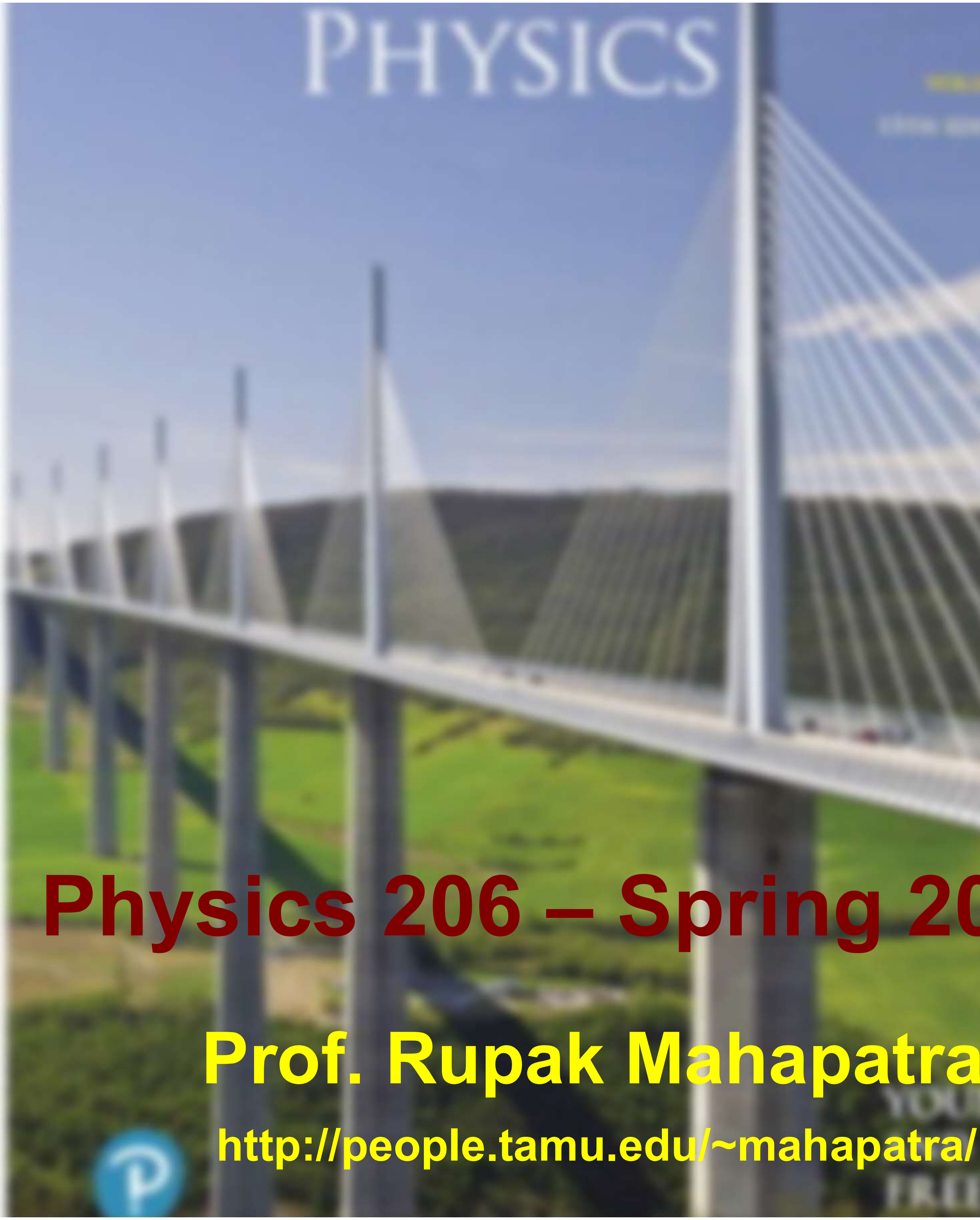

Physics 206 – Spring 2024

Prof. Rupak Mahapatra

http://people.tamu.edu/~mahapatra/

- I am an experimental particle physicist with an undergraduate degree in Chemical Engineering and PhD in Particle Physics
- My group is a leader in the world in making very sensitive cryogenic (milli Kelvin temp) detectors here in my lab
- These are used for Dark Matter and reactor neutrino detection

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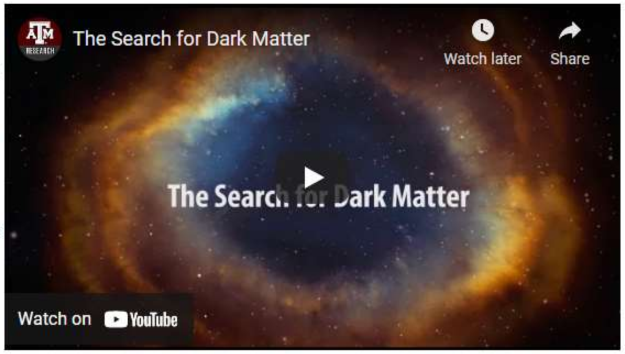
TEXAS A&M UNIVERSITY

Dark Matter, Neutrino and Axion Searches

Funded By

- Home
- SuperCDMS
- MINER
- Instruments
- Collaborators
- Publications
- Group Members
- Contact Info
- Teaching
- Job Opportunities



Dark Matter makes up for more than 85% of the universe, but is yet to be fully understood. It can be felt gravitationally, but can not be seen. The motion of galaxies and clusters are dominated by the presence of this Dark Matter. Dark Matter pervades all space around us, but we do not see it due to its exceptionally low interaction strength with ordinary matter. The most plausible hypothesis for the nature of Dark Matter, based on astrophysical observation and particle physics, is a particle called WIMP (Weakly Interacting Massive Particle). A dark matter particle passes through us every second, yet we do not feel it due to their extremely rare interaction with ordinary matter. Understanding the nature of Dark Matter is one of the biggest quests of Physics.

Due to the rareness of such recoil and the exceptionally low amount of energy released, an experiment needs to not only be very sensitive, but also have the ability to reject fake events, which can come from radioactivity. The experiment that has led the world in the field of low-mass dark matter search is called the Super Cryogenic Dark Matter Search (SuperCDMS), earlier located in USA and the next generation being commissioned in the SNOLAB at Sudbury mines in Canada. The experiment uses very sophisticated detector technology and advanced analysis techniques to enable cryogenically cooled (almost absolute zero temperature at 40 mK) Germanium and Silicon targets to search for the rare recoil of dark matter particles.

