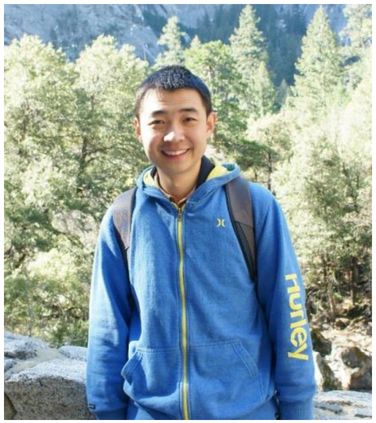


Please feel free to contact me:

Ding Pan
dingpan@ust.hk
http://angstrom.ust.hk/
Office hours: same zoom/classroom after each lecture


We develop and apply computational and numerical methods to understand and predict the properties and behavior of liquids, solids, and nanostructures from **first principles**

# Lecture 1

Physical Quantities, Vectors and 2D Motion

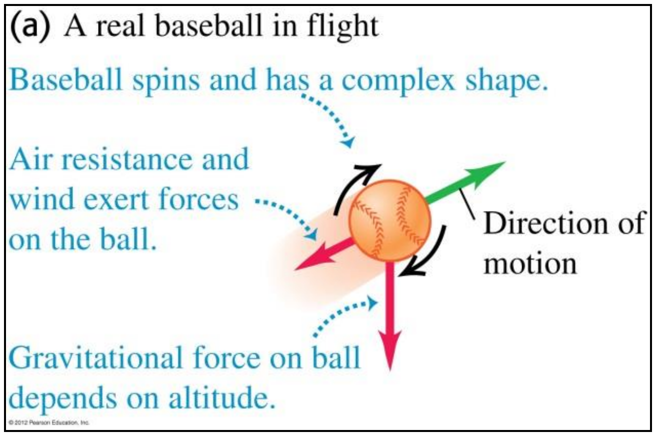
# Intended Learning Outcomes

- After this lecture you will learn:
  1. meanings of theories and models in physics
  2. how to define units for fundamental physical quantities
  3. how to use significant figures
  4. vectors and its algebraic operations: addition and subtraction
  5. displacement, velocity and acceleration in vector notation
  6. to predict the trajectory of projectile motion

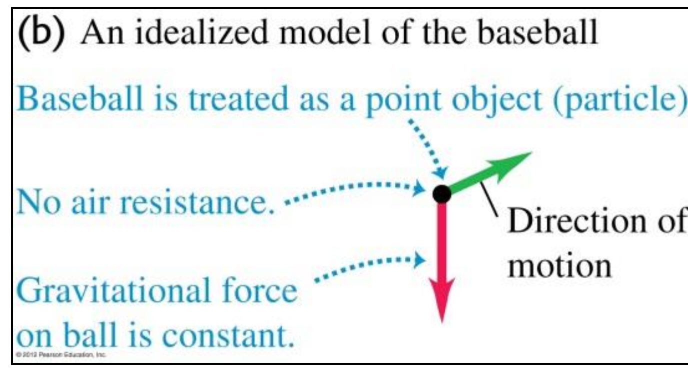
# Physics is an *experimental natural* science

- Theory: an explanation of natural phenomena based on observation and accepted fundamental principles, e.g. theory of evolution in biology
- Model: a simplified version of a physical system that would be too complicated to analyze in full detail

