# Physics 1004: Winter 2010

## Introductory Electromagnetism and Wave Motion

*Please do not sit in back 5 rows*

*Please pick up a copy of the course outline (also on WebCT)*

*Please initial attendance sheet in beside your student number*

*If your number missing, add it at end*

# Physics 1004: Winter 2010
## Introductory Electromagnetism and Wave Motion

- This is section B
  - lectures Tues and Thurs 19:30-21:00 AT102
  - tutorials/labs (start week of Jan 11): HP 4130 one of
    - B6 Thurs 14:30 - 17:30
    - B7 Mon 10:00 – 13:00
    - B8 Wed 8:30 - 11:30
- Lecturer David Asner
- Research Area is Particle Physics
- office Herzberg Physics: Rm 2410
  - asner@physics.carleton.ca
  - http://www.physics.carleton.ca/~asner

# PHYS 1004

## Introductory Electromagnetism and Wave Motion

## Winter 2010

# Course Outline

# 1 Calendar description and prerequisites

## 1.1 Calendar description

This calculus-based course introduces electricity, magnetism, oscillations, waves and optics. The laboratory is an essential and autonomous part of the course.

Precludes additional credit for PHYS 1002 and PHYS 1008.

## 1.2 Prerequisites

You must have successfully completed

(i) MATH 1004 Calculus for Engineering or Physics
or MATH 1007 Elementary Calculus I

PLUS (ii) either be concurrently registered in
ECOR 1101 Mechanics I
or else have passed
PHYS 1003 Introductory Mechanics and Thermodynamics
or PHYS 1001 Foundations of Physics I
or PHYS 1007 Elementary University Physics I (with a grade of at least B−).

If you do not have *both* of these requirements you *must* check with your instructor to obtain permission of the Physics Department to take this course. This could apply, for example, to students who have completed the equivalent of MATH 1004 or PHYS 1003 at another university.

If you withdraw from ECOR 1101 during the term, you will be required to also withdraw from PHYS 1004.

# 2 Who teaches the course, when and where

## 2.1 Lecture Timetable

| CRN | Section | Times | Room | Lecturer | Lecturer's office & contact info |
|---|---|---|---|---|---|
| 10923 | A | Mon 10:00–11:30<br>Wed 10:00–11:30 | AT 102 | Bruce Campbell | Herzberg 3378<br>campbell@physics.carleton.ca<br>613-520-2600 x4322 |
| 14859 | B | Tue 19:30–21:00<br>Thu 19:30–21:00 | AT 102 | David Asner | Herzberg 2410<br>asner@physics.carleton.ca<br>613-520-2600 x8996 |
| 10927 | C | Tue 16:30–18:00<br>Thu 16:30–18:00 | AT 102 | Heather Logan (course coordinator) | Herzberg 2450<br>logan@physics.carleton.ca<br>613-520-2600 x4319 |
| 10930 | M | Tue 18:00–19:30<br>Thu 18:00–19:30 | AT 102 | Peter Krug | Herzberg 3368<br>pkrug@physics.carleton.ca<br>613-520-2600 x8922 |



### 2.4 Tutorial Leaders

## 2.2 Laboratory and Tutorial Timetable

| CRN | Section | Time |
|---|---|---|
| 10924 | A1 | Thu 8:30–11:30 |
| 10925 | A3 | Tue 8:30–11:30 |
| 10926 | A5 | Tue 14:30–17:30 |
| 14860 | B6 | Thu 14:30–17:30 |
| 14861 | B7 | Mon 10:00–13:00 |
| 14863 | B8 | Wed 8:30–11:30 |
| 10933 | C2 | Wed 14:30–17:30 |
| 10928 | C9 | Fri 14:30–17:30 |
| 10932 | M11 | Wed 18:00–21:00 |
| 11703 | M13 | Mon 18:00–21:00 |

**Room:** Herzberg 4130 (all sections)

**Lab supervisor:** Igor Ivanovic

**Supervisor's office & contact info:** Herzberg 3346
igor@physics.carleton.ca
613-520-2600 x5796

*A drop in centre will be arranged: Times & location to be announced in class & posted on WebCT.*

*Senior undergrads will staff it.*

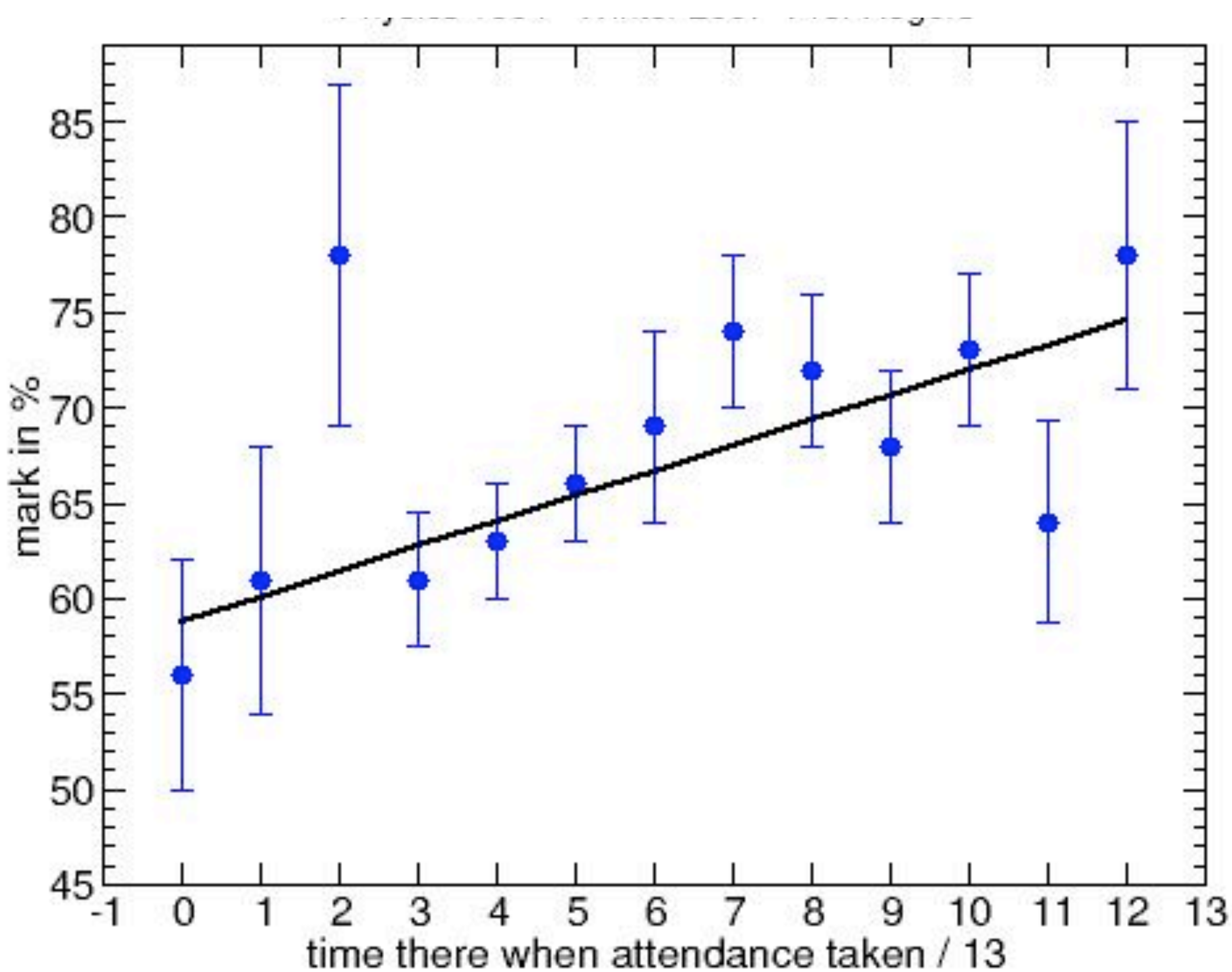


### 2.4 Tutorial Leaders

There will be four tutorial leaders: Elsayed Ali

# Attendance is expected and will be recorded (at the request of engineering)

*There is a strong correlation between attendance and marks.*

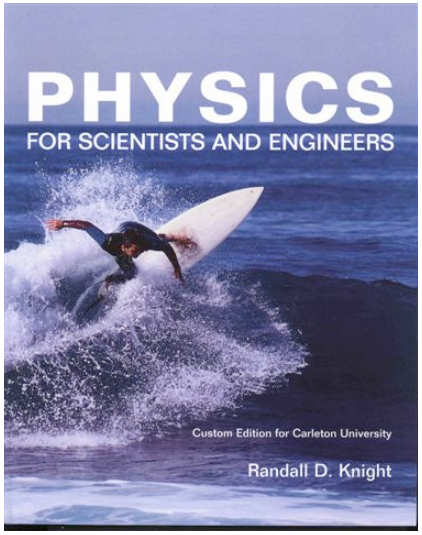



78%

56%

*average of all students with no attendance was 30%*

## 6 Required textbook and materials




**Textbook:** Randall D. Knight, *Physics for Scientists and Engineers*, (Pearson Addison-Wesley, 2007), ISBN 0-136-10696-X. [Available at the Bookstore (Uni Centre) and at Haven Books.]
This is a custom printing specifically for Carleton University containing the chapters we will cover. It is based on the 2nd edition of the text. If you buy it used, it may be missing a 3-page insert on the vector cross product, which we can give you.

**Lab manual:** *Laboratory Manual for PHYS 1004*, Winter 2004 edition or more recent.
[Available at Science Stores, 118 Steacie Building.]
You must bring this with you to each Lab session.

Science stores

strange hours
-closed over
lunch

**Lab booklets:** Five (5) beige booklets, *Carleton University Laboratory Report*.
[Available at the Bookstore (Uni Centre).]
You must bring one with you to each Lab session.

## 5.1 Marks and passing conditions

The marking scheme is as follows:

| | | |
|---|---|---|
| Theory (total 70%) | Weekly WebCT quizzes (best 9 of 11) | 10% |
| | Tutorial Tests (best 4 of 5) | 25% |
| | Final Exam | 35% |
| Lab Experiments | | 30% |
| Course total | | 100% |

In order to pass the course, you overall mark must be greater than 50% AND you must achieve 40% or above on BOTH the Theory AND the Lab Experiments components of the course.

Students with an overall course mark above 50% but who achieve between 40% and 49% on either Lab Experiments or Theory will be given a grade of D−, no matter how good their overall mark is.

### 5.2 Weekly WebCT quizzes

Each week you will have a brief, WebCT-based quiz consisting mostly of conceptual questions or questions requiring a brief calculation. The purpose of these quizzes is to help you learn the material and verify your basic understanding before you move on to the more complicated homework problems associated with the Tutorials. Each week there will be a Self Quiz that you can do for practice as many times as you like, and a time-limited Quiz that will be graded. You should read the relevant textbook sections before you start the time-limited Quiz. The quizzes are open-book. Have lots of scratch paper handy while doing the quiz: even simple calculations are much easier when done on paper than in your head.

There are many ways to subvert the purpose of these quizzes (e.g., working in groups, copying answers). Note though that 60% of the final exam will be made up of similar problems and it is in your interest to put in the effort to learn the material and do the quizzes well by yourself.

WebCT quizzes are under the "Assessments" section of the WebCT page and will be due at 16:00 on Fridays. *It is your responsibility to complete the quiz by the deadline.* There is no way to make up a missed quiz once the deadline has passed. If you have a legitimate technical problem (browser crash, internet failure) and you contact us by email before the deadline, we can reset your quiz for you to start fresh.

Solutions to the WebCT quizzes will be posted shortly after the deadline. You should review the solutions to be sure you understand the answers.

Your best 9 out of the 11 WebCT quizzes will make up 10% of your overall course mark.

## 5.3 Tutorials

There are 5 Tutorials in the term. They take place in your regular lab time slot in Herzberg 4130, alternating weeks with the labs. The Tutorial schedule is given in Sec. 8. During the first two hours of the Tutorial you will work on problems and have the opportunity to ask questions of the TAs. Working in groups is encouraged. During the last hour of the Tutorial will be a 45-minute Test which you do on your own and hand in for marking. The Test will consist of 3 to 5 multiple choice questions plus one or possibly two questions requiring written solutions. Your best 4 out of the 5 Tutorial Tests will make up 25% of your overall course mark.

The Tutorial Tests (and the final exam) will be based on the homework problems given in Sec. 7. It is thus important that you prepare the homework problems prior to the Tutorial and use the Tutorial time to understand these problems well.

Solutions to the Tutorial Tests will be posted in the notice board outside the lab (Herzberg 4130) at the end of each Tutorial week.

**What to bring:** Bring your student ID card, writing instruments, and a calculator, plus a ruler if you want. No other aids are allowed for the Tests. The formula sheets that make up the last two pages of this course outline will be provided to you with the Test.

**Attend your own Tutorial section only.** To be able to write the Test in a different section, you must obtain written permission from your lecturer on a standard form. Such permission will usually be granted only for emergencies or medical reasons, or official activities such as Engineers Without Borders.

**Tutorial Test make-ups:** If you miss a Tutorial Test, immediately contact your lecturer and explain why. If the reason is illness, a doctor's note is required. Students with valid reasons will be given written permission to write the test in a different section later the same week if possible. If this is not possible, you must obtain permission to write a make-up test at the end of term. These will all be written on Wednesday April 7 (during the review period); the time will be announced toward the end of term. Note that you need to get permission *at the time you miss the test* or as soon as you are back at school after an illness or accident. Retroactive permission will not be given at the end of term.

# 7 Homework problems

The following problems, from Knight, are assigned as homework. You should attempt to complete them before the corresponding Tutorial. They will *not* be collected; instead, the Tutorial Test during the last hour of each Tutorial will be based on these assigned problems. During the first 2 hours of each Tutorial you will work on these problems in groups and be able to ask questions of the tutorial TAs. This is your opportunity to clear up any remaining questions on the material before the Tutorial Test. The last set of problems, on material covered during the last two weeks of term, will not be on a Tutorial Test but are fair game for the final exam.

**Tutorial 1:**
Ch. 3 EP# 23, 25, 39, 45
Ch. 10 EP# 5, 37, 41, 51, 55
Ch. 11 EP# 1, 7, 11, 41, 42, 43, 44
Ch. 26 EP# 15, 25, 32, 48, 60, 63

**Tutorial 2:**
Ch. 27 EP# 3, 9, 30, 43, 47, 53
Ch. 28 EP# 1, 2, 29, 30, 39, 48, 52, 53

**Tutorial 3:**
Ch. 29 EP# 52, 63, 70, 72
Ch. 30 EP# 44, 61, 67, 71
Ch. 31 EP# 17, 39, 41, 45, 63, 67

**Tutorial 4:**
Ch. 32 EP# 17, 29, 33, 63, 69, 73
Ch. 33 EP# 5, 11, 17, 43, 49, 55, 66

Many other problems are part of the quizzes!

**Tutorial 5:**
Ch. 34 EP# 28, 31, 37, 38, 40, 52, 59, 79, 80
Ch. 14 EP# 5, 13, 33, 36

**Remaining course material:**
Ch. 36 EP# 19, 35, 40, 43, 47, 61
Ch. 20 EP# 7, 13, 27, 41, 42, 45
Ch. 35 EP# 17, 21, 25, 27

Note: EP = Exercises and Problems. You should also try to do all of the Conceptual Questions at the end of each chapter.

*The purpose of solving problems is to understand the physics, the relationships, not just to find the right equation to "plug and chug"*

## 5.4 Labs

Labs start during the second week of term (January 11–15). Bring your copy of the lab manual and a blank beige lab booklet with you to the first lab. For each lab you will be writing a lab report. Some of these will be Short Reports while others will be Formal Reports. Instructions on writing lab reports will be given during the lab. Lab reports will usually be due at the start of the next lab (not at Tutorials), with the exception of the last two labs for which the report will be written up and turned in before the end of the lab period.

For students repeating this course, you may request to be exempt from the lab (and have your lab mark carried forward from before) if you have completed all the lab experiments with a sufficiently high mark. You must contact Dr. Ivanovic and obtain explicit permission to be exempt from the lab. Note that you will not be exempted from the Tutorials, which meet in alternate weeks during your lab period.

## 5.5 Final Exam

The Final Exam will be held during the exam period, April 8–24 (including Saturdays)—the date will be announced by the university by February 12. All four lecture sections will write the Final Exam together. You may bring only writing implements, a calculator, and a ruler to the Final Exam. The formula sheets that make up the last two pages of this course outline will be provided. The Final Exam will include four problems requiring written solutions, of which you will choose three to do. These problems will be based on the assigned Homework Problems. The exam will also include a few questions relevant to the laboratory.

If you miss the Final Exam for a good reason such as illness, you may apply for a Deferred Exam through the registrar's office. A Deferred Exam replaces only the Final Exam portion of your mark. Deferred Exams for Winter 2010 will be scheduled during June 12–23. In order to be eligible for a Deferred Exam you must have earned at least 7 out of the possible 35 marks on term work in the theory component of the course (i.e., the Tutorial Tests and WebCT quizzes) and at least 12 out of the possible 30 lab marks.

You are expected to read the book ahead of time.