Our group is leading (along with Stanford) the detector development for next generation dark matter detectors utilizing cryogenically cooled semiconductor detectors with Transition Edge Sensors. Using our dedicated semiconductor detector fabrication facility in the Mahapatra group, we are inolved in end to end fabrication of SuperCDMS detectors, starting from bare Ge/Si crystals from vendors and going through a series of steps involving characterization of the crystal purity, detector grade polishing, followed by thin film deposition and photolithographic patterning of the transition edge sensors. Finally, we fully cryogenically characterize these detectors in our labs at TAMU using our newly acquired Bluefors closed-cycle cryogenic systems.

We have also utilized our detector and cryogenics expertise to establish a new experiment to detect coherent scattering of neutrinos (CNS) on these ultra-low threshold detectors and use it as a probe to search for new physics. The new MINER (Mitchell Institute Neutrino Experiment at Reactor) is housed at the Nuclear Science Center (NSC) on the TAMU campus. This experiments hopes to be the first experiment in the world to detect coherent scattering of reactor neutrinos, which would not only open doors to potential new physics, but also have practical applications in nuclear reactor safeguards and non-proliferation: MINER

Axion is another possible candidate for Dark Matter that was hypothized to solve the strong-CP problem in particle physics. There is a very large parameter space for axion mass, since they were never in thermal equilibrium unlike the WIMPs. While supeconducting RF cavities are the leading technolgies for tunable axion searches, the community has recently realized new ideas exist for broadband axion searches from the conversion of photons into axions through the Primakoff process. One such idea is being pursued by our group at the MINER reactor experiment, with the profuse source of photons from the reactor: PRL.

Today's class

- Go through the webpage/syllabus
  - Course components
  - Course schedule
  - Learning Objectives
  - general strategies
  - Chapter 1 – a review of vectors and vector operations

Course Coordinators

Dr. Larry May (larry.may@tamu.edu) and Dr. Mike Youngs (mdyoungs@tamu.edu)

Contact the course coordinators (copy both of them) for questions involving:

- absences and documentation
- any course grade questions not involving iClicker
- non-technical issues involving Mastering Physics (i.e. grades, assignments, etc.)
- Canvas and concept quiz issues (inactive links, missing content)

For iClicker grade questions and absences, contact your instructor.

For technical issues (login errors, website being down, etc.) involving Mastering Physics, contact their technical/customer support.

For missing Canvas information specific to your lecture (i.e. slides, office hours, iClicker) or section (i.e. recitation, TA office hours) contact your Instructor and TA, respectively.

For emails to the coordinators, put course number and section number in the title and include your UIN

- Ex. "Phys 206-531: Question about ____"
- We are responsible for >2000 students this semester, these details will let us help you faster

Absences

All absences from the course involving graded work must be documented according to University Policy in order to be considered for excusal.

Student Rule 07 - https://student-rules.tamu.edu/rule07/

Outlines all parameters for what constitutes an excused absence, how to document it and on what timeline to notify your faculty. You are responsible for knowing and following these guidelines

For absences involving major (coordinated) assignments such as recitation and exams, use the link in the "Absence Report Form" Module on Canvas

Documentation verifying absence **must** be included in this form in order for an absence to be considered for excusal. This form must be filled out within 2 business days of the last date of absence (per SR07), or the absence will be unexcused. If you are waiting on documentation, fill out the form within 2 days, the documentation can be added to the form after submission, as soon as you have it

For absences from lecture involving iClicker, directly contact your lecture instructor, do *not* use the absence form

Excused absences as defined by Student Rule 07 only apply to *physical* attendance and participation, not online work with extended access windows

Extensions for online submissions are not possible unless your absence documentation explicitly specifies your inability to complete *online* work for an *extended* period of time

Note: technology failure (such as servers being offline, power outage, device stopped working, lack of internet, etc.) do **not** constitute excused absences for online submissions

The due dates for online submissions are *final* due dates, not the day you have to start it – begin working on assignments early to stay ahead and prevent last-minute catastrophes

All excused absences will be judged at the sole discretion of the course coordinators

Exams

Common exams (same exam and time for all 206 students)

Exam 1 M 2/12 7:30-9:30pm
Exam 2 M 3/25 7:30-9:30pm
Exam 3 M 4/15 7:30-9:30pm

Comprehensive Exam Friday 4/26 5:00-7:00pm

Locations of Exams are TBD and will be announced via Canvas leading up to exams

You are expected to bring something to write with, an appropriate calculator and your student ID to all exams

All other exam materials will be provided

Required Materials

- The text is “University Physics”, 15th ed., Young and Freedman, Chapter 1-11, 13-14
- Canvas for registration to Pearson’s online homework (Mastering Physics)
- iClicker will be used in this class. Details for iClicker can be found on the Instructor Specific page in Canvas
  - Don’t buy the physical clickers - we will only use the web version/app
- A calculator that cannot wirelessly connect to the internet
  - This means no “smart” devices are allowed: no phones, tablets, laptops or smart watches during exams
  - A student using a non-approved calculator or “smart” device on an exam will obtain a zero for that exam.
  - For full list of approved calculators, we use the SAT calculator policy
  - https://satsuite.collegeboard.org/sat/what-to-bring-do/calculator-policy

Grade Breakdown

Grades will be determined based on the following criteria.

Exam total (LOs) – 4 exams	(70%)
Recitation	(6%)
iClicker	(6%)
Mastering Physics Chapter Homework	(6%)
Prelectures	(6%)
Concept Quizzes (Canvas)	(6%)
Total	(100%)

The grade breakdown for the class is as follows:

≥ 90 = A
80-89 = B
65-79 = C
50-64 = D
< 50 = F

Due dates

Homework assignments are due by midnight two nights before an exam

Example: Chs. 1-3 and Math Review due Sat. Feb. 10th by 11:59pm

Prelectures are due Saturday nights by 11:59pm the weekend before we will start a topic (according to the schedule on the syllabus)

Example: Chs. 1 & 2 prelectures are due Sat. Jan. 20th by 11:59pm

Concept Quizzes are due by midnight two nights before an exam

Example: Chs. 2 & 3 CQ due Sat. Feb. 10th by 11:59pm

Don't wait until the last minute to do your assigned work.

Late work policies – Course-wide identical due dates

Homework: Not accepted late

Pre-lectures: 20% penalty per day

Concept Quizzes: Not accepted late

"How do I do better in this course?"

Unfortunately, there is no singular answer for this question. Every student is different. Every student will need a different amount of time spent with the course. There are a few approaches that can help many students though and they are the same approaches to most math, physics, chemistry and engineering courses.

