ
nano-	$\times 10^{-9}$	n
pico-	$\times 10^{-12}$	p
femto-	$\times 10^{-15}$	f

units & dimensions

most quantities we measure have **dimensions** and we need to choose **units**

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the closest thing to standardized scientific units is **SI** (*Système international d'unités*) :

- length in meters (m)
- mass in kilograms (kg)
- time in seconds (s)

...

but you might be more familiar with “Imperial” :

- length in inches, feet, miles ...
- mass in pounds ...
- time in seconds

...

we need to be able to convert between unit systems

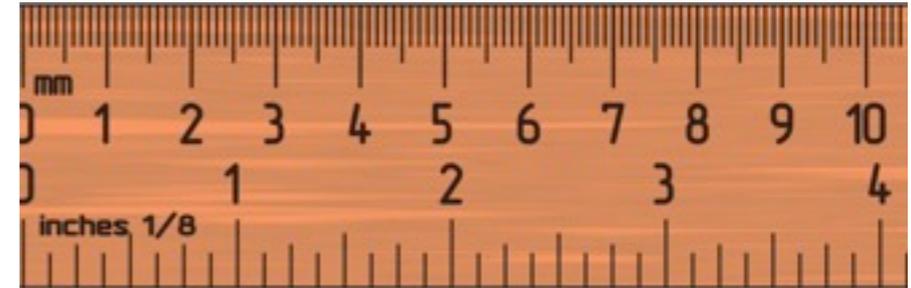
unit conversions

lots of ways to do this - one way is to use standard algebra rules

e.g. converting inches to cm

$$1 \text{ in} = 2.54 \text{ cm}$$

$$\Rightarrow 1 = \frac{2.54 \text{ cm}}{1 \text{ in}} \quad \& \quad 1 = \frac{1 \text{ in}}{2.54 \text{ cm}}$$



e.g. what is 12 inches expressed in cm ?

$$12 \text{ in} = \frac{2.54 \text{ cm}}{1 \text{ in}} \times 12 \text{ in} = 30.48 \text{ cm}$$

e.g. what is 14 cm expressed in inches ?

$$14 \text{ cm} = \frac{1 \text{ in}}{2.54 \text{ cm}} \times 14 \text{ cm} = 5.51 \text{ in}$$

significant figures - a bad joke



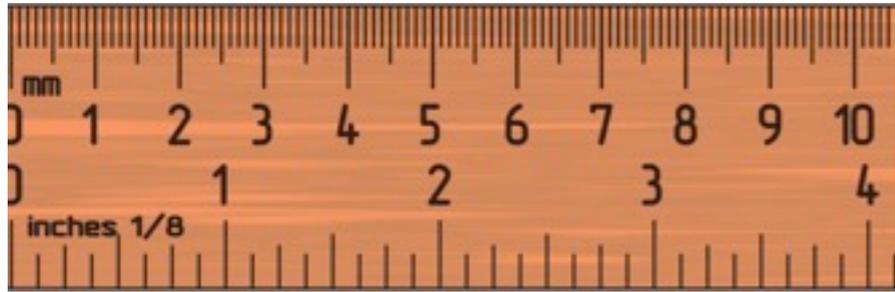
A father takes his son to a natural history museum. The son asks “Dad, when did that dinosaur die?”. The father replies “Sixty-seven million and twenty-seven years ago”. The son wonders “How do you know that?”. The father says “Well, I visited this museum twenty-seven years ago and the docent said it was sixty-seven million years old”.

Hopefully you get the joke.