# Example: Throwing a Baseball




throw away
“unimportant”
parts




use *theory* to make prediction

means calculation

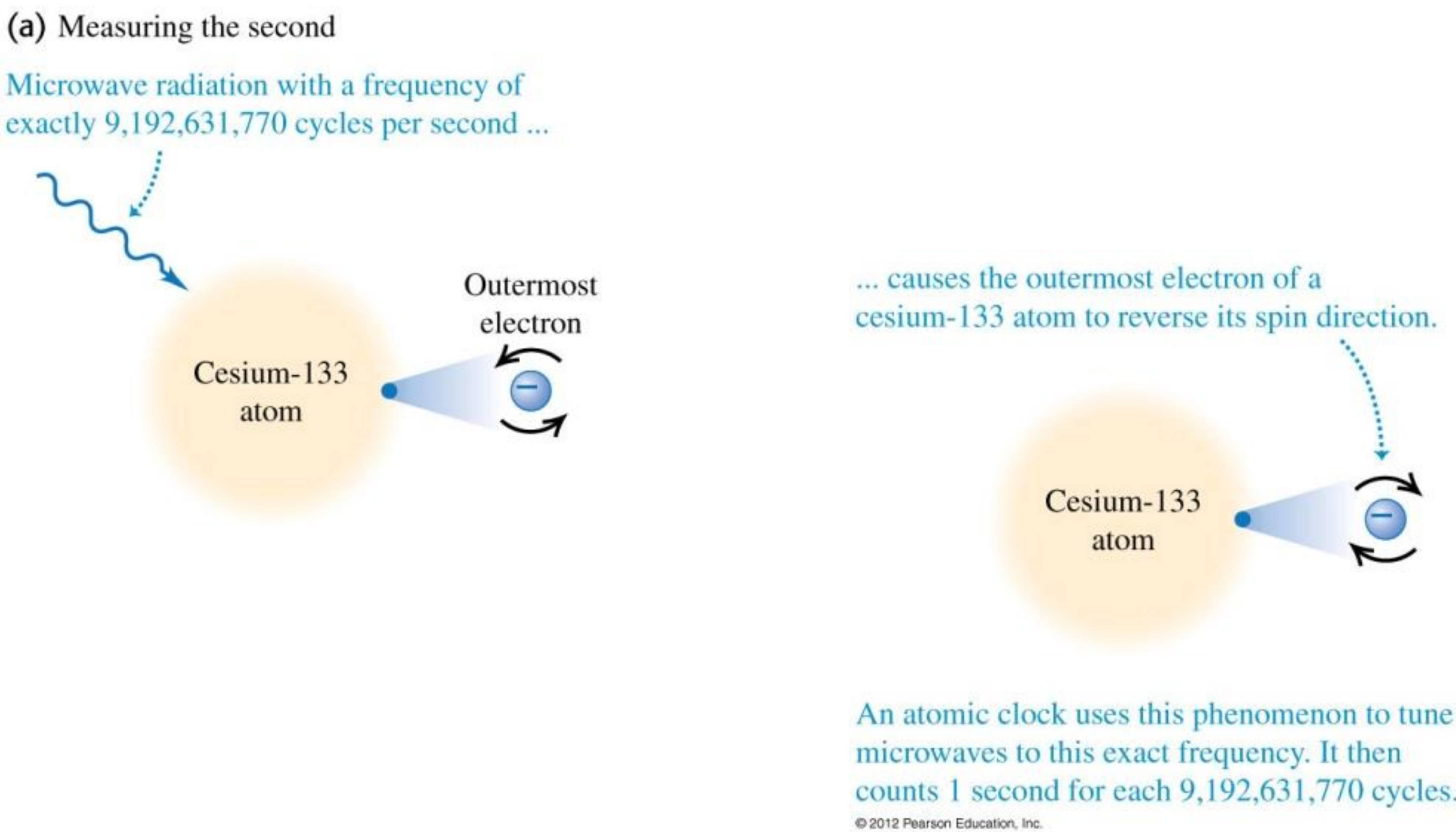
# Standards and Units

# *International Standard* (SI)

- The *International Standard*, or SI (Système International) Units
  - TIME: in second
  - LENGTH: in meter
  - MASS: in kilogram