•Study concepts, definitions, terms and phrases

•Study the equation sheet

•In Canvas, there is an example set of "flashcards" going through the Chapter 2 & 3 equations and some of the concepts, phrases and physical laws of that chapter.

•When it takes you several attempts to solve a problem, don't immediately move to the next question. Ask yourself, "What am I missing? What didn't I understand?"

•Be careful when studying solutions that are posted by someone else. It doesn’t help to see. You need to do it

•A good general rule when working problems is this: for every incorrect problem, solve 3 more

•Treat previous/practice exams like the actual exam

•This is perhaps the most difficult thing to hear. There is no way to become a skilled problem solver in physics/math/chemistry/engineering/etc without solving problem after problem after problem until you see the patterns in getting from the prompt through the solution to the answer.

•For some people, this may only take a handful of problems or examples.
•For others, This may take hundreds.
•Each student is unique, but the necessary path is to just solve problems.

The lectures – Just in Time Teaching (means review)

1. View the pre-lectures on Mastering before we meet
2. Take short quizzes to test your understanding of the concepts
3. I urge you to provide feedback so I know what to concentrate on in class ("just-in-time teaching")
4. We aim to have a more interactive lecture-session: clickers and problem-solving strategies. This is meant to be a review style lecture.
5. Follow up with resources available to you and doing problem after problem in the homework

Make sure you understand things as we go through them; it's ***very easy*** to fall behind in this course, and ***nearly impossible*** to catch back up!

What to expect in this course

- Expect to work and put a lot of time into this course
- Expect to truly learn the material. Memorization *won't* get you a good grade; there are no short cuts.
- You can't just see how a couple of problems are solved and expect to do well in the exam
- Expect a fast pace: ~1 chapter/week!
- Expect to get frustrated, confused, mad

- Expect to learn to think more critically
- Expect to understand most of the physical phenomena you experience in everyday life
- Expect to develop good study habits and a strong work ethic which will serve you well in other courses and future careers!

Strategies

- The obvious: come to class, go to recitations, do the work *yourself*, study and practice problems
- The not as obvious:
  - Student: "It makes sense in class, but then I'm lost when I get back home and try to do homework"

  Me: Read textbook and work out examples to get a better understanding

  - Student: "I come to class and have done well on the homework; so why did I bomb your test???"

  Me:
    - "Did you do the homework on your own?"
    - "Did you copy a similar example as worked out in the solution manual or on the web?"
    - "Did you use the book as you did it?"
    - "Did you only use the formula sheet as you worked problems?"
- http://mechanics.physics.tamu.edu/index.shtml#resources

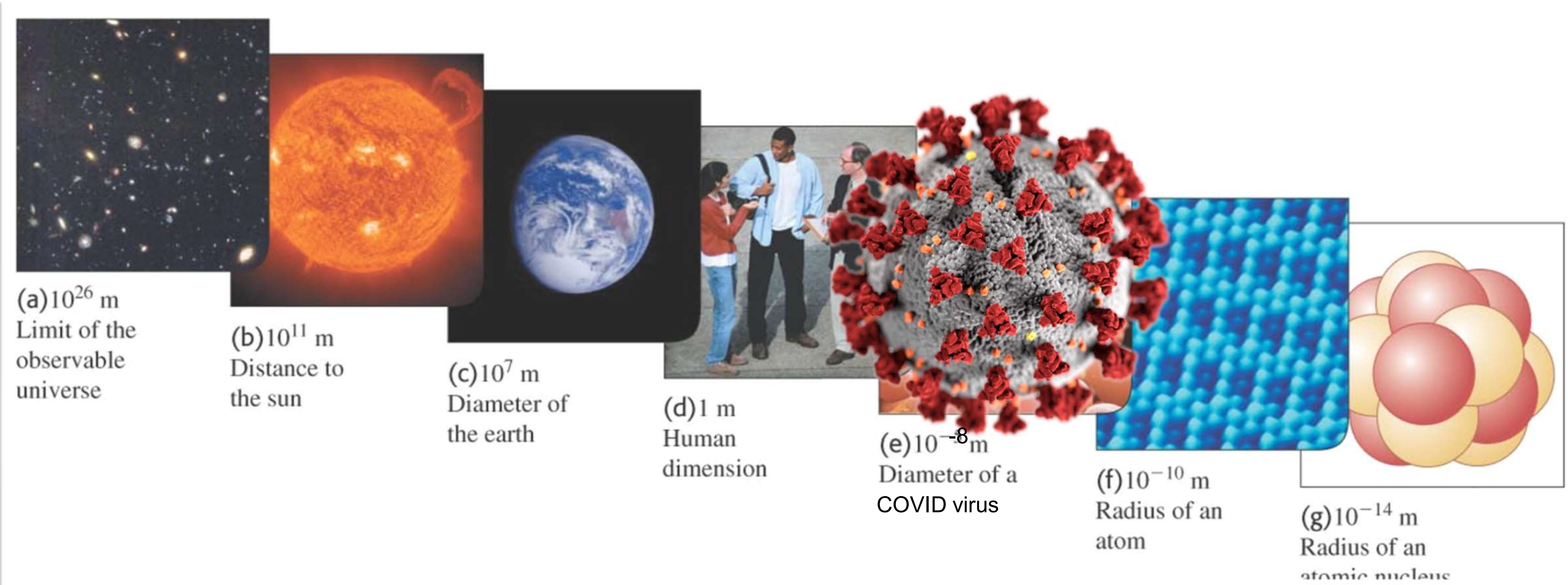
Chapter 1

Units, Physical Quantities, and Vectors

Standards and units

Base units are set for length (meter or m), time (seconds or s), and mass (Kilogram or Kg).