Not all examinable material will be covered in lectures

WebCT quizzes may include material not yet covered in lectures.

| Lecture | Topic | Textbook sections Covered today | Self study |
|---|---|---|---|
| 1, 2 | Intro to the course; vectors, kinetic and potential energy, Hooke's law | Ch. 3 (all), Ch. 10.1–10.5 | Ch. 3 |
| 3 | Basic energy model, work & kinetic energy, forces, work and potential energy, power | Ch. 11.1–11.5, 11.9 | 11.1, 11.9 |
| 4 | Electric charge; Coulomb's law; electric field | Ch. 26 (all) | 26.1, 26.3 |
| 5, 6 | Electric field, field lines, dipoles, continuous charge distributions; lines, disks, planes; motion of charged particles in E field. Start Ch. 28, symmetry of fields. | Ch. 27 (all) | 27.1, 27.5 |
| 7, 8 | Gauss's law; electric flux, conductors Start Ch. 29 electric potential | Ch. 28 (all) | 28.1 |
| 9 | Electrical potential energy: point charges, dipole; electric potential: point charge, many charges, dipoles, capacitors, electric potential of charge dist'ns | Ch. 29 (all) | 29.6 |
| 10 | Potential from field, field from potential; conductors in electrostatic equilibrium | Ch. 30.1–30.4 | 30.2 |
| 11 | Capacitance; parallel plate, spherical, cylindrical; parallel & series combinations; energy stored; dielectrics | Ch. 30.5–30.7 | – |
| 12 | Electric current, current density; resistance, resistivity; Ohm's law; power. Start Kirchhoff's laws | Ch. 31 (all) Ch. 32 (start) | 31.1 |
| | *Reading Week* | | |
| 13 | DC circuits; energy and power, resistors in parallel & series, real batteries; grounding, RC circuits | Ch. 32 (all) | 32.1, 32.8 |

| | | Textbook sections | |
|---|---|---|---|
| **Lecture** | **Topic** | **Covered today** | **Self study** |
| 14, 15 | Intro to magnetism, Biot-Savart law, field due to long straight conductor, magnetic dipole, Ampère's law, force on a moving charge and on current-carrying wires, torque on a current loop, motor, solenoids, ferromagnetism | Ch. 33 (all) | 33.1, 33.2, cross product handout |
| 16, 17 | Induced currents, motional emf, magnetic flux; eddy currents; Lenz's and Faraday's laws, induced electric fields | Ch. 34.1–34.6 | 34.1 |
| 18, 19 | Induced currents, generators, inductors, inductance; self-inductance of a solenoid; RL circuits; magnetic energy in inductors & magnetic fields | Ch. 34.7 (skip transformers, metal detector), 34.8, 34.10 | – |
| 20 | Simple harmonic motion (SHM), terminology, spring-block system, energy in SHM, LC oscillator | Ch. 14.1–14.4, Ch. 34.9 | 14.1, 14.2 |
| 21, 22 | Alternating currents; AC source with separate R, L, C elements; power factor, rms quantities | Ch. 36.1–36.4, 36.6 | 36.1 |
| 23 | Introduction to travelling waves; electromagnetic spectrum | Ch. 20.1–20.5 | 20.1, 20.2 |
| 24 | Travelling electromagnetic wave, Poynting vector, polarization | Ch. 35.5 (focus on Figs. 35.19, 35.20, and speed of light), 35.6, 35.7 | 35.5 |

# 8 Schedule of lectures, labs, and tutorials

## 8.1 Schedule

| Week | Activities |
|---|---|
| Week 1 (Jan 4–8) | Lectures 1 and 2<br>No lab or tutorial<br>WebCT Quiz 1 due at 16:00 on Friday |
| Week 2 (Jan 11–15) | Lectures 3 and 4<br>Lab: Intro to the Lab; Error Analysis;<br>Introduction to DC Circuits (15% of your lab mark;<br>Short Report due at start of next lab)<br>WebCT Quiz 2 due at 16:00 on Friday<br>*Fri Jan 15 is the last day to change courses or sections* |
| Week 3 (Jan 18–22) | Lectures 5 and 6<br>Tutorial 1<br>WebCT Quiz 3 due at 16:00 on Friday |
| Week 4 (Jan 25–29) | Lectures 7 and 8<br>Lab: Kirchhoff's Rules (15% of your lab mark;<br>Short Report due at start of next lab)<br>DC Circuits lab report due at start of lab<br>WebCT Quiz 4 due at 16:00 on Friday |
| Week 5 (Feb 1–5) | Lectures 9 and 10<br>Tutorial 2<br>WebCT Quiz 5 due at 16:00 on Friday |
| Week 6 (Feb 8–12) | Lectures 11 and 12<br>Lab: RC Time Constant (25% of your lab mark;<br>Formal Report due at start of next lab)<br>Kirchhoff's Rules lab report due at start of lab<br>WebCT Quiz 6 due at 16:00 on Friday<br>*The final exam schedule will be available by Fri Feb 12* |
| Reading Week (Feb 15–19) | No lectures, labs, or tutorials |
| Week 7 (Feb 22–26) | Lectures 13 and 14<br>Tutorial 3<br>WebCT Quiz 7 due at 16:00 on Friday |
| Week 8 (Mar 1–5) | Lectures 15 and 16<br>Lab: Oscilloscope part 1<br>RC Time Constant lab report due at start of lab<br>WebCT Quiz 8 due at 16:00 on Friday |

| Week | Activities |
|---|---|
| Week 9 (Mar 8–12) | Lectures 17 and 18<br>Tutorial 4<br>WebCT Quiz 9 due at 16:00 on Friday<br>*Fri Mar 12 is the last day to withdraw from a course* |
| Week 10 (Mar 16–19) | Lectures 19 and 20<br>Lab: Oscilloscope part 2 (25% of your lab mark;<br>Short Report due at the end of this lab period)<br>WebCT Quiz 10 due at 16:00 on Friday |
| Week 11 (Mar 22–26) | Lectures 21 and 22<br>Tutorial 5<br>WebCT Quiz 11 due at 16:00 on Friday |
| Week 12 (Mar 29–Apr 2) | Lectures 23 and 24<br>Lab: Simple Lens (20% of your lab mark;<br>Short Report due at the end of this lab period)<br>*Note Fri Apr 2 is a holiday and Mon Apr 5 follows a Friday schedule.*<br>*If you have a Friday lab, it will meet on Mon Apr 5 at your usual lab time.* |
| Review period (Apr 6–7) | Lecture review session<br>Tutorial Test make-ups (Apr 7; for those given written permission during term)<br>Lab make-ups (for those given permission during term) |

# Cheat sheets

**We will have covered all of this by the end of term!**

**Reference material for exam and tutorial tests**

$N_A = 6.022 \times 10^{23}$ mol$^{-1}$
$G = 6.674 \times 10^{-11}$ N m$^2$kg$^-2$
$g = 9.81$ m s$^{-2}$
$m_e = 9.109 \times 10^{-31}$ kg
$m_p = 1.673 \times 10^{-27}$ kg
$e = 1.602 \times 10^{-19}$ C
$K = 1/(4\pi\epsilon_0) = 8.988 \times 10^9$ N m$^2$C$^{-2}$
$c = 2.998 \times 10^8$ m/s
Permittivity, free space,
$\epsilon_0 = 8.854 \times 10^{-12}$ C$^2$N$^{-1}$m$^{-2}$
Permeability, free space,
$\mu_0 = 4\pi \times 10^{-7}$ T m A$^{-1}$= (H/m)

1 J = 1 N × 1 m  1 eV = $1.602 \times 10^{-19}$ J
1 C = 1 A × 1 s  1 V = 1 J/C
1 Ω = 1 V/A  1 F = 1 C/V
1 Wb = 1 T m$^2$  1 H = 1 T m$^2$ /A
1 Hz = 1 s$^{-1}$  1 T = 1 N/(A m) [$10^4$ Gauss]

$(1+x)^n = 1 + nx + n(n-1)x^2/2! +$
$n(n-1)(n-2)x^3/3! + ...$if $|x| < 1$
$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$
$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$

$v_f^2 = v_i^2 + 2a\Delta s \quad s_f = s_i + v\Delta t + \frac{1}{2}a(\Delta t)^2$
$v_f = v_i + a\Delta t$
Spring-block:$F = -k\Delta s \quad U_{sp} = \frac{1}{2}k(\Delta s)^2$
$W > 0 \Rightarrow$ energy transferred to an object by force
$K = \frac{1}{2}mv^2, \quad \Delta K = K_f - K_i \quad U_g = mgh$
Ignoring dissipative energy losses:
$\Delta E_{\text{sys}} = \Delta K + \Delta U = W_{\text{ext}}$ or $E_f = E_i + W_{\text{ext}}$
Conservation of $E_{\text{mech}}$ in an isolated system
($W_{\text{ext}} = 0$):
$\Delta E_{\text{mech}} = \Delta K + \Delta U = 0$
Work-KE theorem: $\Delta K = W_{\text{net}}$ [J]

Work $W_{force} = \int_i^f \vec{F} \cdot d\vec{s}$ [J]
Power $P = dW/dt = \vec{F} \cdot \vec{v}$ [W]
$\Delta U = U_f - U_i = -W_{force}$ [J]
If external agent does work against force:
$\Delta U = W_{ext}$
A force is conservative if the work to move a mass or charge between two points is path independent.

Coulomb's Law:
$F_{1\text{on}2} = F_{2\text{on}1} = \frac{K|q_1||q_2|}{r^2}$ [N]

**Shell Theorems:** A shell of uniform charge: 1) attracts or repels an external charge as if all of the shell's charge were at its centre; and 2) exerts no net electrostatic force on a charge in it interior.

$\vec{E} = \vec{F}/q_0$ [N C$^{-1}$ or V/m]

Electric Dipole
2 charges $+q, -q$ separated by $s$; dipole moment $|\vec{p}| = qs$ directed from $-q$ to $+q$
$\vec{\tau} = \vec{p} \times \vec{E} \quad U = -\vec{p} \cdot \vec{E}$

Electric Fields:
point charge: $|\vec{E}| = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$
non-conducting ∞ sheet: $|\vec{E}| = \eta/(2\epsilon_0)$
conducting ∞ sheet: $|\vec{E}| = \eta/(\epsilon_0)$
Gauss's Law:
$\Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$
Electric potential, $V = U/q_0$ [V] where $U$ is the electrostatic potential energy

$\Delta V = V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s}$
$\vec{E}$ from V: $E_s = -\frac{\partial V}{\partial s}$
$V$ of point charge: $V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$
System of 2 charges: $U_{12} = V_1 q_2 = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r}$
for several charges: $U = U_{12} + U_{13} + U_{23} + ...$

Capacitance: $C = Q/\Delta V_C$ [F]
parallel-plate capacitor: $C = \frac{\epsilon_0 A}{d}$
in series: $1/C_{eq} = \sum_i 1/C_i$
in parallel: $C_{eq} = \sum_i C_i$
$U_C = \frac{1}{2}C(\Delta V_C)^2$
$u_E = \frac{1}{2}\epsilon_0 E^2$
with dielectrics: $\epsilon_0 \rightarrow \epsilon = \kappa\epsilon_0$,
dielectric constant: $\kappa = \epsilon/\epsilon_0$

Current: $I = dQ/dt$ [A]
Current density: $\vec{J} : |\vec{J}| = I/A$ in direction of $\vec{E}$
$v_d$ is drift speed: $n_e$ is conduction e$^-$/m$^3$
$J = n_e e v_d$
Resistance: $R = \Delta V_R/I$ [Ω]
Ohms law $\Rightarrow R$ independent of $\Delta V_R$
$R = \rho L/A$ units of resistivity $\rho$ are [Ωm].
Conductivity $\sigma = 1/\rho$ [Ω$^{-1}$m$^{-1}$]
$J = \sigma E \quad J = n_e e v_d$
R in parallel: $\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$

R in series: $R_{eq} = \sum_i R_i$
Power, $P = iV$ (general case).
If Ohm's law holds: $P = i^2 R = V^2/R$

emf: $\mathcal{E} = \frac{dW}{dQ}$ [V]
Kirchhoff's Rules:
Loop: $\sum_i \Delta V_i = 0$
Junction $\sum_i I_i = 0$
RC circuit:
Discharging: $Q(t) = Q_0 e^{-t/\tau} \quad \tau = RC$ [s]
Charging: $Q(t) = Q_{max}(1 - e^{-t/\tau}) \quad Q_{max} = C\mathcal{E}$

Magnetic Fields: Biot-Savart Law:
moving point charge: $\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v} \times \hat{r}}{r^2}$
current element: $\vec{B} = \frac{\mu_0}{4\pi}\frac{I\Delta\vec{s} \times \hat{r}}{r^2}$
long straight wire: $\vec{B} = \frac{\mu_0}{2\pi}\frac{I}{d}$(tangent to circle,rhr)
Force from $\vec{B}$
moving charge: $\vec{F}_{\text{on q}} = q\vec{v} \times \vec{B}$
wire current: $\vec{F}_{\text{wire}} = I\vec{\ell} \times \vec{B}$
2 parallel wires: $F_{||\text{ wires}} = \frac{\mu_0 \ell I_1 I_2}{2\pi d}$
(|| attract, anti|| repel)

Magnetic dipoles:
loop's magnetic dipole moment: $\vec{\mu} = NIA$ (rhr I)
mag field on axis: $\vec{B}_{\text{loop}} = \frac{\mu_0}{4\pi}\frac{2\vec{\mu}}{z^3}$
Torque on current loop: $\vec{\tau} = \vec{\mu} \times \vec{B}$
Potential energy of magnetic dipole: $U = -\vec{\mu} \cdot \vec{B}$
Ampere's Law: $\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}}$
$B_{\text{solenoid}} = \mu_0 n I$ where $n = N/\ell$

Magnetic Flux through loop:
$\Phi_m = N \int_{\text{loop}} \vec{B} \cdot d\vec{A}$ [Wb]
Faraday's Law: $\mathcal{E} = \left|\frac{d\Phi_m}{dt}\right|$
with direction of induced current such that induced $\vec{B}$ will oppose the change in $\Phi_m$.
Induced electric field: $\mathcal{E} = \oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_m}{dt}$

Inductance: $L$ [H] =[Wb/A]
solenoid: $L = \frac{\Phi_m}{I} = \frac{\mu_0 N^2 A}{\ell}$
$\mathcal{E}_{\text{coil}} = L\left|\frac{dI}{dt}\right|$ direction from Lenz's Law
$\Delta V_L = -L\frac{dI}{dt}$
$U_{\text{inductor}} = \frac{1}{2}LI^2 \quad u_B = \frac{1}{2\mu_0}B^2$
LR circuit: $I = I_0 e^{-t/\tau} \quad \tau = \frac{L}{R}$

oscillatory motion: $x(t) = A\cos(\omega t + \phi_0)$
angular frequency $\omega$ [rad/s]
frequency $f = \omega/2\pi$ (Hz)
period $T = 1/f$ [s]

Spring-block system: $U = \frac{1}{2}kx^2$
$x$ displacement, $k$ spring constant $\omega = \sqrt{\frac{k}{m}}$

LC Circuit: $\omega = \sqrt{\frac{1}{LC}}$
$Q(t) = Q_0 \cos\omega t$

AC circuits:
capacitive reactance: $X_C = 1/(\omega C)$ [Ω]
inductive reactance: $X_L = \omega L$ [Ω]

$I_{rms} = I_{max}/\sqrt{2} \quad V_{rms} = V_{max}/\sqrt{2}$
$\mathcal{E}_{rms} = \mathcal{E}_{max}/\sqrt{2} \quad P_{ave} = I_{rms}^2 R$

Travelling waves:
$v = \lambda f \quad k = 2\pi/\lambda \quad \omega = vk$
$D(x,t) = A\sin(kx - \omega t + \phi_0)$

Electromagnetic waves:
$E = E_{max}\sin(kx - \omega t), B = B_{max}\sin(kx - \omega t)$
$c = 1/\sqrt{\epsilon_0\mu_0} \quad E = cB \quad \vec{E} \perp \vec{B}$

Poynting vector: $\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$ [W/m$^2$]
$I = S_{ave} = E_{rms}^2/(c\mu_0)$
index of refraction: $n = c/v$

Malus's Law
initially unpolarized: $I = \frac{1}{2}I_0$
initially polarized: $I = I_0\cos^2\theta$

Error Propagation Equations
$\sigma_z = \left[\left(\frac{\partial z}{\partial x}\sigma_x\right)^2 + \left(\frac{\partial z}{\partial y}\sigma_y\right)^2 + ...\right]^{\frac{1}{2}}$
for $z = ax + by - cu + ...$
$\sigma_z = \left[(a\sigma_x)^2 + (b\sigma_y)^2 + (c\sigma_u)^2 + ...\right]^{\frac{1}{2}}$
for $z = Ax^n y^m u^{-p}$
$\sigma_z = z\left[(n\sigma_x/x)^2 + (m\sigma_y/y)^2 + (p\sigma_u/u)^2 + ...\right]^{\frac{1}{2}}$

# How the lectures work

- the text is great: STUDY IT - make notes from it
- not presenting the derivations done in the text.
  - will highlight a few central concepts and help you develop strategies for doing problems
  - but you must learn the book material yourself
  - you are responsible for the entire contents as specified in the outline (there are 4 lecture sections & 1 exam)
  - ask questions about things you don't understand
- I will ask questions during the lecture and ask you to think about the answers - and, on occasion, discuss with your neighbour : otherwise I expect reasonable silence

- I would be delighted if everyone in the class got an A+
  - but it is up to you to do the thinking and the work.