# Time (Second)

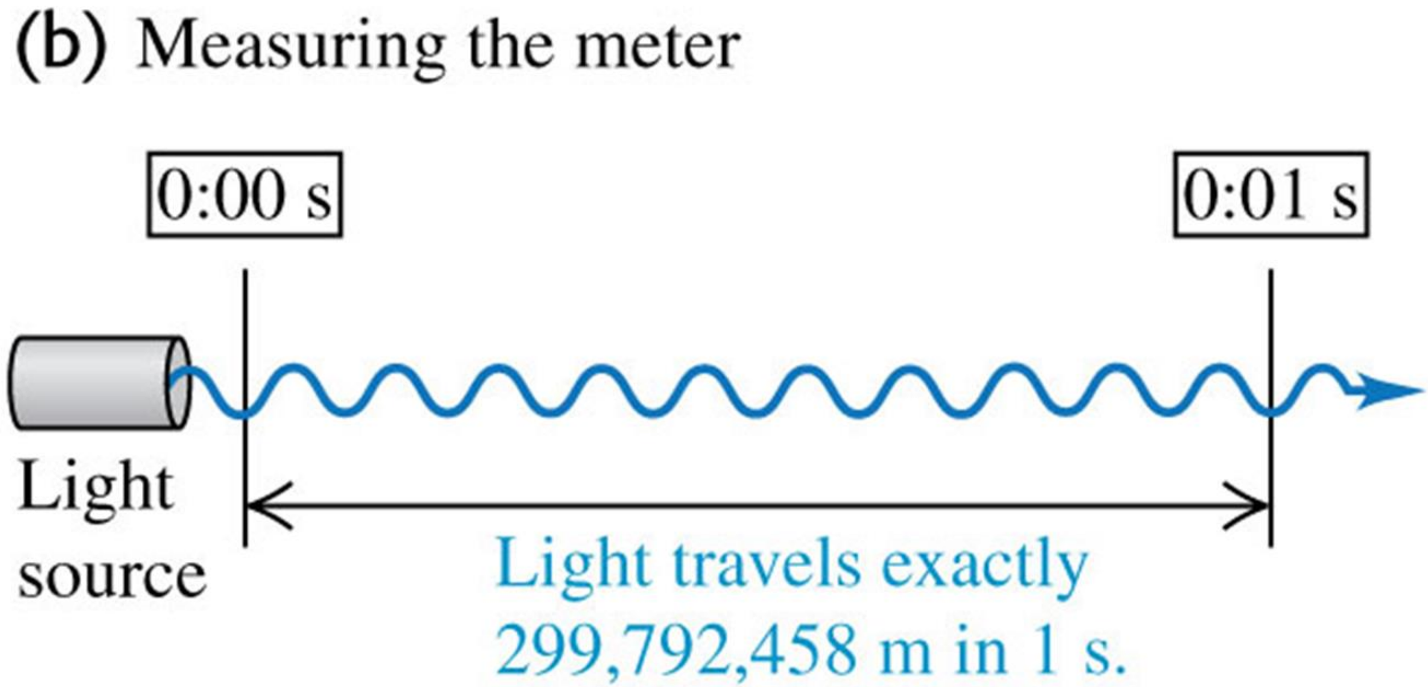
Starting 1967, defined using an atomic clock



# Length (Meter)

starting 1983, defined based on the **speed of light** in vacuum, which is *defined* to be (exactly)

$$c = 299{,}792{,}458 \text{ m/s}$$



# Mass (Kilogram)



Previous defined to be the mass of a metal cylinder kept at the International Bureau of Weight and Measures in France

Starting 2018, kilogram is defined based on a fundamental constant of nature called **Planck's constant**, which is *defined* to be (exactly)

$$h = 6.62607015 \times 10^{-34}\ \mathrm{kg{\cdot}m^2}/s$$

# Uncertainty and Significant Figures

- What is the difference among the following representations of $\pi$?
  1) 3.14

     means between 3.135 and 3.145, or $3.14 \pm 0.005$
  2) 3.1416

     means $3.1416 \pm 0.00005$
  3) 22/7 Zu's ratio: 355/113

     ⚠ rational number usually means exact, misleading here, not exact!

- What is the difference between 3 and 3.00?

⚠ Be careful about the number of significant figures

- What are the problems with the following representation?

$$\underbrace{2.017676}_{} \pm 0.0132$$

smaller than error, *meaningless!*

error estimation cannot be so accurate! Usually take 1, at most 2 sig. fig.

keep the same decimal places

should be

_____ $\pm$ _____

# Note: Uncertainty Propagation in Calculations

**Multiplication or division:**
Result may have no more significant figures than the starting number with the fewest significant figures:

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

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

**Addition or subtraction:**
Number of significant figures is determined by the starting number with the largest uncertainty (i.e., fewest digits to the right of the decimal point):