This is basically what **significant figures** is all about, we need to indicate how precisely we know a number.

significant figures

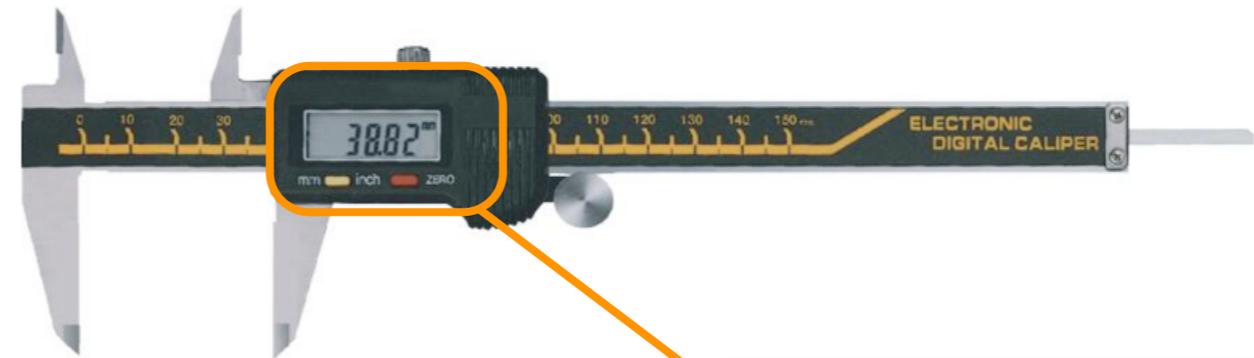
precision of measurement



precise to ~ 1 mm

e.g. 39 mm

which really means between
38 mm and 40 mm



precise to ~ 0.01 mm



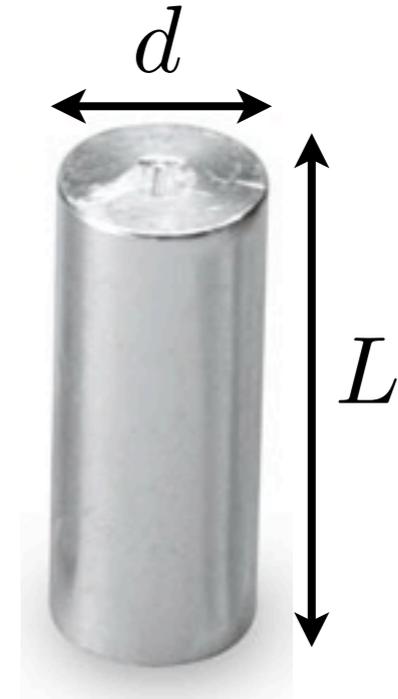
e.g. 38.82 mm

which really means between
38.81 mm and 38.83 mm

significant figures - propagating precision

when you 'use' a measured number in a calculation, make sure to quote only the precision you really have

e.g. suppose we measured the dimensions of this cylinder
and work out the volume using $V = \pi \left(\frac{1}{2}d\right)^2 L$



measure d with the calipers $d = 12.05$ mm

measure L with the ruler $L = 62$ mm

$$V = 3.14159 \times (0.5 \times 12.05 \text{ mm})^2 \times 62 \text{ mm}$$

$$= \del{7070.58} \text{ mm}^3 \quad \text{but we don't know the volume this precisely !}$$

limit is the measurement of $L = 62$ mm - just two sig. fig.

$$= 7.1 \times 10^3 \text{ mm}^3$$

significant figures - propagating precision

the 'rule of thumb' is always limit by the least precise number

e.g. $28.92 \text{ m} + 1.478 \text{ m} = 30.398 \text{ m}$

this figure wasn't determined
in the first number

$28.92 \text{ m} + 1.478 \text{ m} \rightarrow 28.92 \text{ m} + 1.48 \text{ m} = 30.40 \text{ m}$

rounded
here

e.g. $1.794 \times 10^6 - 2.9 \times 10^5 = 1.794 \times 10^6 - 0.29 \times 10^6 \rightarrow 1.79 \times 10^6 - 0.29 \times 10^6 = 1.50 \times 10^6$

this zero is
significant

order of magnitude estimation

a useful skill is to be able to estimate roughly the magnitude of some quantity

we talk about 'order of magnitude' and we mean accurate in powers of ten

e.g.

$\mathcal{O}(10)$ students in class today

$\mathcal{O}(10)$ miles to Newport News

$\mathcal{O}(100)$ miles to New York city

$\mathcal{O}(1000)$ miles to Los Angeles

$\mathcal{O}(10^5)$ kilometers to the moon

$\mathcal{O}(10^{-10})$ meters - size of an atom