# How the lectures work (cont)

- make notes during the class!!!
  I will be posting notes from current lectures

- use lecture time productively (if you need to sleep, find a place to lie down outside the class)

- if you listen to something, you remember 10%
- if you see something you remember 20%
- if you write something, you remember 50%
- So write things down, and redo it to get to 100%
- (these numbers made up, and vary for individuals, but the point is valid. Writing is essential to learning)

# Read the textbook's

# Preface to the student

- We do not explicitly use the student workbook
  - you may benefit by using it
- expectation:
  - average 2 hours of study outside of class for every hour in the classroom

*Take out a piece of paper.*

*Write down a systematic way to convert an electric field strength of 30 kV/cm into V/m .*

Is it?

a) 30 V/m

b) 300 V/m

c) 3,000 V/m

d) 30,000 V/m

e) 300,000 V/m

f) 3,000,000 V/m

*Ans:* $$E = 30\,\frac{kV}{cm} = 30\,\frac{kV}{cm} \times 1000\,\frac{V}{kV} \times 100\,\frac{cm}{m} = 3,000,000\,\frac{V}{m}$$

On main area of WebCT for course

**Guidelines for complete solutions in Physics 1004 Problems**

When doing problems for Physics 1004 tutorial tests, tutorial assignments or the final exam, we expect clarity and logic in the answers. We will be assigning marks for this clarity and logic. Certain things are always expected.

1. All answers must include the units unless the answer is a pure number (eg a ratio). Marks will be lost if the proper units are not given explicitly. This applies even if the answer is an algebraic expression which represents a quantity.

2. If the answer is a vector, the direction as well as the magnitude must always be specified in some manner (eg by an angle with respect to some specified direction, or a clear and precise description in words such as up, away from the ground, etc, or a proper specification of the vector in unit vector notation with $\vec{i}, \vec{j}, \vec{k}$).

3. When an equation is introduced, except for completely trivial situations, there must be some indication of why it applies in this case, and how it applies or marks will be deducted. If you are not sure if a situation is completely trivial, give an explicit rationale. One component of this is explaining what all the symbols in the equation refer to or mean, by defining them before or after the equation is introduced.

4. Whenever the units of a quantity are being converted to other units, it is mandatory to show how this is done except in trivial situations (e.g. given r = 2 cm, then to convert to m one can write $r = 2$ cm $= 0.02$ m but it is safer to write $r = 2\ \text{cm}\frac{1}{100}\ \frac{\text{m}}{\text{cm}} = 0.02\ \text{m}$). For any quantity which is a ratio of units, one must use the following format for each conversion, preferably at the start of the solution:

   Given electric field magnitude: $E = 30\frac{\text{kV}}{\text{cm}} = 30\ \frac{\text{kV}}{\text{cm}} \times 1000\ \frac{\text{V}}{\text{kV}} \times 100\ \frac{\text{cm}}{\text{m}} = 3,000,000\ \frac{\text{V}}{\text{m}}$

*On main area of WebCT for course*

5. When numerical values are being substituted into an equation, it is essential first to write the equation with the variables in algebraic form (eg F = ma) and then to rewrite the equation with the numerical values and their units in place prior to doing the evaluation. Failure to do this will cause marks to be deducted. This step also allows the markers to see if you understood what the equation is about and can be part of item 3, and if you show an understanding of the equation but make a clerical/numerical error then you will still get part marks.

6. The algebraic form of results should be maintained as long as reasonable in the solution of a problem, especially as this may lead to cancellations in the final answer.

7. Answers must be given to the correct number of significant figures as discussed on the course WebCT page.

8. In some questions a figure will be a mandatory part of the answer. However, in almost any problem, drawing a properly labelled figure as the first step in finding the solution is a good approach and can earn you part marks even if you do not completely solve the problem.

Example 1 (trivial, but to make the above clear)
Question: The force on a 3.0 kg mass is 3 mN. What is the acceleration?
Answer:
Newton's second law states $F = ma$ where $F$ is the net force acting on a rigid body, $m$ is the mass of the body and $a$ is the acceleration.
Thus:

$$a = \frac{F}{\mathrm{m}} = \frac{(3\ \mathrm{mN}\frac{1\ \mathrm{N}}{1000\ \mathrm{mN}})}{(3.0\ \mathrm{kg})} = 1.0 \times 10^{-3}\ \ \frac{\mathrm{m}}{s^2}$$

The acceleration is in the same direction as the force.

In the above it is not essential to name the law. One could just as well say: "It is known that the net force $F$ acting on a rigid body of mass $m$ is related to the acceleration $a$ of the body by: $F = ma$."
It may also be more convenient to do all of the unit conversions first, so another acceptable solution is:
$3\ \mathrm{mN} = 3\ \mathrm{mN}\frac{1}{1000}\ \frac{\mathrm{N}}{\mathrm{mN}} = 3 \times 10^{-3}\mathrm{N}$
It is known that the net force $F$ acting on a rigid body of mass $m$ is related to the acceleration $a$ of the body by: $F = ma$, thus

$$a = \frac{F}{\mathrm{m}} = \frac{3 \times 10^{-3}\mathrm{N}}{(3.0\ \mathrm{kg})} = 1.0 \times 10^{-3}\ \ \frac{\mathrm{m}}{s^2}$$

The acceleration is in the same direction as the force.

# Office Hours

- When is good for office hours? (2 x 1h)
  - I will circulate a doodle poll to the class
  - Respond if you want your input to count
- other meeting times can be arranged by e-mail – asner@physics.carleton.ca

# General comments

- the course uses SI units almost exclusively.
  - On my part of the WebCT page there is a link to some basic rules for use and writing of SI units.
- significant figures

# Significant figures

-WebCT cares about significant figures

-most problems are to 3 sig fig

How many sig figs are there in each of the following?

| | | |
|---|---|---|
| 1.23456789 | 8 or 9 | *9* |
| 1.23 | 2 or 3 | *3* |
| 123.0 | 1, 3 or 4 | *4* |
| 0.00123 | 3, 5 or 6 | *3* |
| $3.0 \times 10^3 \equiv$ 3.0E3 | 1, 2 or 3 | *2* |
| 20.00 | 1,2 or 4 | *4* |
| 3000. | 1 or 4 | *4* |
| 3000 | 1, 4, undefined | *1 or undefined (often means 4)* |

Significant figures are not to be confused with decimal places

1.23, 12.3 123 and 0.000123

all have 3 sig figs

# Chap 3: Vectors & Coordinate Systems

- Interesting Background Information
  - 1/3 of students have working knowledge of vectors
  - 1/3 of students have partial knowledge of vectors
  - 1/3 of students have no useful knowledge of vectors

- You need to understand vectors cold!

- There is a strong correlation between NOT doing well in this course and NOT understanding vectors.

- Vectors are a tool you need to master to demonstrate you understand the physics.

# Learning Objectives

- To understand the basic properites of vectors
- To add and subtract vectors both graphically and using components
- To be able to decompose a vector into its components and to reassemble vector components into a magnitude and a direction
- To recognize and use the basic unit vectors
- To work with tilted coordinate systems

# Reading Quiz

- Before each lecture you must read the relevant sections of the textbook
- You will get much more out of the lectures
- At the beginning of each class there will be a "Reading Quiz"
- The purpose of this quiz is for you to gauge for yourself if you understood enough of what you read to benefit from the lecture

What is a vector?

A. A quantity having both size and direction
B. The rate of change of velocity
C. A number defined by an angle and a magnitude
D. The difference between initial and final displacement
E. None of the above

What is a vector?

✔ **A. A quantity having both size and direction**

B. The rate of change of velocity

C. A number defined by an angle and a magnitude

D. The difference between initial and final displacement

E. None of the above

What is the name of the quantity represented as $\hat{i}$ ?

A. Eye-hat
B. Invariant magnitude
C. Integral of motion
D. Unit vector in *x*-direction
E. Length of the horizontal axis

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A. Eye-hat
B. Invariant magnitude
C. Integral of motion
✔ **D. Unit vector in *x*-direction**
E. Length of the horizontal axis

This chapter shows how vectors can be added using

A. graphical addition.
B. algebraic addition.
C. numerical addition.
D. both A and B.
E. both A and C.

This chapter shows how vectors can be added using

A. graphical addition.
B. algebraic addition.
C. numerical addition.
✔ **D. both A and B.**
E. both A and C.

To *decompose* a vector means

A. To break it into several smaller vectors.
B. To break it apart into scalars.
C. To break it into pieces parallel to the axes.
D. To place it at the origin.
E. This topic was not discussed in Chapter 3.

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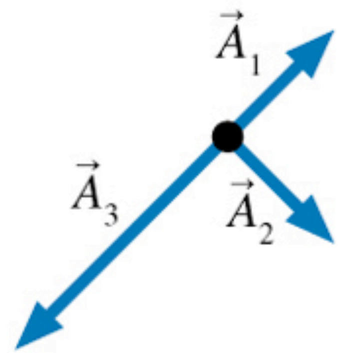
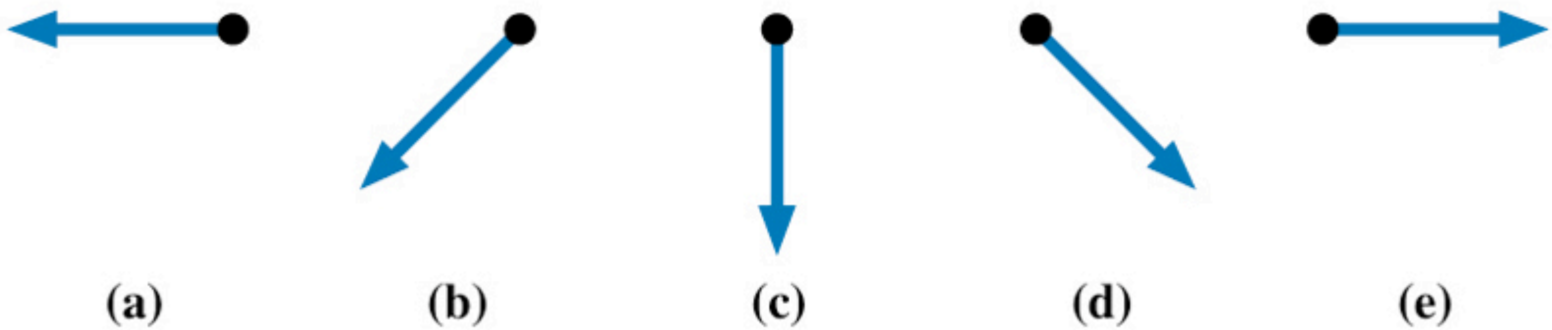
✔ **C. To break it into pieces parallel to the axes**.
D. To place it at the origin.
E. This topic was not discussed in Chapter 3.

# Physical Example

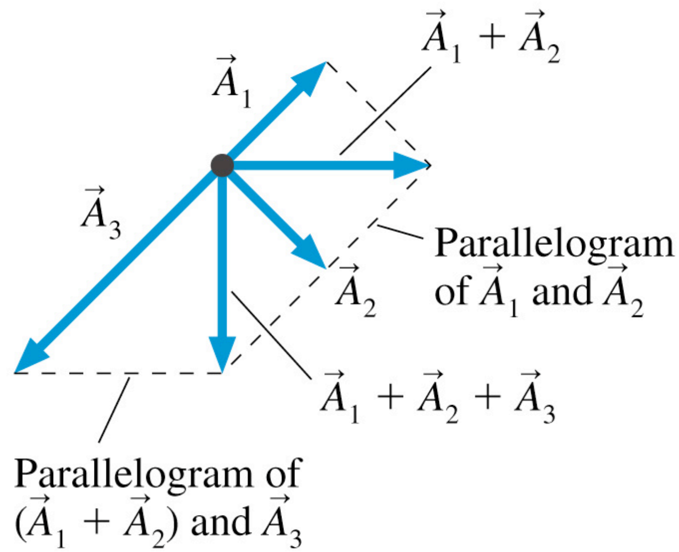
- Quantities that are fully described by a single number (with units) are called scalar quantities
  - Mass (kg) - *m* - *scalars get italic symbols*
  - Temperature (°C) - *T*, Volume (cm$^3$ or mL) - *V*
  - Pressure (*P*), density ($\rho$), energy (*E*), charge (*q*), voltage (*V*)
- Our universe has three (spatial) dimensions so some quantities also require a direction - vector quantities
  - Directions: Go three blocks South
- *A* vector quantity has magnitude AND direction
  - e.g. position, displacement, force, electric field

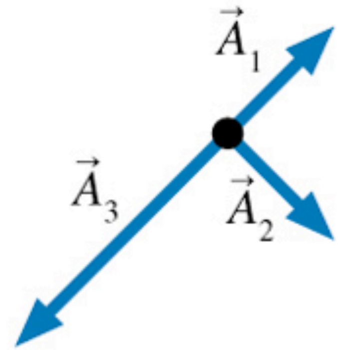
**Which figure shows** $\vec{A}_1 + \vec{A}_2 + \vec{A}_3$ **?**

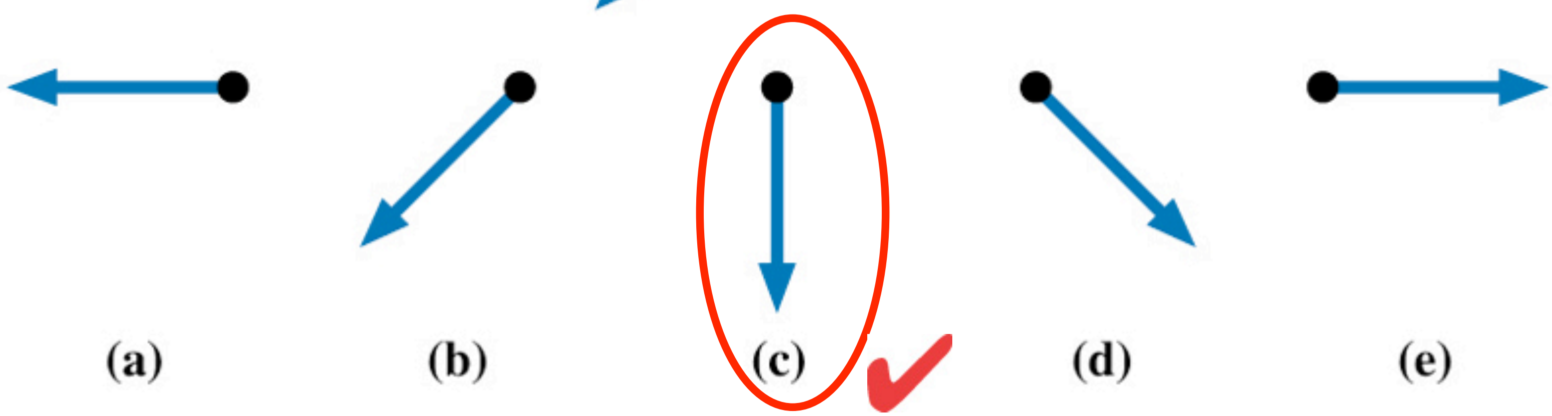


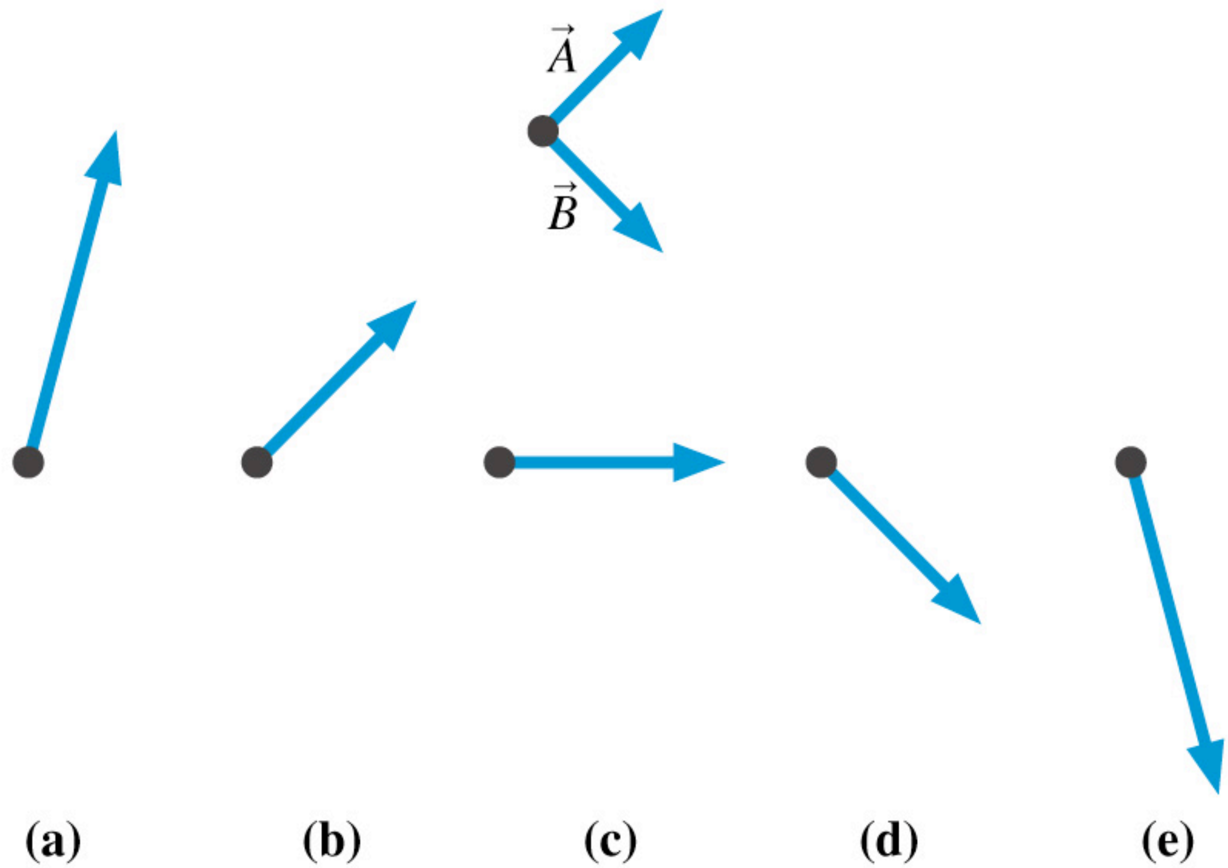
## Which figure shows $\vec{A}_1 + \vec{A}_2 + \vec{A}_3$ ?