$$27.153 + 138.2 - 11.74 = 153.6$$

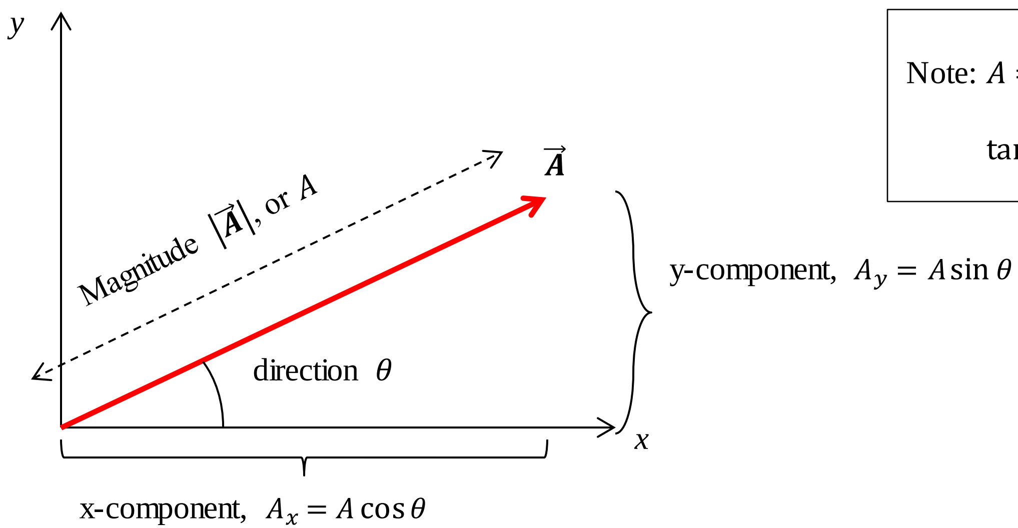
Question: What is the density (in $kg/m^3$) of a rock of mass 1.80 kg and volume $6.0 \times 10^{-4}\ m^3$?
(a) $3 \times 10^3\ kg/m^3$, (b) $3.0 \times 10^3\ kg/m^3$, (c) $3.00 \times 10^3\ kg/m^3$, (d) $3.000 \times 10^3\ kg/m^3$

# Vector

# Vector

An "arrow" in space, has magnitude (length) and direction

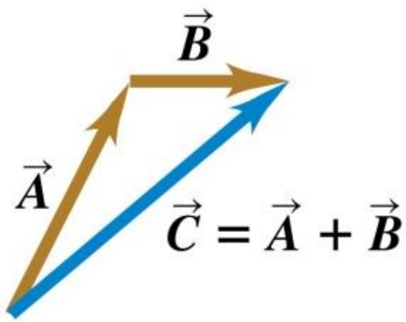
e.g. in 2D Cartesian coordinates (due to René Descartes)



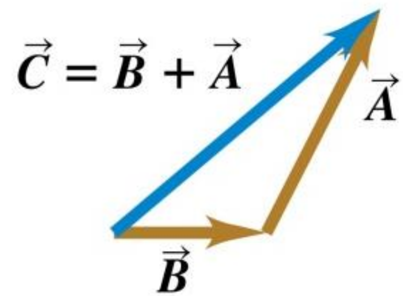

Note: $A = \sqrt{A_x^2 + A_y^2}$ (Pythagoras thm)