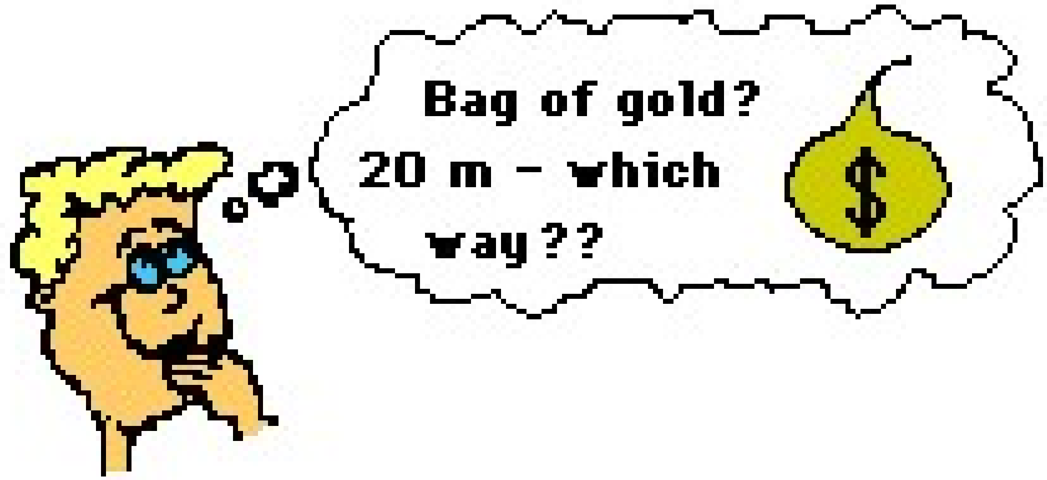
Unit prefixes size the unit to fit the situation.



Kilo=k=10^{3}
Centi=c=10^{-2}
Mili=m=10^{-3}
Nano=n=10^{-9}

Vectors

Why we care about them
Addition & Subtraction
Unit Vectors
Multiplication



Three dimensions: *X*, *Y* and *Z*.

Need a way of saying how much in each direction

Vector has a magnitude AND a direction

10 miles in the south direction

Scalar is just number

Mass of your car

Where am I?

Let's say I'm here

You're here (origin)

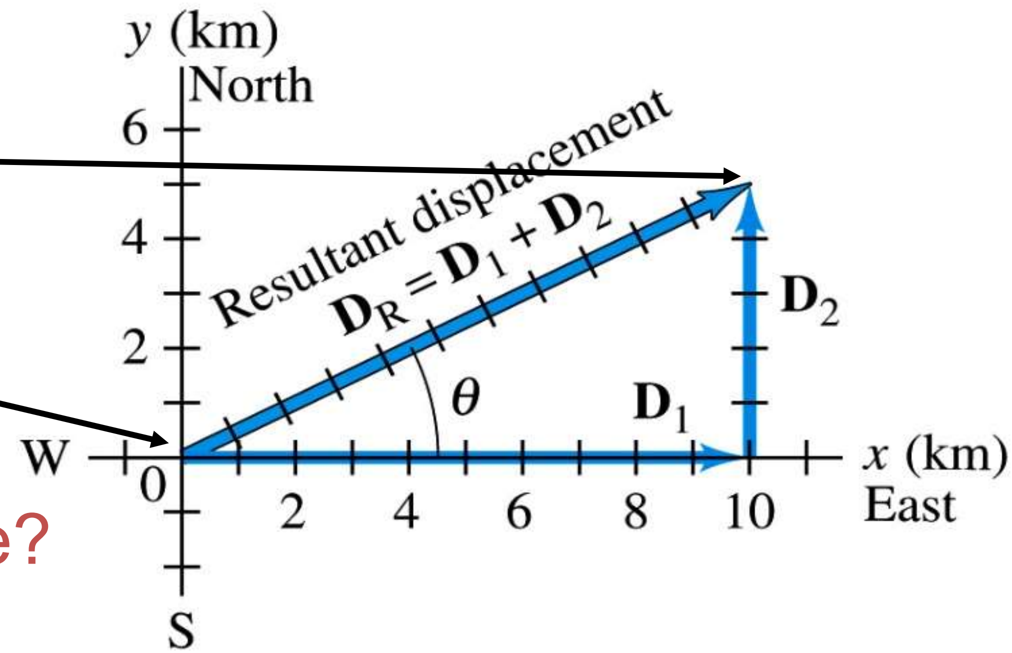
I call you on the cell phone.

How do I tell you how to get to me?

2 equivalent ways:

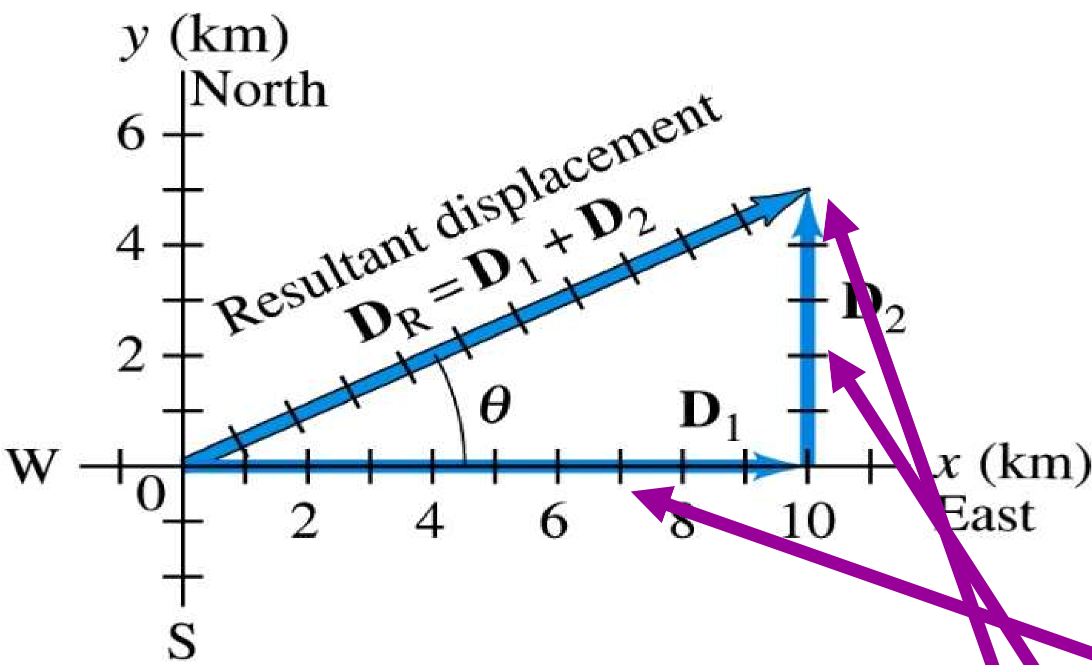
•Travel 11.2 km at an angle of 26.5 degrees

•Travel 10 km East then 5 km North



A single vector in arbitrary direction can be thought of as two vectors in nice simple directions (like *X* and *Y*). This can make things *much easier*

Vector Addition



To specify where I am, often doing the two vector version is easier

Represent Graphically:

Lay down first vector

Lay down second vector

Put the <u>tail</u> at the <u>head</u> of the first vector

The "Sum" is where I am

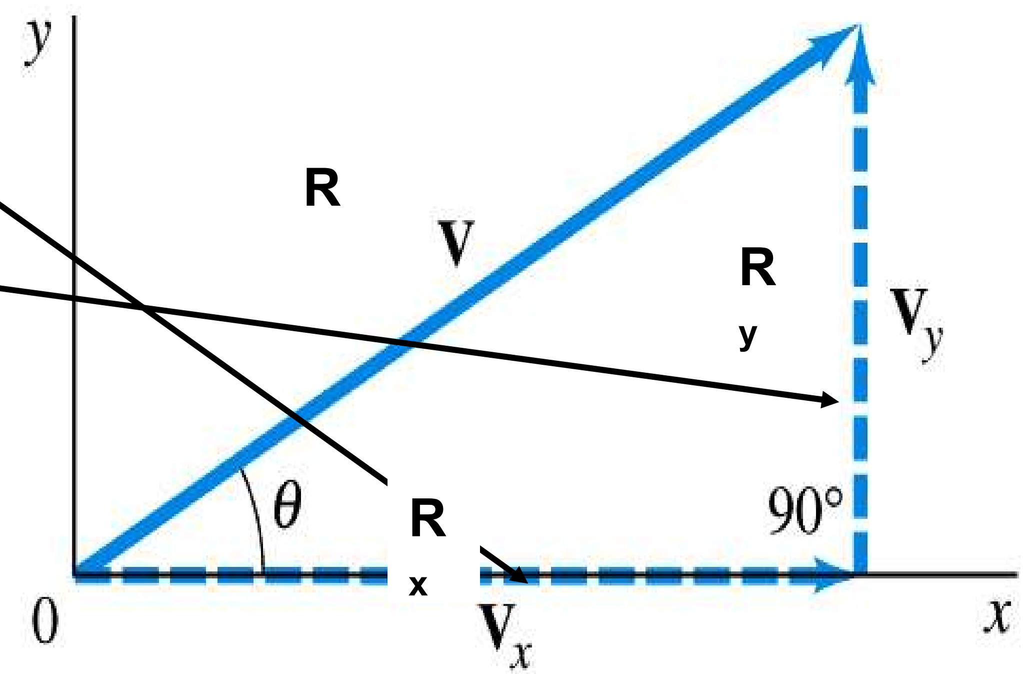
Re-write my location

Describe my location in terms of the sum of two vectors

$$\vec{R} = \vec{R}_X + \vec{R}_Y$$

$$|R_X| = |R|\cos\Theta$$

$$|R_Y| = |R|\sin\Theta$$



Careful when using the sin and cos

Specifying a Vector

Two equivalent ways:

1. Components V_x and V_y
2. Magnitude V and angle θ

Switch back and forth

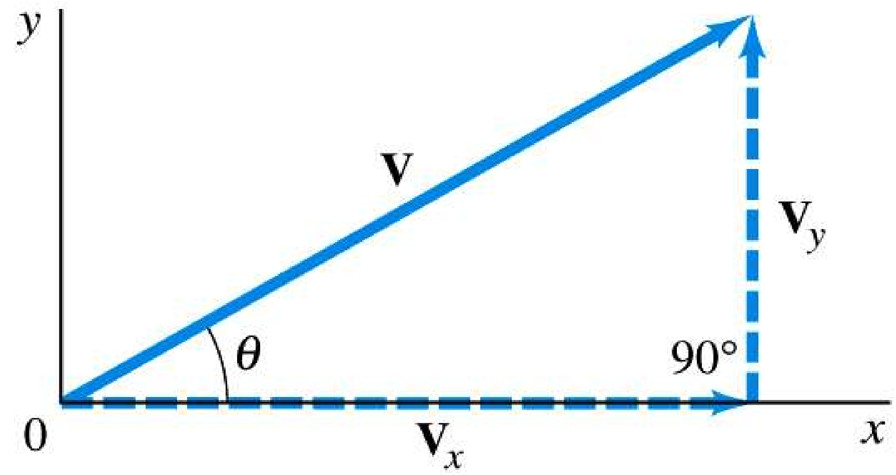
Magnitude of V

$|V| = (v_x^2 + v_y^2)^{½}$

Pythagorean Theorem

$tan\theta = v_y / v_x$

Either method is fine, pick one that is easiest for you, but be able to use both



$$\sin\theta = \frac{V_y}{V}$$

$$\cos\theta = \frac{V_x}{V}$$

$$\tan\theta = \frac{V_y}{V_x}$$

$$V^2 = V_x^2 + V_y^2$$

Unit Vectors

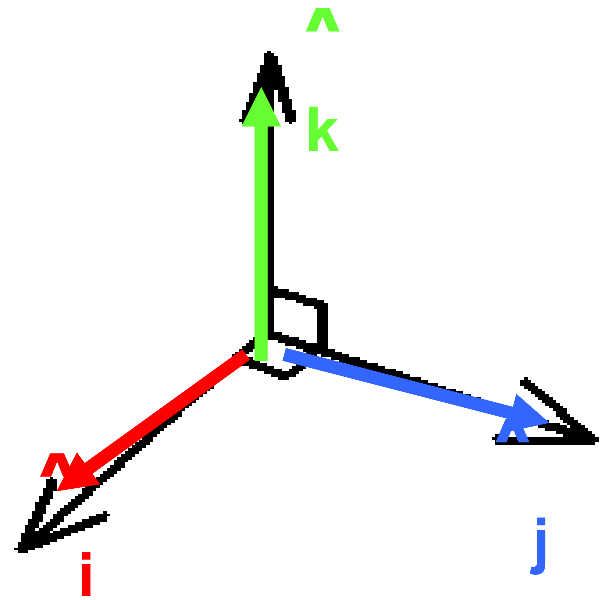
x

Another notation for vectors:

Unit Vectors denoted i, j, k

Magnitude of 1

Only purpose is to point in space



$\hat{i}$ means 1 in the x direction

$\hat{j}$ means 1 in the y direction

$\hat{k}$ means 1 in the z direction

$$\vec{V} = V_x \hat{i} + V_y \hat{j} + V_z \hat{k}$$

Unit Vectors

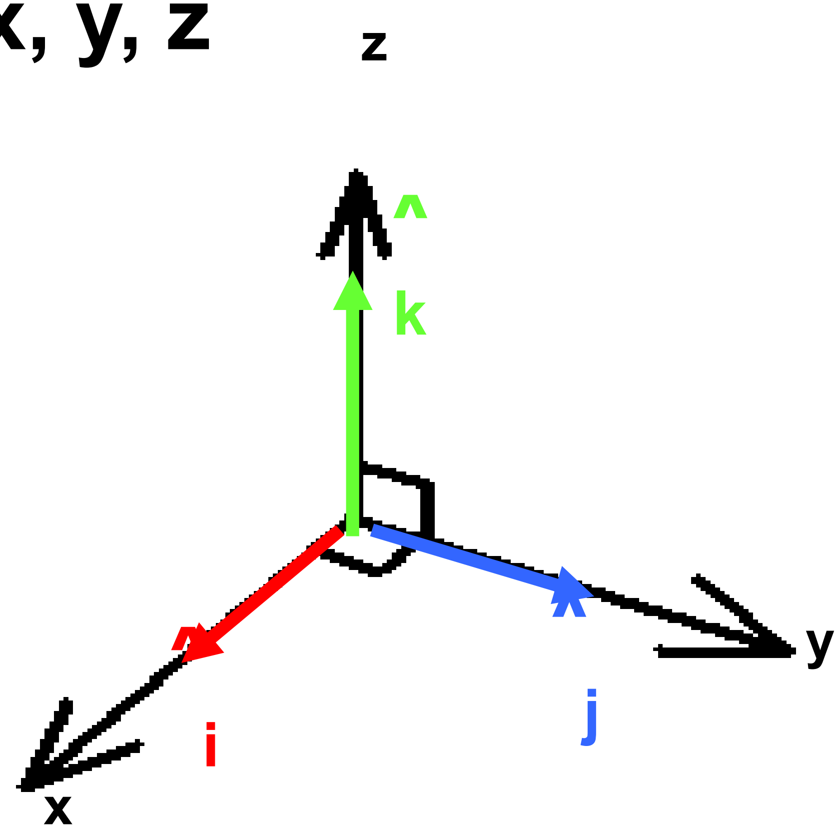
Similar notations, but with **x, y, z**

$\hat{x}$ is the same as $\hat{i}$

$\hat{y}$ is the same as $\hat{j}$

$\hat{z}$ is the same as $\hat{k}$

$$\vec{V} = V_x \hat{x} + V_y \hat{y} + V_z \hat{z}$$



Vector in Unit Vector Notation

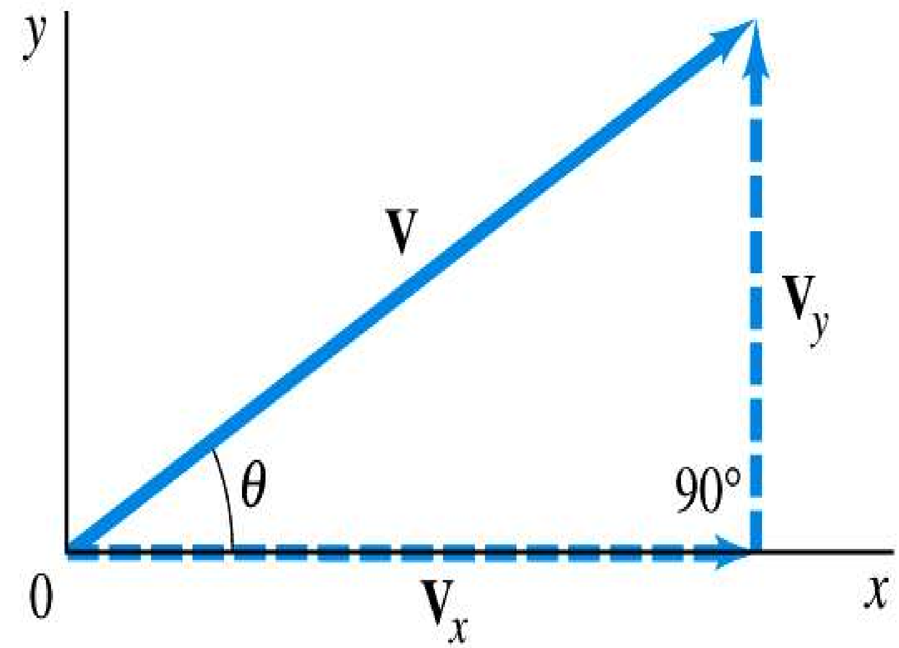
$$|V_X| = |V|\cos\Theta$$

$$|V_Y| = |V|\sin\Theta$$

$$\vec{V} = \vec{V}_X + \vec{V}_Y$$

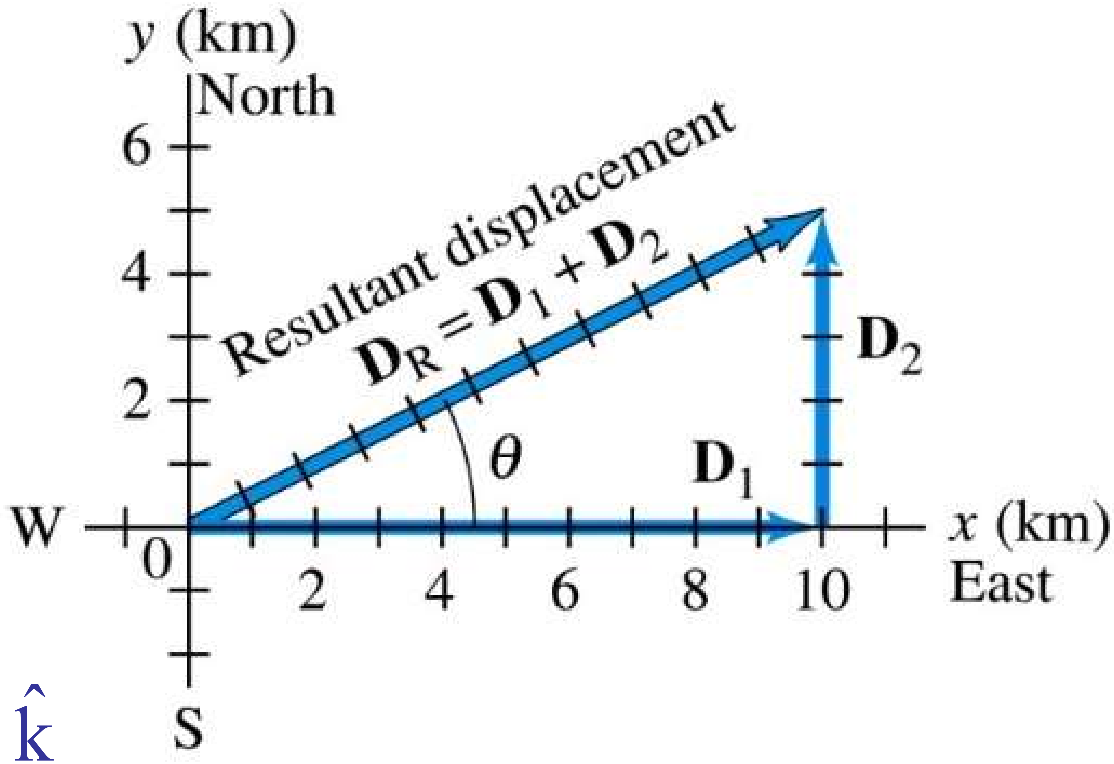
$$\vec{V} = V_X\hat{i} + V_Y\hat{j}$$

$$\vec{V} = |V|\cos\Theta\hat{i} + |V|\sin\Theta\hat{j}$$



General Addition Example

Add two vectors using the hats, *j*-hats and *k*-hats