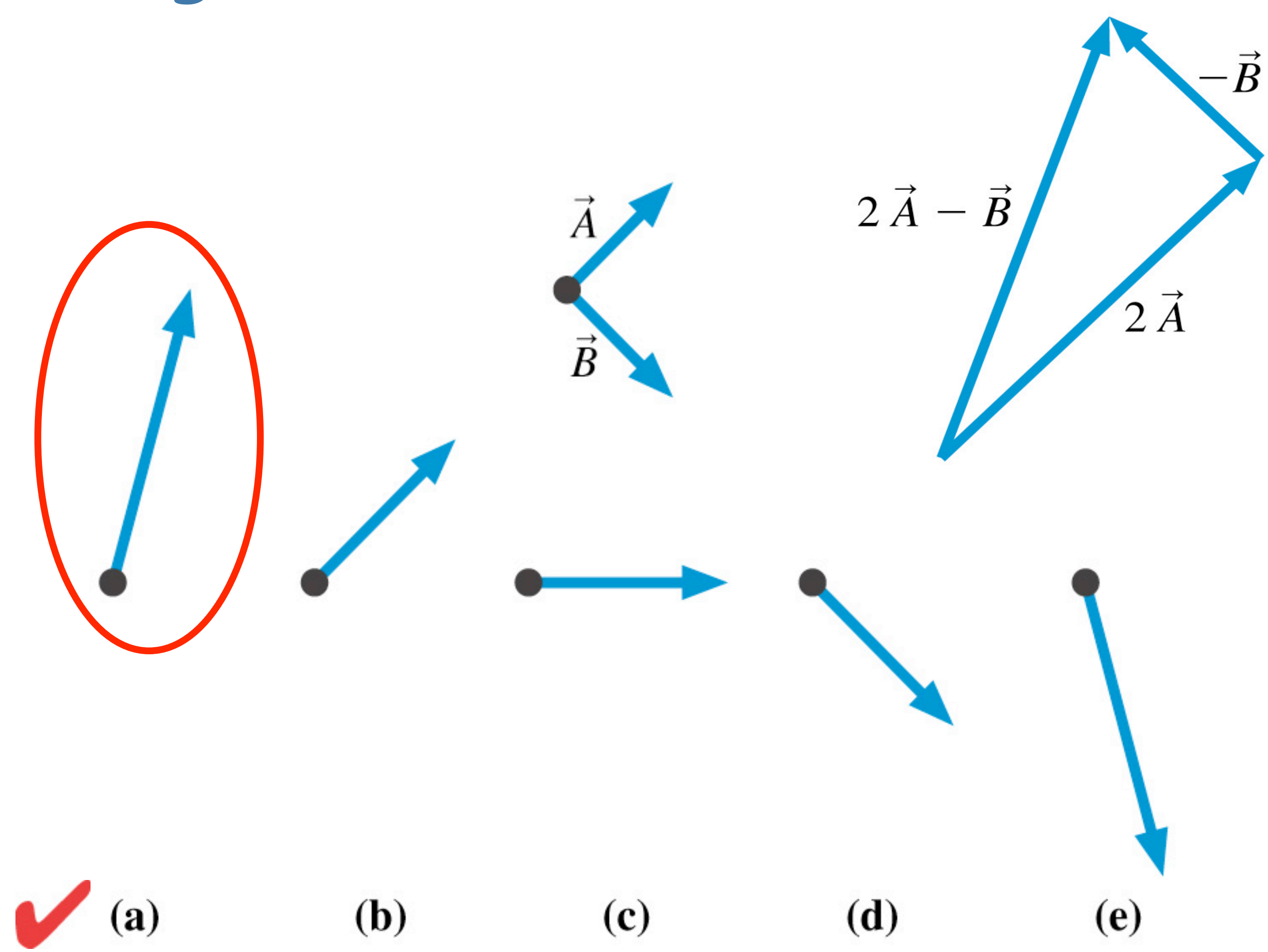



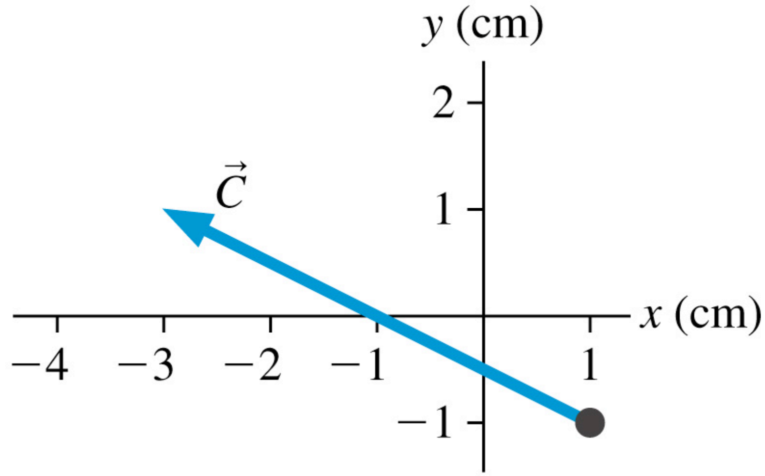
Which figure shows $2\vec{A} - \vec{B}$ ?



# Which figure shows $2\vec{A} - \vec{B}$ ?



# What are the x- and y-components $C_x$ and $C_y$ of vector $\vec{C}$ ?




A. Cx = 1 cm, Cy = –1 cm

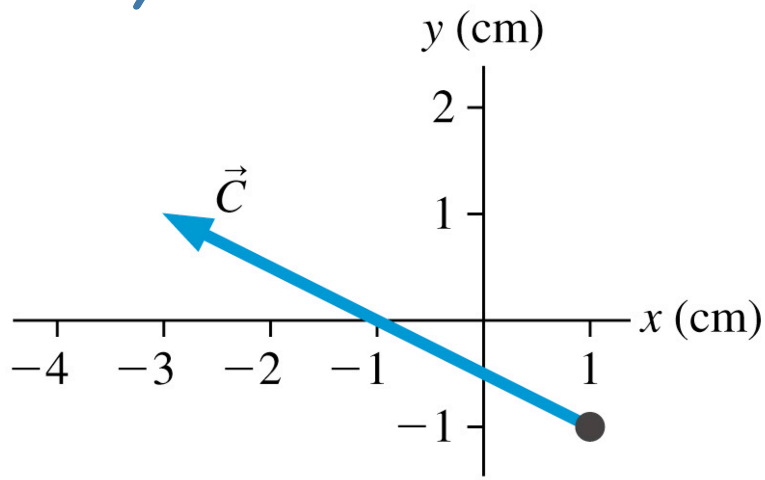
B. $C_x$ = –3 cm, $C_y$ = 1 cm

C. Cx = –2 cm, Cy = 1 cm

D. $C_x$ = –4 cm, $C_y$ = 2 cm

E. $C_x$ = –3 cm, $C_y$ = –1 cm

## What are the x- and y-components $C_x$ and $C_y$ of vector $\vec{C}$ ?




A. Cx = 1 cm, Cy = –1 cm

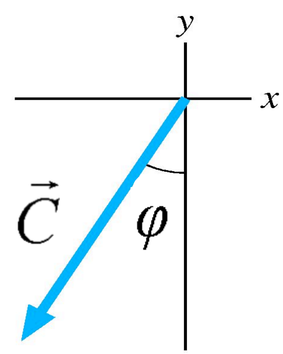
B. $C_x$ = –3 cm, $C_y$ = 1 cm

C. Cx = –2 cm, Cy = 1 cm

✔**D. $C_x$ = –4 cm, $C_y$ = 2 cm**

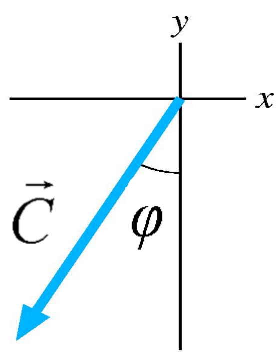
E. $C_x$ = –3 cm, $C_y$ = –1 cm

## Angle $\phi$ that specifies the direction of $\vec{C}$ is given by




A. $\tan^{-1}(C_y / C_x)$
B. $\tan^{-1}(C_x / |C_y|)$
C. $\tan^{-1}(C_y / |C_x|)$
D. $\tan^{-1}(C_x / C_y)$
E. $\tan^{-1}(|C_x| / |C_y|)$

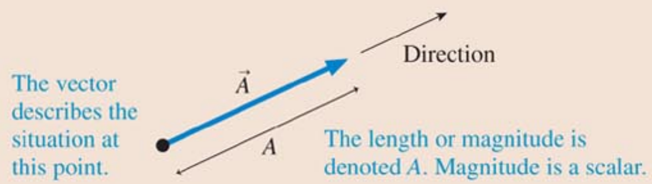
# Angle $\phi$ that specifies the direction of $\vec{C}$ is given by




A. $\tan^{-1}(C_y / C_x)$
B. $\tan^{-1}(C_x / |C_y|)$
C. $\tan^{-1}(C_y / |C_x|)$
D. $\tan^{-1}(C_x / C_y)$
✔ **E. $\tan^{-1}(|C_x| / |C_y|)$**

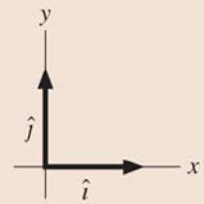
## Important Concepts

A vector is a quantity described by both a magnitude and a direction.




### Unit Vectors

Unit vectors have magnitude 1 and no units. Unit vectors $\hat{\imath}$ and $\hat{\jmath}$ define the directions of the $x$- and $y$-axes.






## Terms and Notation

scalar quantity
vector quantity
magnitude
resultant vector
graphical addition
zero vector, $\vec{0}$
Cartesian coordinates
quadrants
component vector
decomposition
component
unit vector, $\hat{\imath}$ or $\hat{\jmath}$
algebraic addition

# Using Vectors

## Components

The component vectors are parallel to the $x$- and $y$-axes:

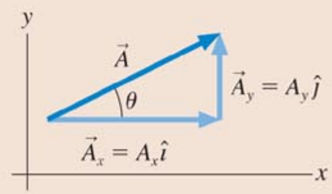
$$\vec{A} = \vec{A}_x + \vec{A}_y = A_x\hat{\imath} + A_y\hat{\jmath}$$

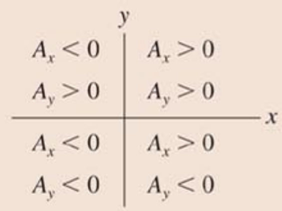
In the figure at the right, for example:

$$A_x = A\cos\theta \qquad A = \sqrt{A_x^{\,2} + A_y^{\,2}}$$

$$A_y = A\sin\theta \qquad \theta = \tan^{-1}(A_y/A_x)$$

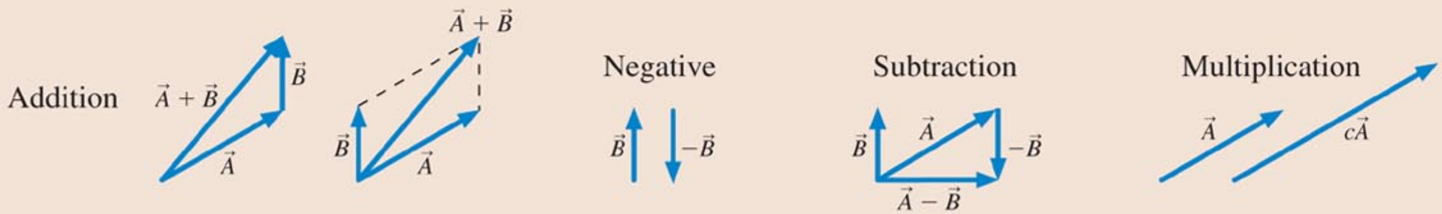
▶ Minus signs need to be included if the vector points down or left.




The components $A_x$ and $A_y$ are the magnitudes of the component vectors $\vec{A}_x$ and $\vec{A}_y$ *and* a plus or minus sign to show whether the component vector points toward the positive end or the negative end of the axis.

## Working Graphically



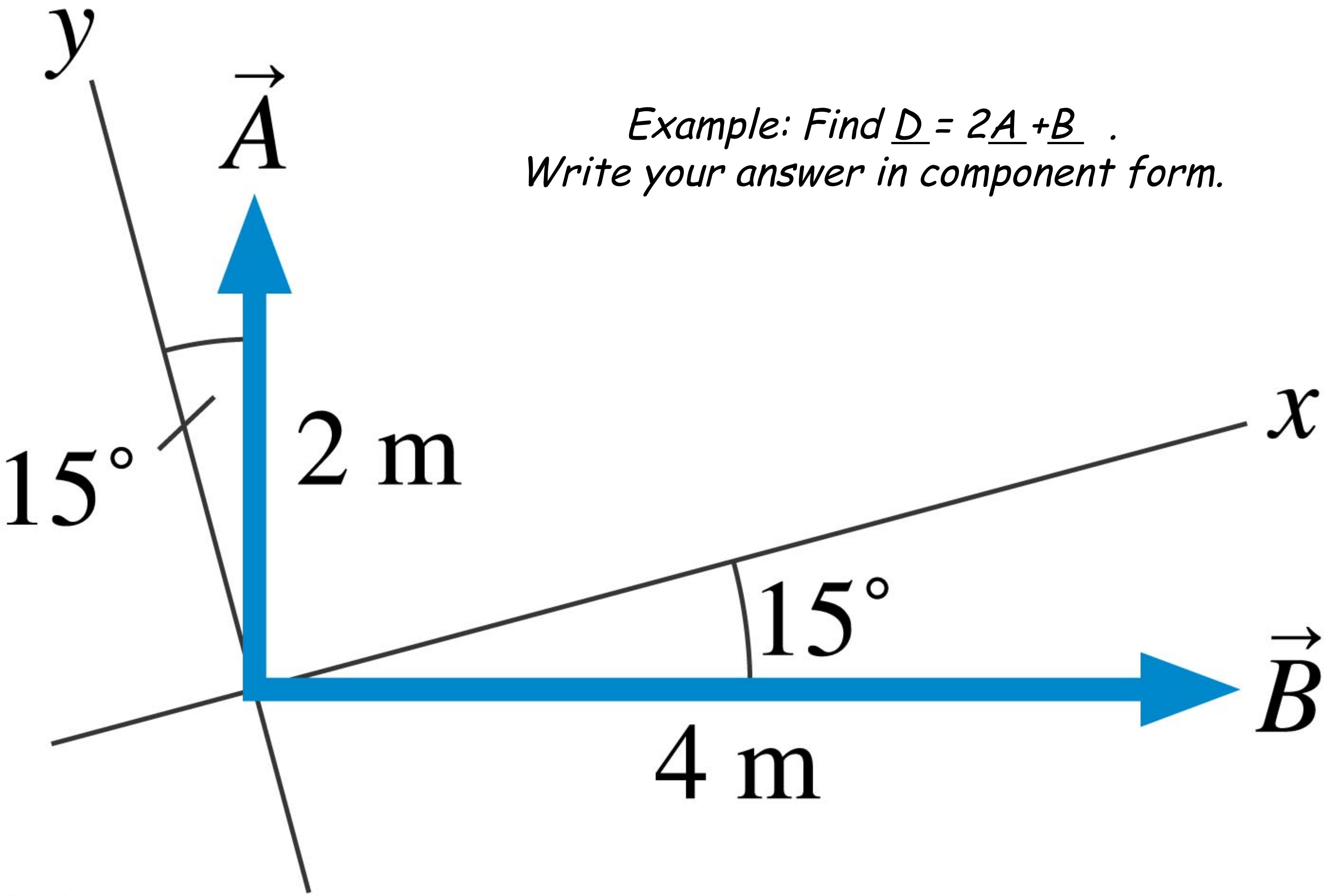

## Working Algebraically

Vector calculations are done component by component:

$$\vec{C} = 2\vec{A} + \vec{B} \qquad \text{means} \qquad \begin{cases} C_x = 2A_x + B_x \\ C_y = 2A_y + B_y \end{cases}$$

The magnitude of $\vec{C}$ is then $C = \sqrt{C_x^2 + C_y^2}$ and its direction is found using $\tan^{-1}$.

Example: Find D = 2A +B .
Write your answer in component form.



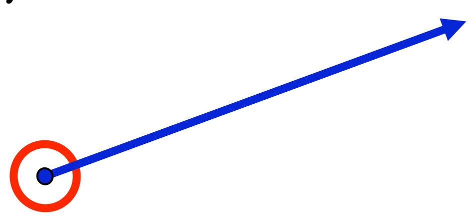
# Vector review

Vector techniques are essential to this course.

Study Ch 3 of the text and know it cold!

What is a vector **a** or $\vec{a}$ ?

*It is a quantity which has both direction and magnitude.*



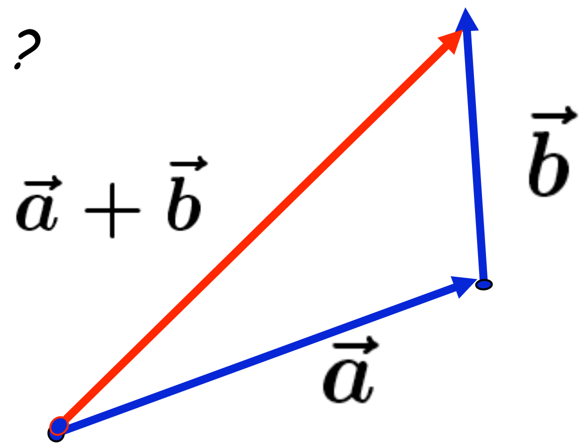
It is associated with the position at its tail.

'the displacement relative to that tail'

or 'the force acting on an object there'

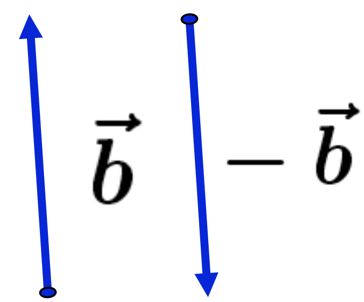
# Vector review (cont)

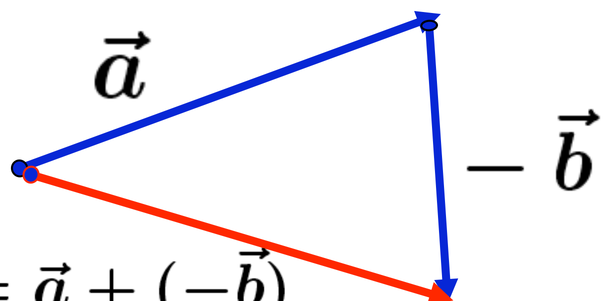

*What is* $\vec{a} + \vec{b}$ ?




*What is* $\vec{a} - \vec{b}$ ?

*What is* $-\vec{b}$ ?



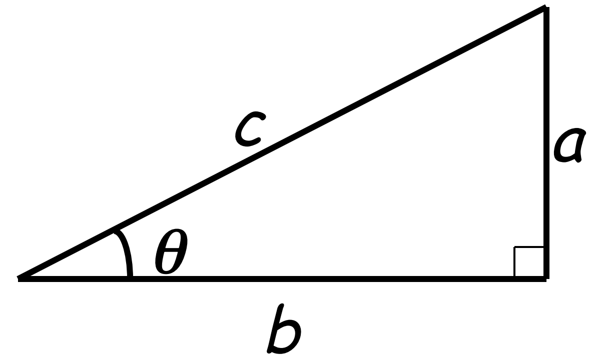




$$\vec{a} - \vec{b} = \vec{a} + (-\vec{b})$$

$$(\vec{a} - \vec{b}) + \vec{b} = \vec{a}$$

# Vector review (cont)

Elementary trigonometry




$$= \frac{a}{b}, \frac{a}{c}, \frac{b}{c}, \frac{c}{b}, \frac{b}{a}, \frac{c}{a}$$

$\cos\theta = b/c \Rightarrow b = c\cos\theta$

$\sin\theta = a/c$

$\tan\theta = a/b$

$\cot\theta = b/a$

$\sec\theta = c/b$

$\csc\theta = c/a$

$$\sin^2\theta + \cos^2\theta = \cos 2\theta, \quad 1, \quad \sin 2\theta \quad ?$$

$$= (a/c)^2 + (b/c)^2 = (a^2 + b^2)/c^2 = c^2/c^2 = 1$$

# Vector review (cont)

Components of Vectors

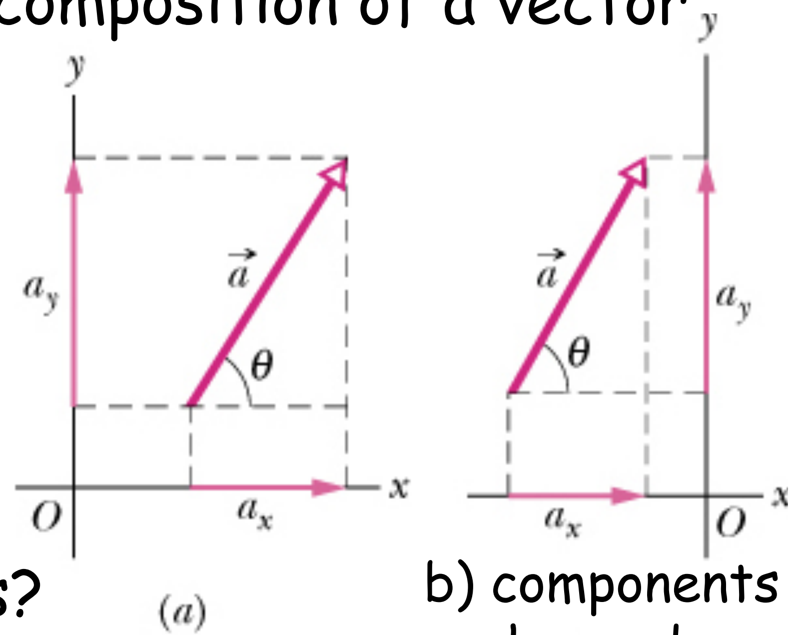
Decomposition of a vector

*What are x and y components of vector **a** which has magnitude $a = |\mathbf{a}|$ and direction $\theta$ wrt x axis?*

Are the components vectors? Yes

Directions? same as x, y axes

What are magnitudes of components?




b) components unchanged

$$a_x = a\cos\theta$$
$$a_y = a\sin\theta$$

*What is the magnitude of **a** in terms of $a_x$ and $a_y$?*

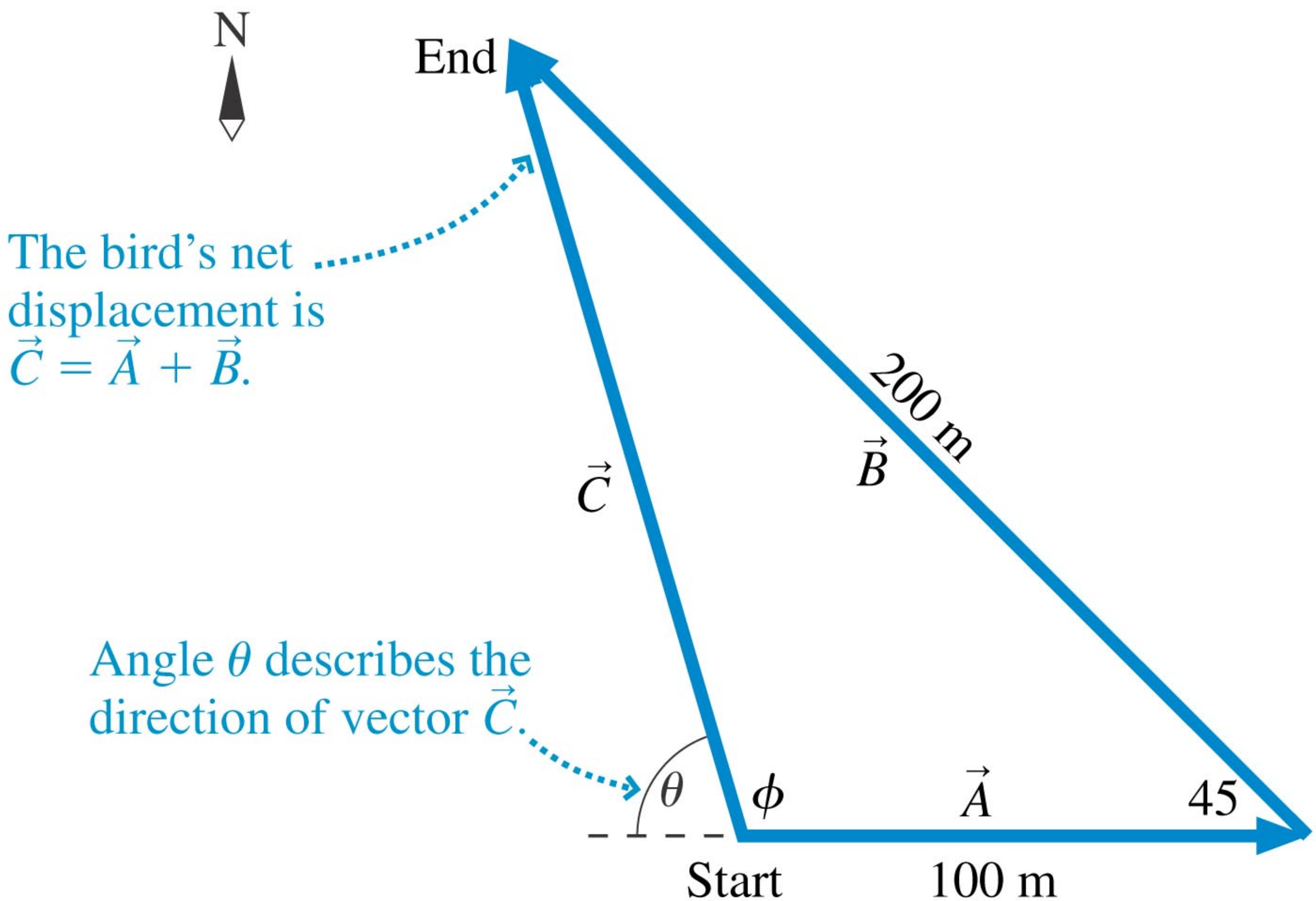
$$a = \sqrt{a_x^2 + a_y^2}$$

*What is the angle $\theta$ in terms of components $a_x$ and $a_y$?*

$$\tan\theta = \frac{a_y}{a_x}$$

# Example 3.1 from text

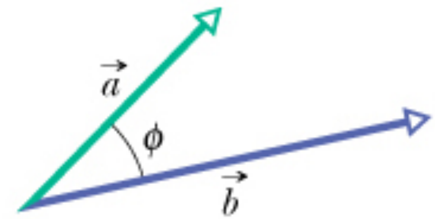
- A bird flies 100 m due east, then 200 m northwest, what is the bird's net displacement?



# Vector review (cont)

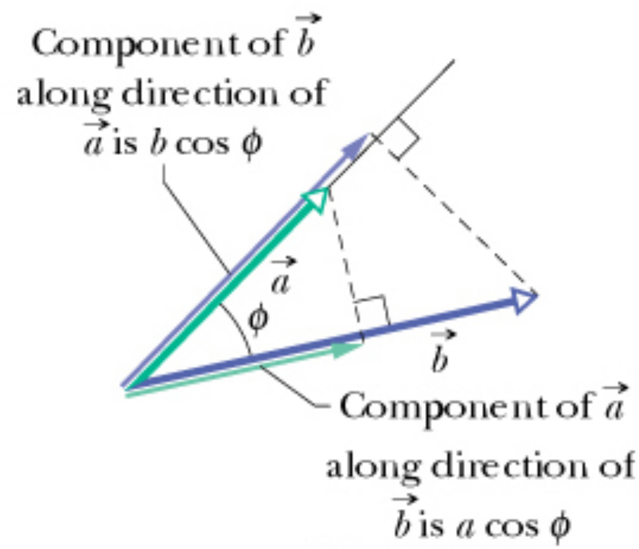
## Multiplying Vectors: dot or scalar product

$$\vec{a} \cdot \vec{b} = ab \cos\phi$$




(a)

The dot product can be considered as the magnitude of one of the vectors (a) times the scalar component of the second vector along the direction of the first (b cosϕ).



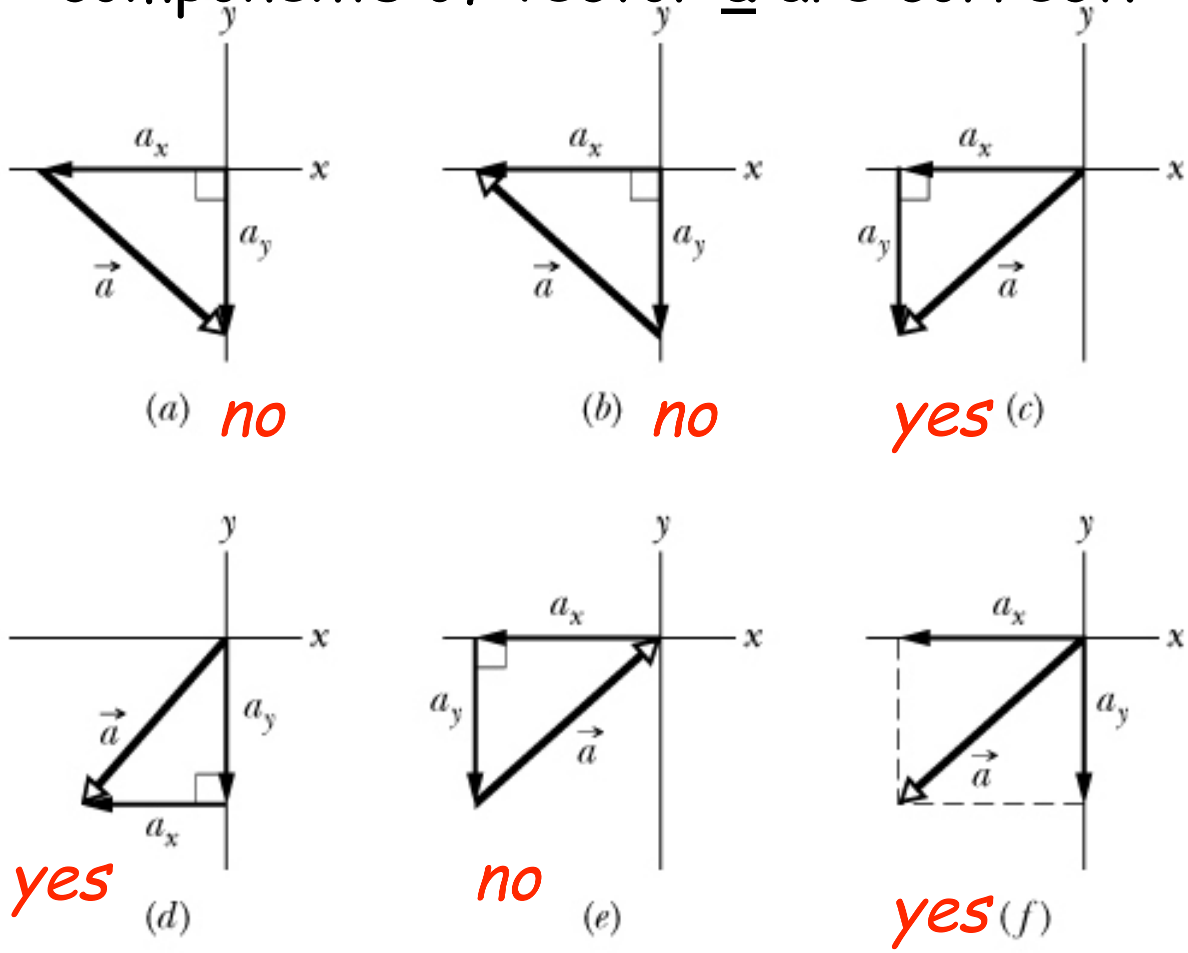

(b)

a, b aligned ==> $\vec{a} \cdot \vec{b} = ab$

a ⊥ b ==> $\vec{a} \cdot \vec{b} = 0$

# Vector review (cont)

Which of these methods for combining the x and y components of vector **a** are correct?




*Components must be head to tail and* ***a*** *must extend from tail of one to head of the other*

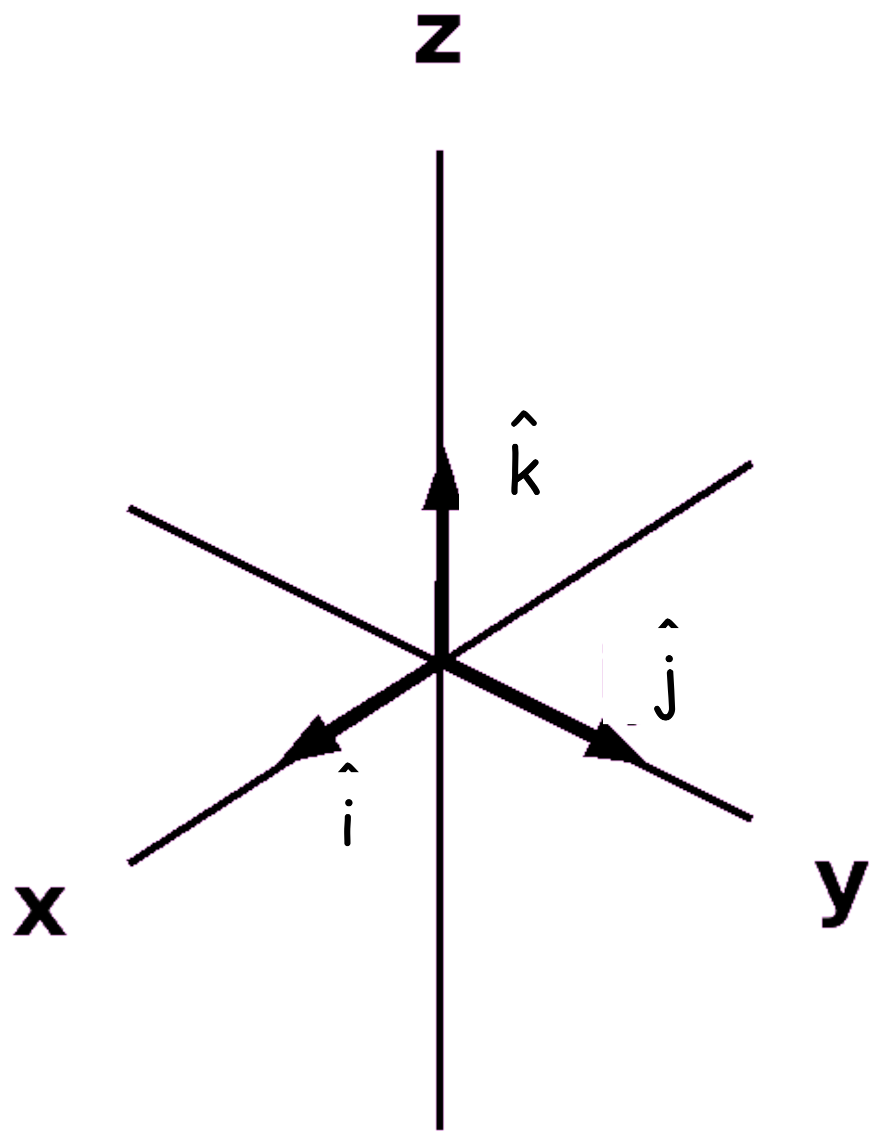
Note: if a component is opposite the axis direction, then, eg, $a_y$ is <0

(but its magnitude, $|a_y|$ is > 0)

# Unit vectors

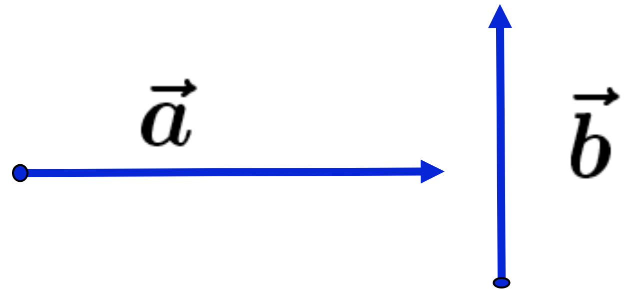
Three vectors are defined with unit magnitude and direction along the positive x, y and z axes.