$$\vec{D}_R = \vec{D}_1 + \vec{D}_2$$

$$\vec{D}_1 = 10\,\text{km}\,\hat{i} + 0\,\text{km}\,\hat{j} + 0\,\text{km}\,\hat{k}$$

$$\vec{D}_2 = 0\,\text{km}\,\hat{i} + 5\,\text{km}\,\hat{j} + 0\,\text{km}\,\hat{k}$$

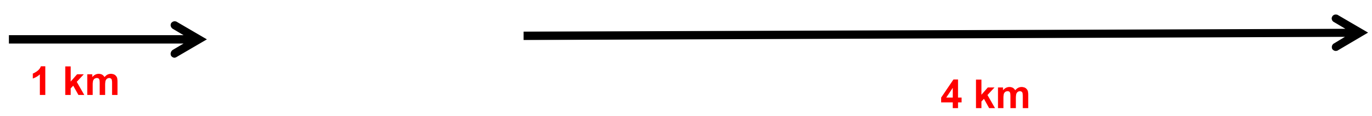
$$\Rightarrow \boxed{\vec{D}_R = 10\,\text{km}\,\hat{i} + 5\,\text{km}\,\hat{j} + 0\,\text{km}\,\hat{k}}$$

Simple Multiplication

Multiplication of a vector by a scalar

Let's say I travel 1 km east. What if I had gone 4 times as far in the same direction?

→Just stretch it out, multiply the magnitudes

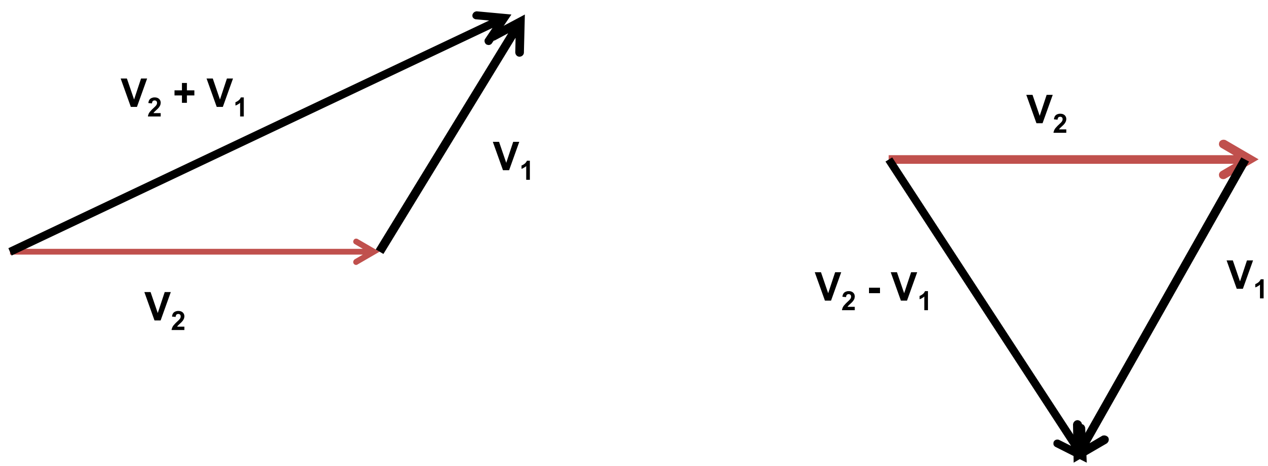


Negatives:

Multiplying by a negative number turns the vector around

Subtraction

Subtraction is same as addition, except the second vector is first made negative and then the two are added together



$$\vec{V}_2 - \vec{V}_1 = \vec{V}_2 + (-\vec{V}_1)$$

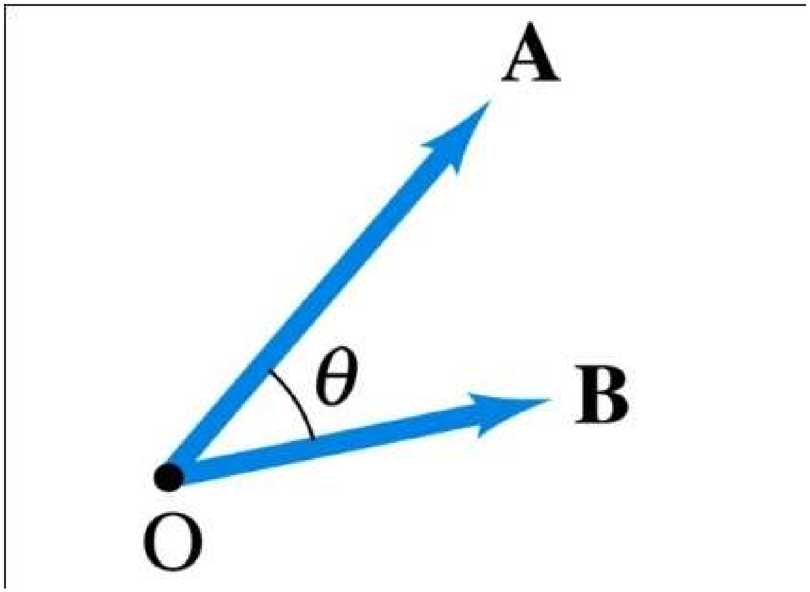
How do we Multiply Vectors?