They form the basis of a right-handed coordinate system



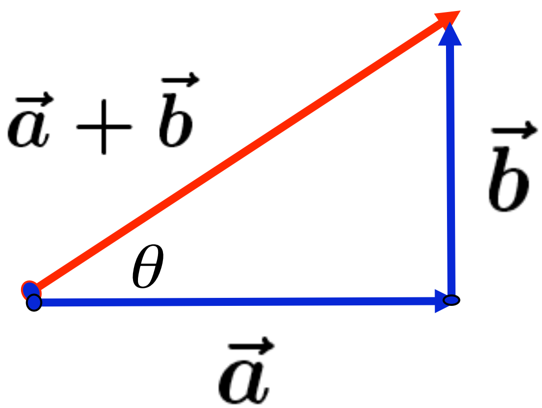
# Question

$|\mathbf{a}| = 3$ $|\mathbf{b}| = 2$



For the vectors a and b,
what are:

i) $\vec{a} + \vec{b}$



$|\mathbf{a} + \mathbf{b}| =$ sqrt(4+9)=3.6

$\tan\theta =$ $2/3 \Rightarrow \theta = 34^0$

ii) $\vec{a} \cdot \vec{b}$ Is this a scalar or a vector? Ans: *scalar*

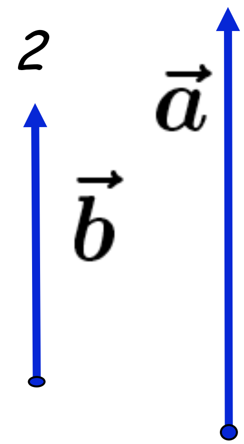
$$\vec{a} \cdot \vec{b} = ab\cos\phi = 0$$

where $\phi$ =90 is the angle between $\vec{a}$ and $\vec{b}$

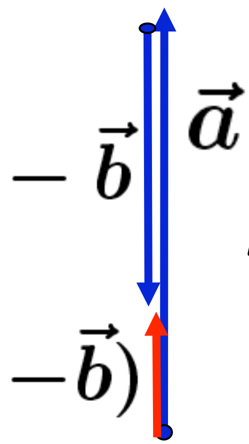
# Question

For the vectors a and b,
what are:

/**a**/ = 3   /**b**/ = 2




1) $\vec{a} - \vec{b}$



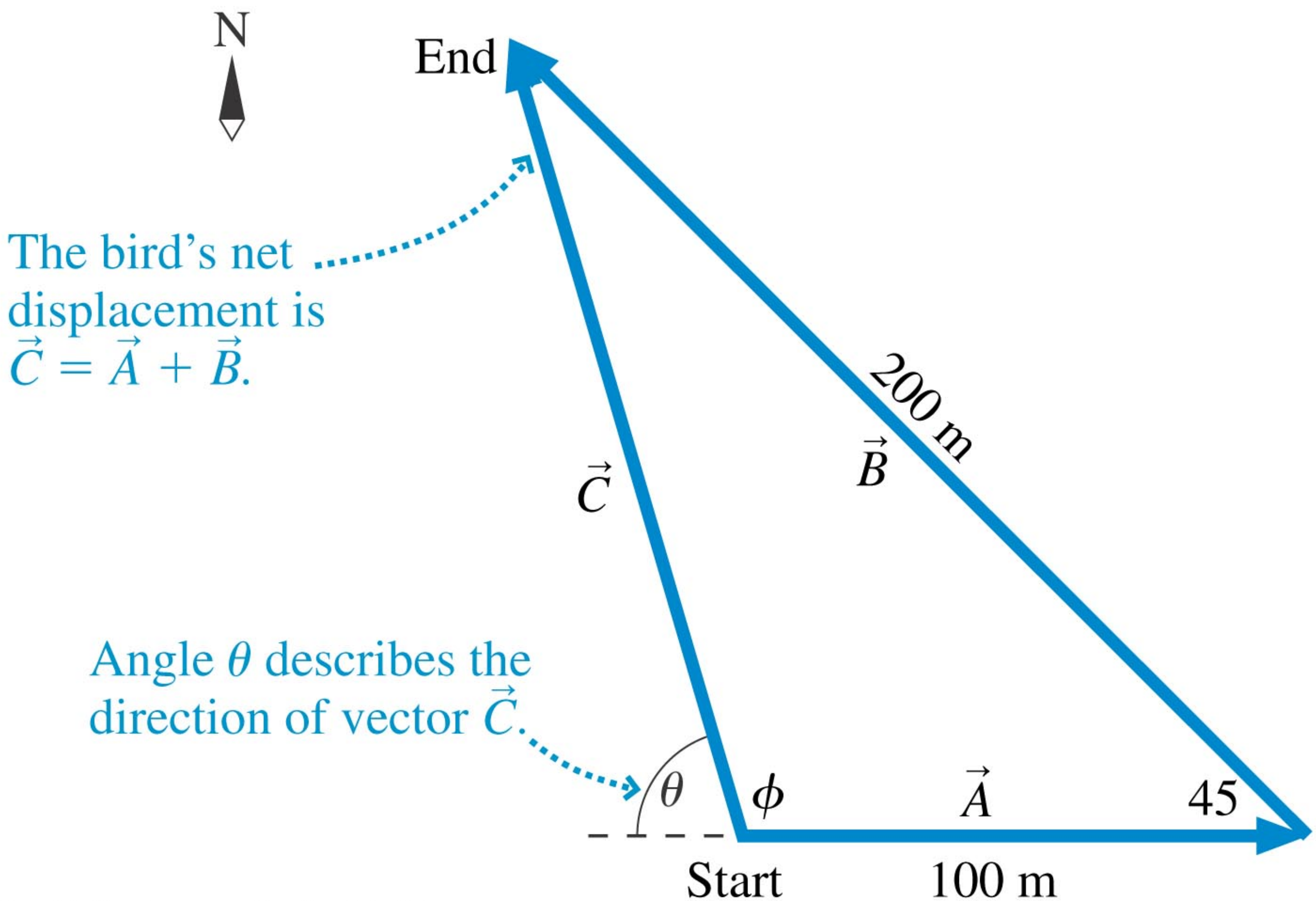

/**a** - **b**/ = 3 - 2 = 1

$$\vec{a} - \vec{b} = \vec{a} + (-\vec{b})$$

2) $\vec{a} \cdot \vec{b}$   $\vec{a} \cdot \vec{b} = ab\cos\phi$   = ab cos 0 = ab

# Example 3.6 from text

- A bird flies 100 m due east, then 200 m northwest, what is the bird's net displacement?

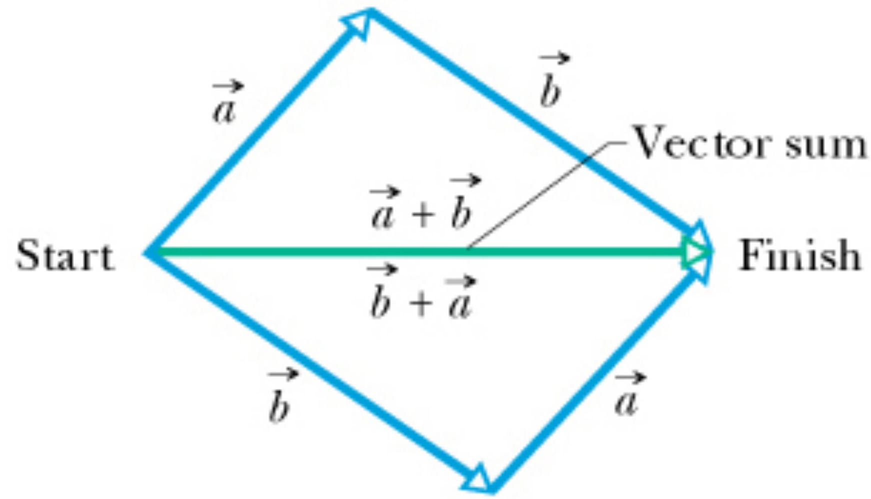


# Vector review

addition is commutative

$$\vec{a} + \vec{b} = \vec{b} + \vec{a}$$

( $\vec{a}$ ≡ **a** )



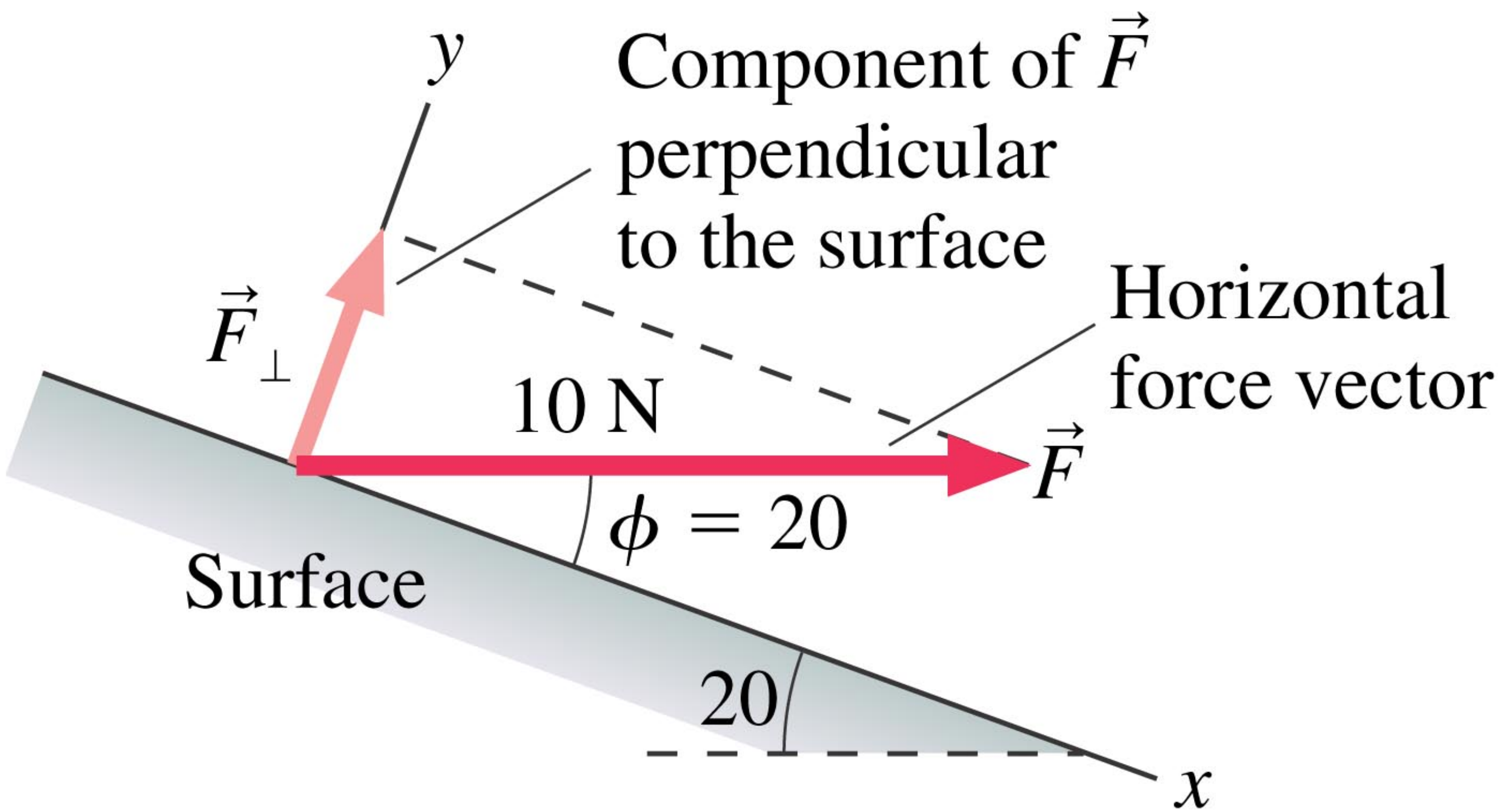

Magnitudes of **a** and **b** are 3 m and 4 m, and **c** = **a** + **b**.
Considering various orientations of **a** and **b**,

what is the maximum magnitude of **c**? 1 m, 4 m, 7 m 7 m

what is the minimum magnitude of **c**? 1 m, 4 m, 7 m 1 m

# Example 3.7 from text

- A horizontal force <u>*F*</u> with strength 10 N is applied to a surface. The surface is tilted at a 20° angle. Find the component of the force perpendicular to the surface.



The end of vector review

# Chapter 10.1-10.5: Energy

- To begin developing a concept of energy
  - What it is?
  - How it is transformed?
- To introduce the concepts of kinetic and potential energy
- To learn Hooke's law and the new idea of a restoring force
- To learn how to interpret energy diagrams