First way: <u>Scalar Product</u> or <u>Dot Product</u>

Why Scalar Product?
Because the result is a scalar (just a number)

Why a Dot Product?
Because we use the notation *A·B*

$$\vec{A}\cdot\vec{B} = |A||B|\cos\theta$$

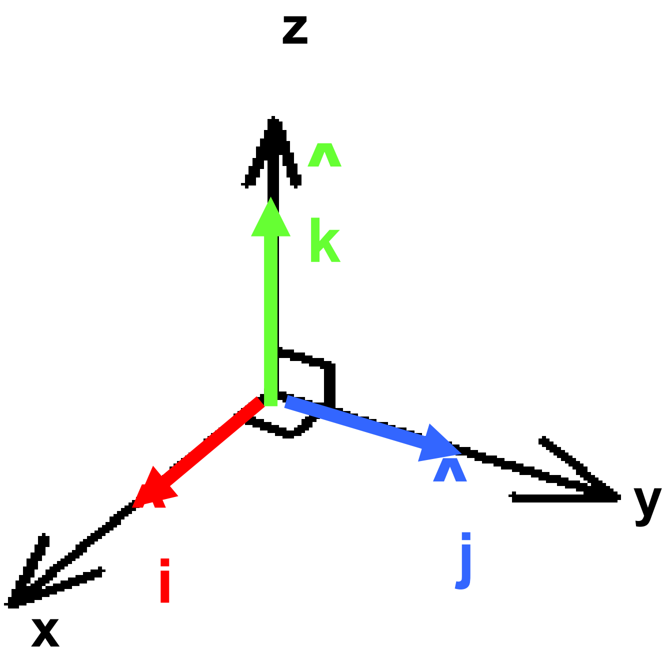


First Question:

$$\vec{A} \cdot \vec{B} = |A||B| Cos\Theta$$

What is $\hat{i} \bullet \hat{i}$?

What is $\hat{i} \bullet \hat{j}$?



Harder Example

$$\vec{A} = A_X\,\hat{i} + A_Y\,\hat{j}$$

$$\vec{B} = B_X\,\hat{i} + B_Y\,\hat{j}$$

What is $\vec{A} \bullet \vec{B}$ using Unit Vector notation?

Vector Cross Product

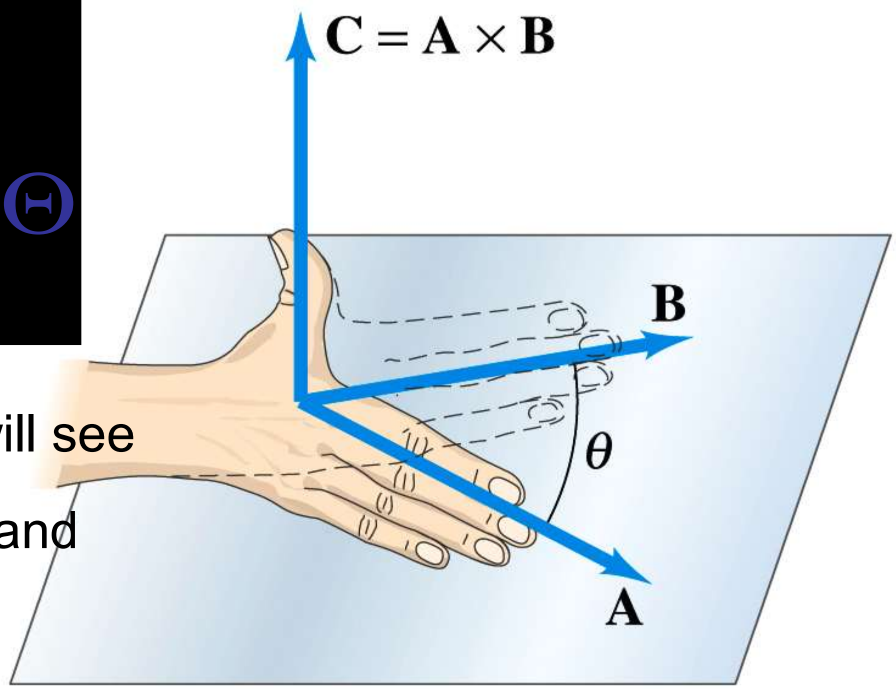
$$\vec{C} = \vec{A} \times \vec{B}$$

$$|C| = |A|\,|B| \operatorname{Sin} \Theta$$

This is the last way of multiplying vectors we will see

Direction from the "right-hand rule"

Swing from A into B!



Vector Cross Product Cont...

Multiply out, but use the Sinq to give the magnitude, and RHR to give the direction

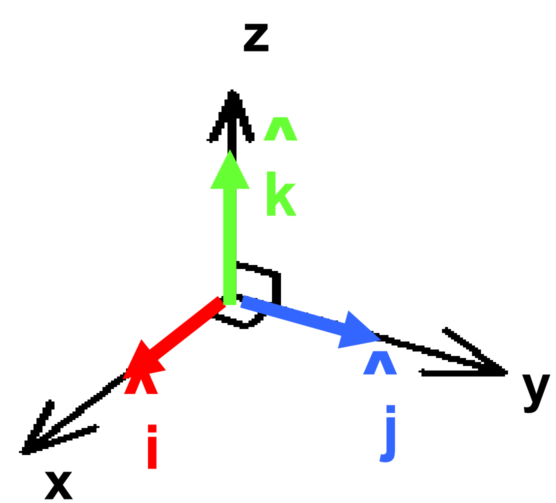
$$\vec{C} = \vec{A} \times \vec{B}$$

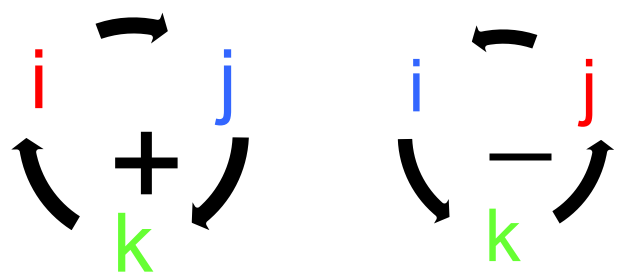
$$|C| = |A|\,|B| \operatorname{Sin}\Theta$$

$$\hat{i} \times \hat{i} = 0 \ \ (\sin\theta = 0)$$

$$\hat{i} \times \hat{j} = \hat{k} \ \ (\sin\theta = 1)$$

$$\hat{i} \times \hat{k} = -\hat{j} \ \ (\sin\theta = 1)$$





Cross Product Example

$$\vec{A} = A_X \hat{i} + A_Y \hat{j}$$

$$\vec{B} = B_X \hat{i} + B_Y \hat{j}$$

What is $\vec{A} \times \vec{B}$ using Unit Vector notation?