Energy is a physical quantity with properties somewhat similar to

A. money.
B. heat.
C. a liquid.
D. work.
E. momentum.

Energy is a physical quantity with properties somewhat similar to

✔ **A. money.**

B. heat.

C. a liquid.

D. work.

E. momentum.

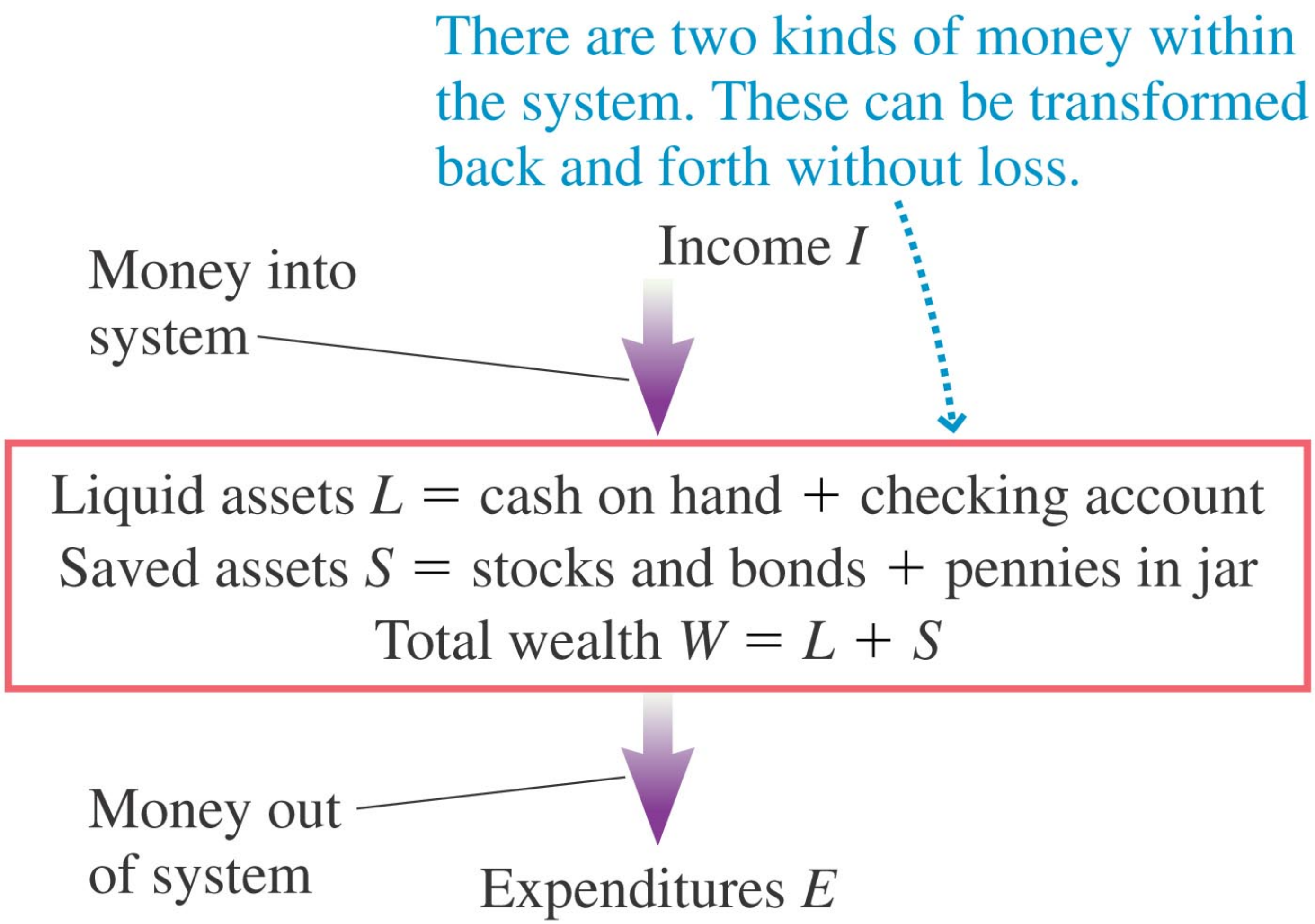
Hooke’s law describes the force of

A. gravity.
B. tension.
C. a spring.
D. collisions.
E. none of the above.

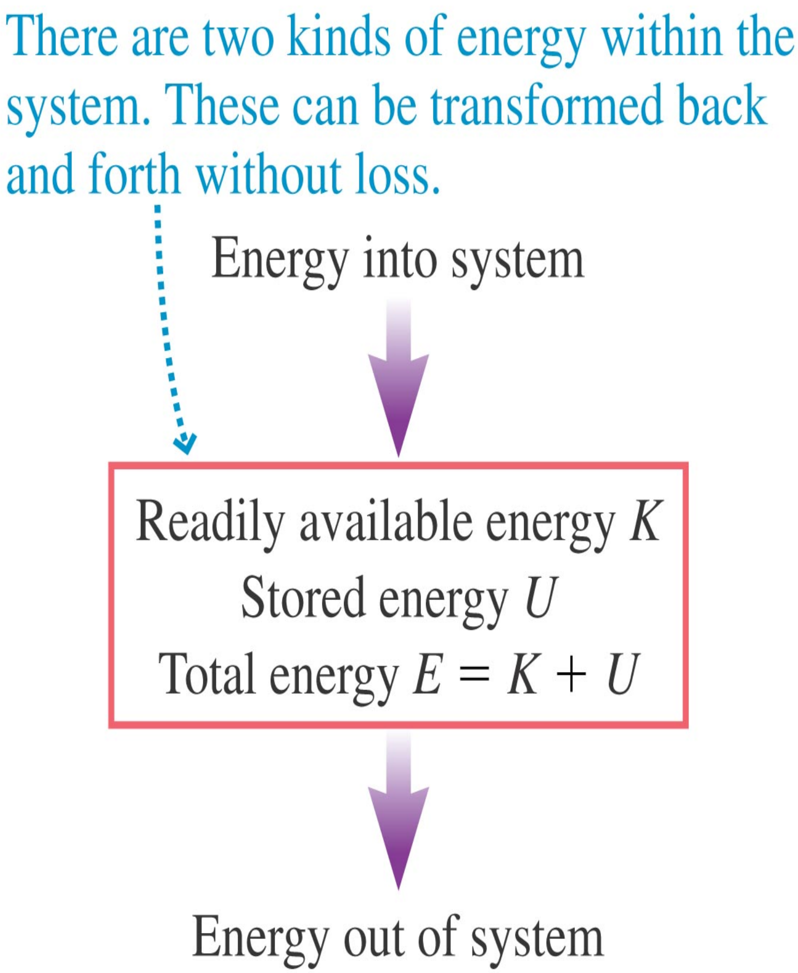
Hooke's law describes the force of

A. gravity.
B. tension.
✔ **C. a spring.**
D. collisions.
E. none of the above.

# A "Natural Money" called Energy



# Kinetic and Gravitational Energy





- Kinetic Energy
  - Energy associated with motion
  - $K = 1/2\ m\ v^2$ (J)
  - $1\ J = 1\ kg\ m^2/s^2$
- Potential energy
  - Gravitational potential
    - $U = mgy$ (J)
  - Elastic potential
    - $U = 1/2\ k(\Delta x)^2$ (J)

# A few examples

- A block slides down a frictionless ramp of height *h*. It reaches velocity *v* at the bottom. To reach velocity 2*v*, the block would need to slide down a ramp of height
  a) 1.41h
  b) 2h
  c) 3h
  d) 4h ✔
  e) 6h

# A few examples

- A block is shot up a frictionless 40° slope with initial velocity *v*. It reaches a height *h* before sliding back down. The same block is shot with the same velocity up a frictionless 20° slope.

a) 2h
b) h ✔
c) 0.5 h
d) Greater than h, but can't predict exact value
e) Less than h, but can't predict exact value

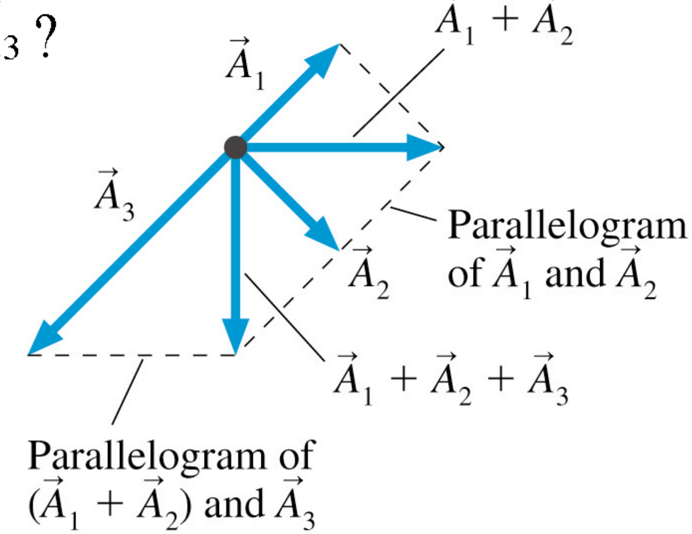
# A few examples

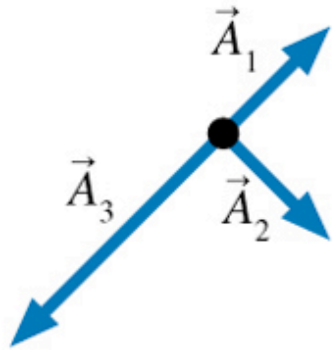
- Two balls, one twice as heavy as the other are dropped from the roof of a building. Just before hitting the ground, the heavier ball has
  a) One-half
  b) The same amount
  c) twice ✔
  d) Four times

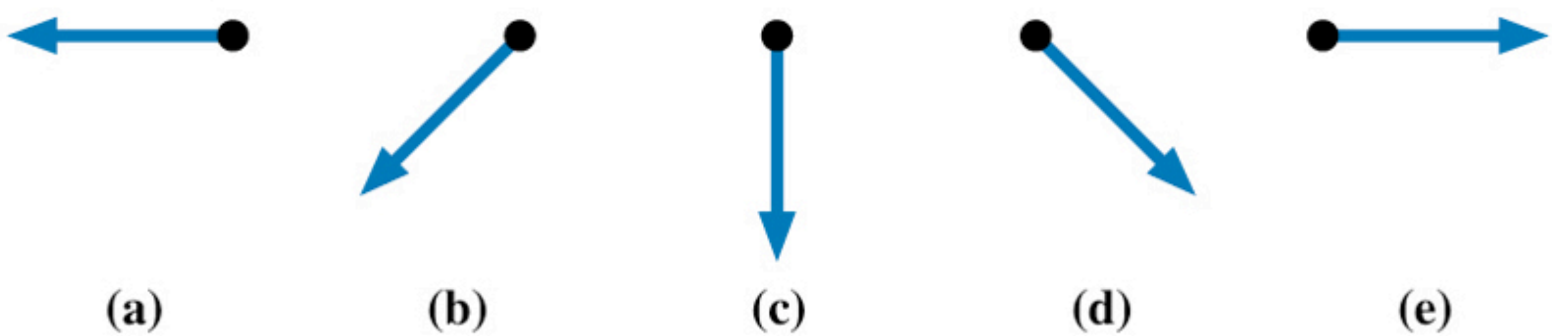
  the kinetic energy of the lighter ball

# End here

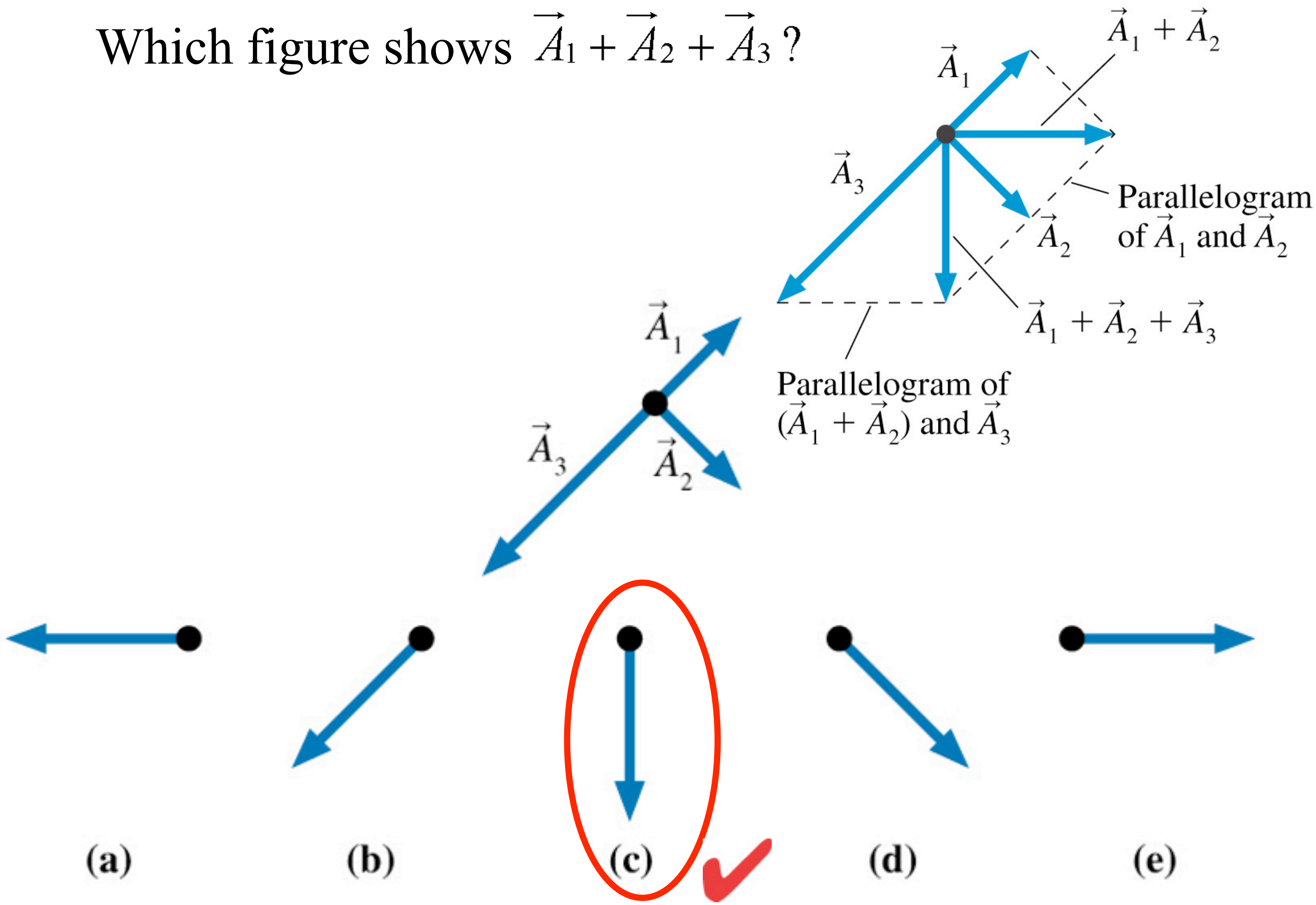
Which figure shows $\vec{A}_1 + \vec{A}_2 + \vec{A}_3$ ?



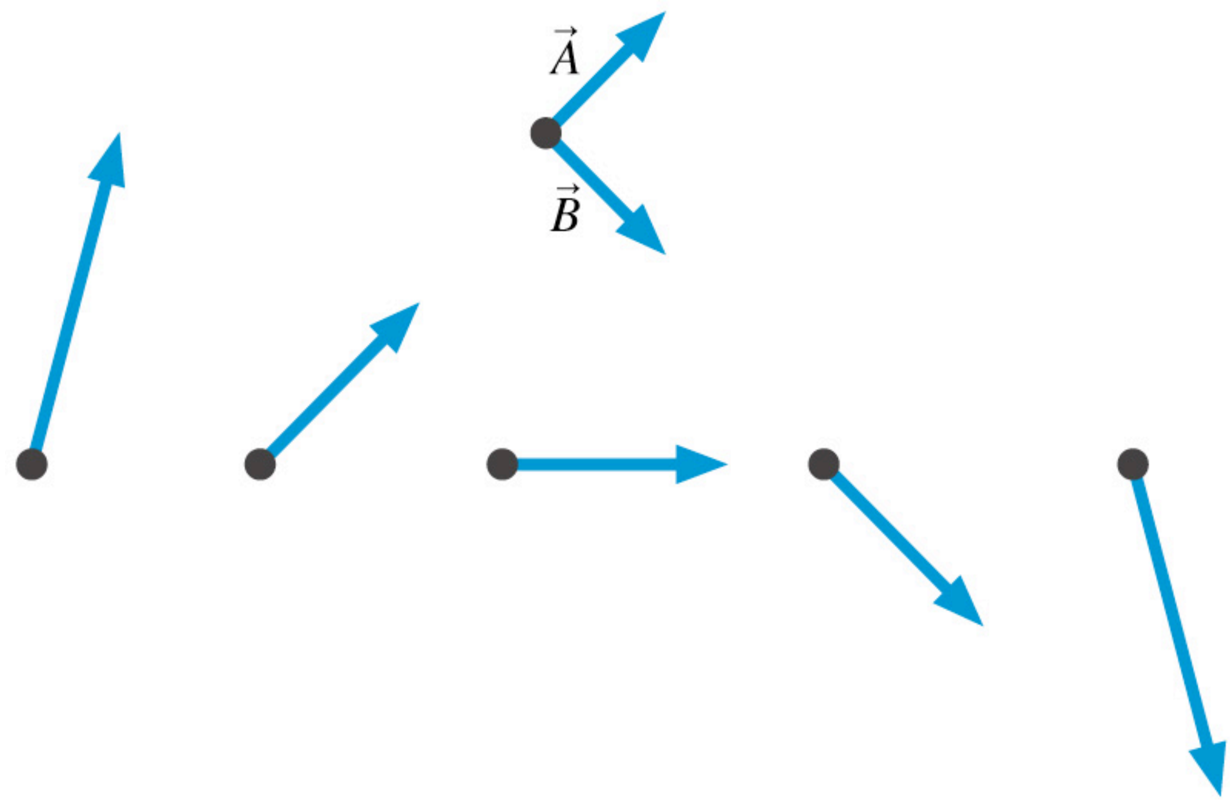



Which figure shows $\vec{A}_1 + \vec{A}_2 + \vec{A}_3$ ?

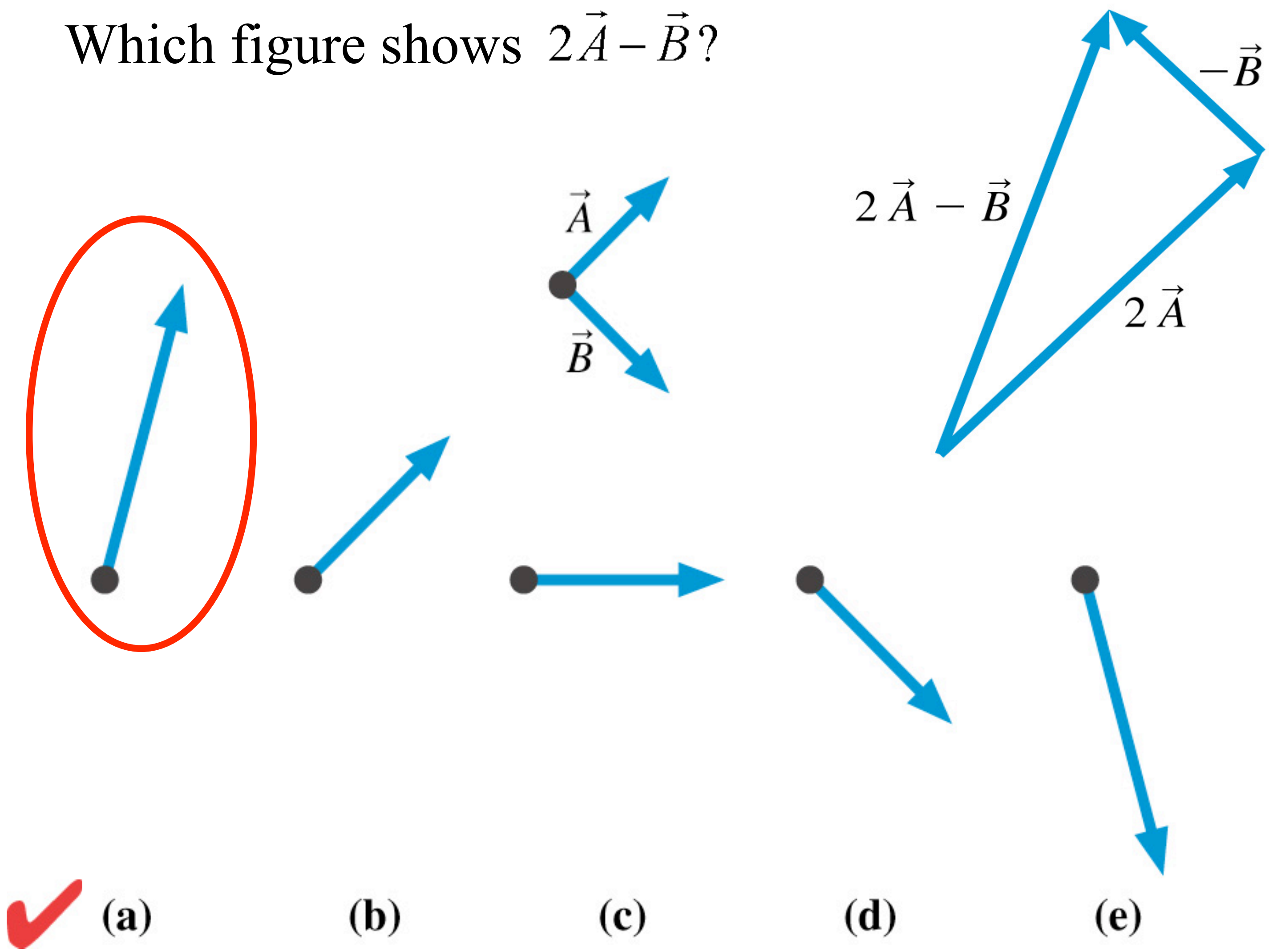


Which figure shows $2\vec{A} - \vec{B}$?

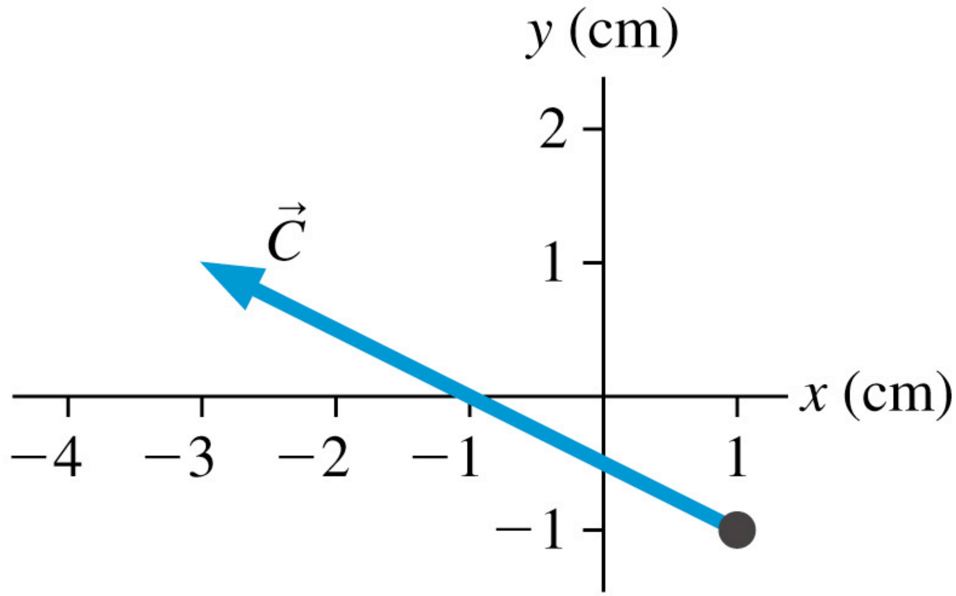



(a) (b) (c) (d) (e)

Which figure shows $2\vec{A} - \vec{B}$?

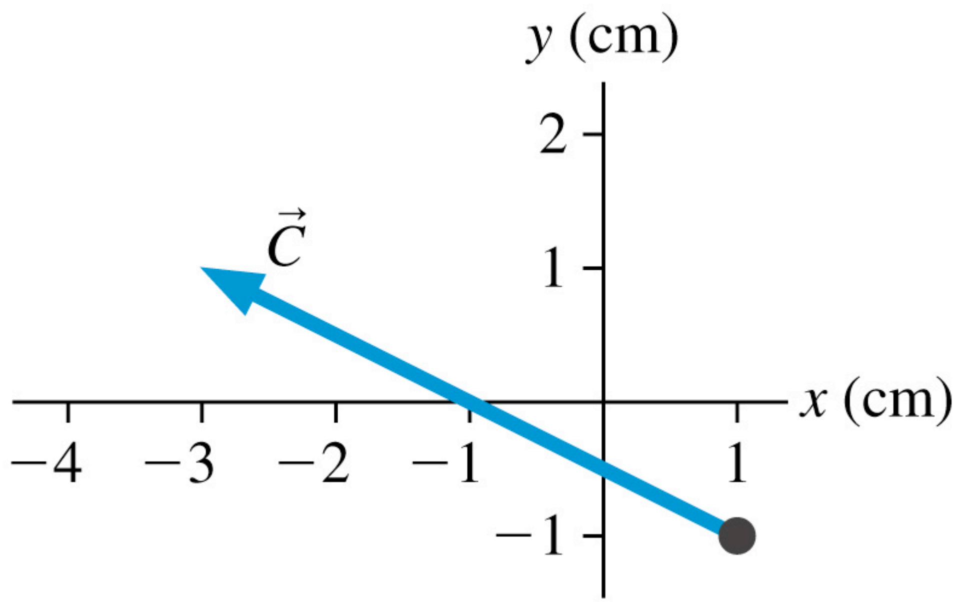


What are the $x$- and $y$-components $C_x$ and $C_y$ of vector $\vec{C}$?




A. $C_x = –3$ cm, $C_y = 1$ cm
B. $C_x = –4$ cm, $C_y = 2$ cm
C. $C_x = –2$ cm, $C_y = 1$ cm
D. $C_x = –3$ cm, $C_y = –1$ cm
E. $C_x = 1$ cm, $C_y = –1$ cm

What are the $x$- and $y$-components $C_x$ and $C_y$ of vector $\vec{C}$?




A. $C_x = -3$ cm, $C_y = 1$ cm

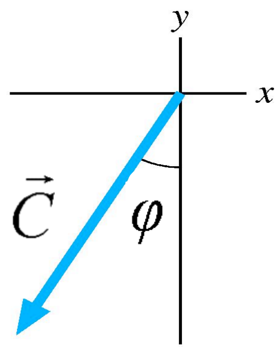
✔ **B. $C_x = -4$ cm, $C_y = 2$ cm**

C. $C_x = -2$ cm, $C_y = 1$ cm

D. $C_x = -3$ cm, $C_y = -1$ cm

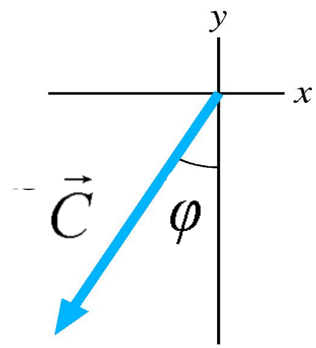
E. $C_x = 1$ cm, $C_y = -1$ cm

Angle $\varphi$ that specifies the direction of $\vec{C}$ is given by



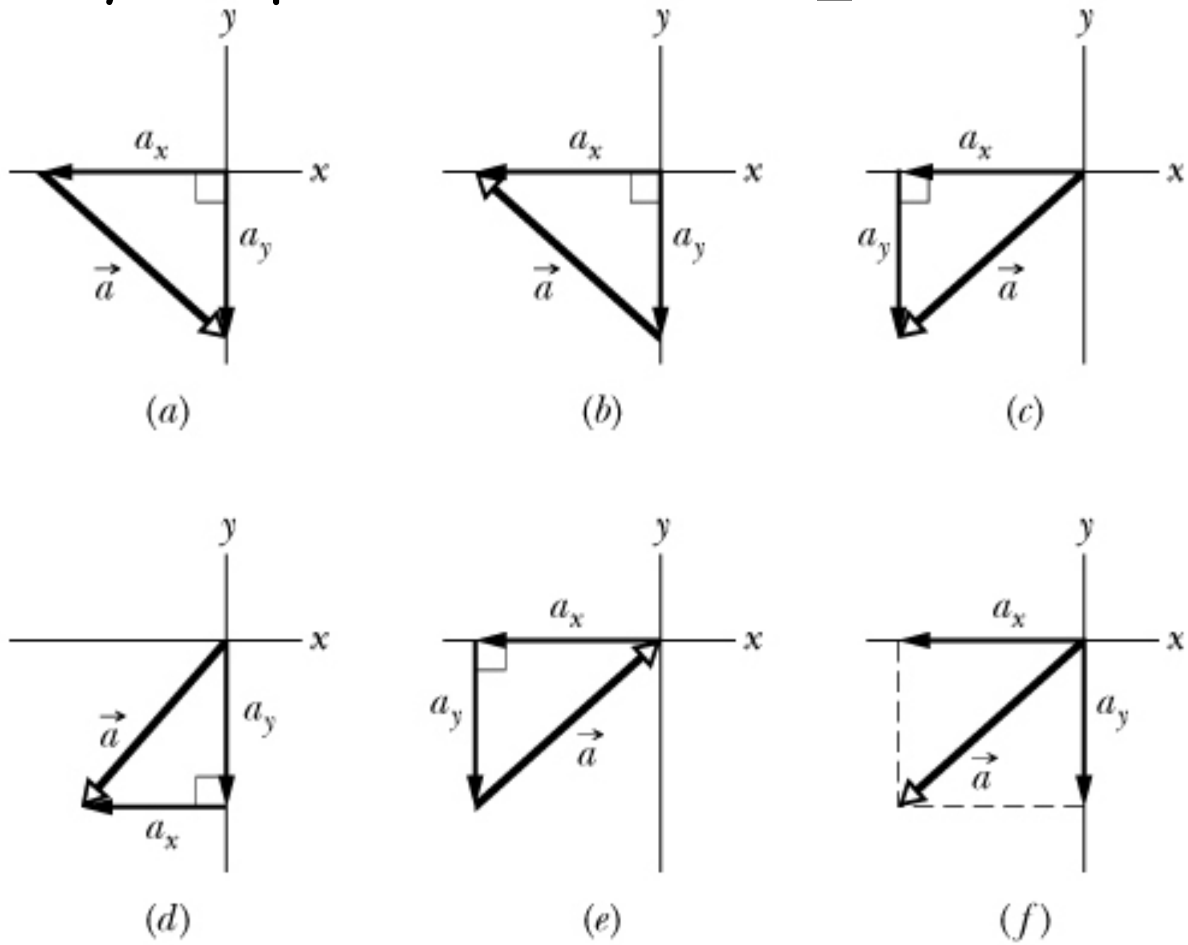

A. $\tan^{-1}(C_x/C_y)$
B. $\tan^{-1}(C_x/|C_y|)$
C. $\tan^{-1}(|C_x|/|C_y|)$
D. $\tan^{-1}(C_y/C_x)$
E. $\tan^{-1}(C_y/|C_x|)$

Angle $\varphi$ that specifies the direction of $\vec{C}$ is given by




A. $\tan^{-1}(C_x/C_y)$
B. $\tan^{-1}(C_x/|C_y|)$
**C. $\tan^{-1}(|C_x|/|C_y|)$**
D. $\tan^{-1}(C_y/C_x)$
E. $\tan^{-1}(C_y/|C_x|)$

Which of these methods for combining the x and y components of vector **a** are correct?




*Components must be head to tail and **a** must extend from tail of one to head of the other*

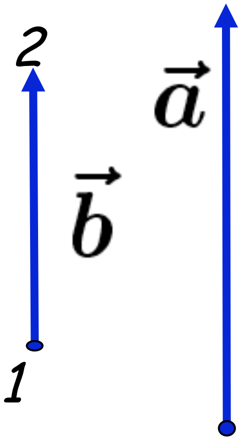
Note: if a component is opposite the axis direction, then, eg, $a_y$ is <0

(but its magnitude, $|a_y|$ is > 0)

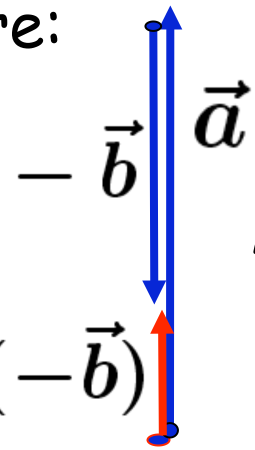
# Question

For the vectors a and b, what are:

$|\mathbf{a}| = 3 \quad |\mathbf{b}| = 2$




$\vec{a} - \vec{b}$




$|\mathbf{a} - \mathbf{b}| = 3 - 2 = 1$

$$\vec{a} - \vec{b} = \vec{a} + (-\vec{b})$$

$\vec{a} \cdot \vec{b}$

$$\vec{a} \cdot \vec{b} = ab\cos\phi \quad = ab \cos 0 = ab$$

$\vec{a} \times \vec{b}$

$$\vec{c} = \vec{a} \times \vec{b}$$

$$c = ab\sin\phi \quad = 6 \sin 0 = 0$$

*Direction?*

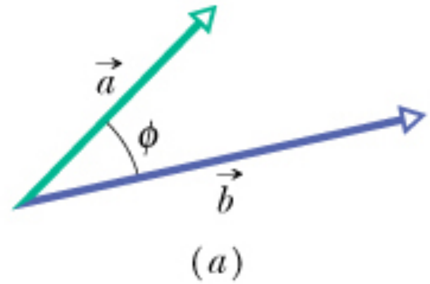
*Right hand rule: Magnitude 0 => not needed:*
*No angle to sweep out anyway.*

# Vector review (cont)

Multiplying Vectors: vector or cross product

$$\vec{c} = \vec{a} \times \vec{b}$$

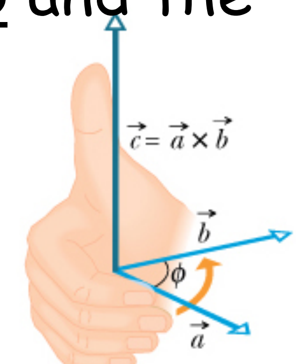
$$c = ab \sin\phi$$




where f is the smaller of the two

angles between the vectors and

c is ⊥ the plane containing a and b and the direction follows the right hand rule (when the tails of the vectors are together, fingers sweep a into b and the thumb points in the direction of c).




What is the direction of c for the upper figure?

# What is a scientific theory?

*What is the Newtonian theory of gravitation?*

*We know the law of gravitation*

$$F = G\frac{mM}{r^2}$$

*where G is a universal constant, m, M are the masses of two bodies a distance r apart and F is the force acting on each body towards the other.*

*Does the theory tell us what makes gravity work?*
*If not, is it still a theory of gravitation?*

"In science, a theory is a proposed description, explanation, or model of the manner of interaction of a set of natural phenomena, capable of predicting future occurrences or observations of the same kind, and capable of being tested through experiment or otherwise falsified through empirical observation."
Wikipedia

# What is a scientific theory?

*According to Karl Popper (Austrian/British philosopher of science, 1902-1994), a scientific theory only has content if it makes predictions that might be falsified, thereby disproving the theory. (http://plato.stanford.edu/entries/popper/)*

*So we need predictions and there need to be predictions that could be shown to be wrong by observing or measuring something.*

*But it doesn't have to explain "Why" in a fundamental way (of course it is "better" if it does).*

*Note that creationism or "intelligent design" are not scientific theories because they make no falsifiable predictions.*

# Back to gravitation

*Here is a more fundamental theory of gravitation:*

*Consider space being filled with invisible particles which collide (from all directions equally) with all objects with mass and transfer some small momentum to them. Two masses shadow each other and thereby lead to a net force between the objects which decreases as $1/r^2$ because the area shadowed decreases by that amount.*

*Problem is, the theory predicts that a moving object would hit more of these particles on the front and lead to a slowing force on any moving object.*

*Experimentally, we know such a force does not exist*

*=> the theory does not apply.*

# Gravity and scientific theories (cont)

*In practice, for gravity the mathematical expression*

$$F = G\frac{mM}{r^2}$$

*is all we have. We know what gravity does, but we don't know how it does it.*

*But it is a perfectly good theory and predicts how the planets move (with minor exceptions due to general relativity), it predicts a rockets' trajectory, why we stay on the surface of the earth, etc, etc.*

# Reading Quiz Questions

- What is a vector?
- What is the name of the quantity represented by $\hat{\mathrm{i}}$ ?
- Chapter 3 shows how vectors can be added using
  a) graphical addition
  b) Vector addition
  c) Numerical addition
  d) a) and b)
  e) a) and c)
  f) a), b) and c)
- To decompose a vector means
  a) To break it into several smaller vectors
  b) To break it apart into scalars
  c) To break it into pieces parallel to the axes
  d) To place it at the origin
  e) This topic was not discussed in Chapter 3.

A *perfectly elastic collision* is a collision

A. between two springs.
B. that conserves potential energy.
C. that conserves thermal energy.
D. that conserves kinetic energy.
E. All of B, C, and D.

A *perfectly elastic collision* is a collision

A. between two springs.
B. that conserves potential energy.
C. that conserves thermal energy.
D. that conserves kinetic energy.
✔ **E. All of B, C, and D.**