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

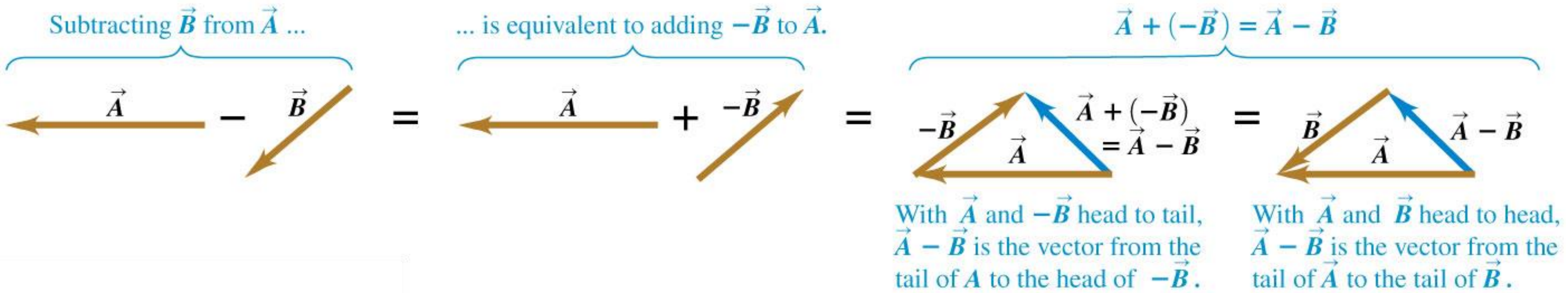
# Addition




or



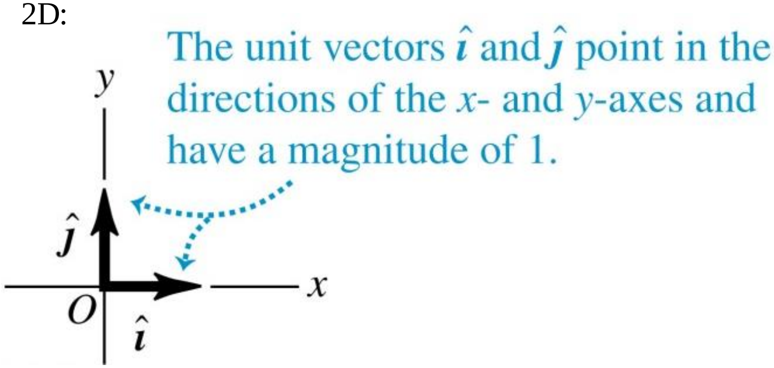
# Subtraction



# Unit Vectors

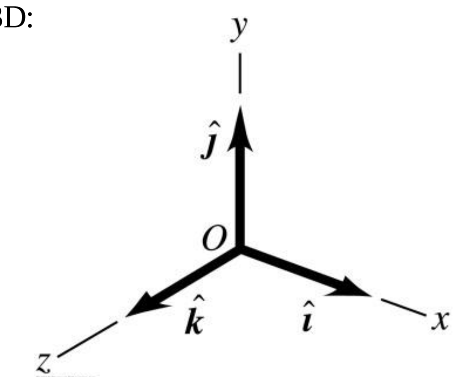
Vectors of unit magnitude are called <u>unit vectors</u>. Most commonly used unit vectors are $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$, along $x$, $y$, and $z$ directions in Cartesian coordinates

2D:




$$\boxed{\vec{\boldsymbol{A}} = A_x\hat{\imath} + A_y\hat{\jmath}}$$

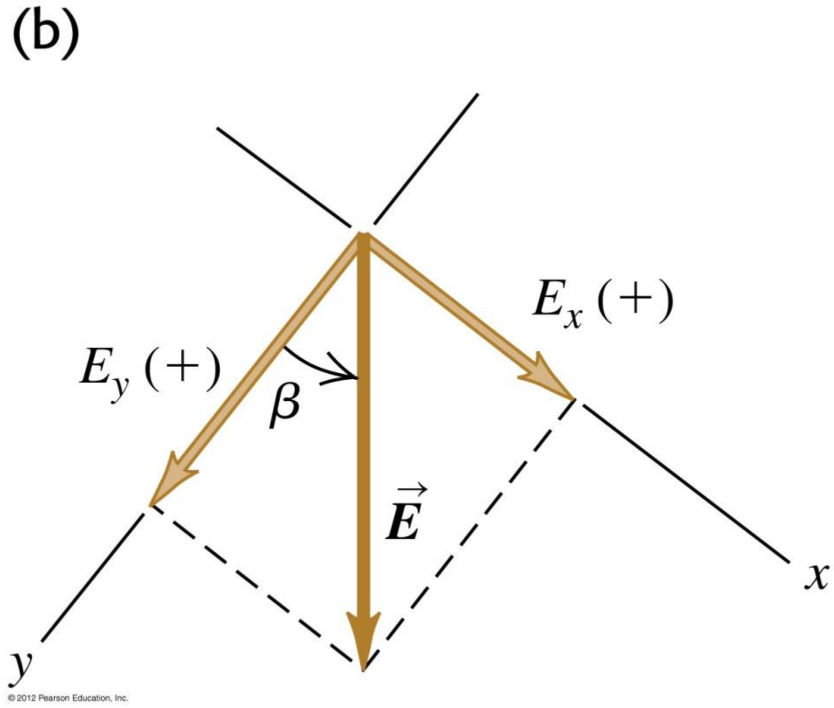
3D:




$$\boxed{\vec{\boldsymbol{A}} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}}$$

Q1.1

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




A. $E_x = E \cos \beta$, $E_y = E \sin \beta$

B. $E_x = E \sin \beta$, $E_y = E \cos \beta$

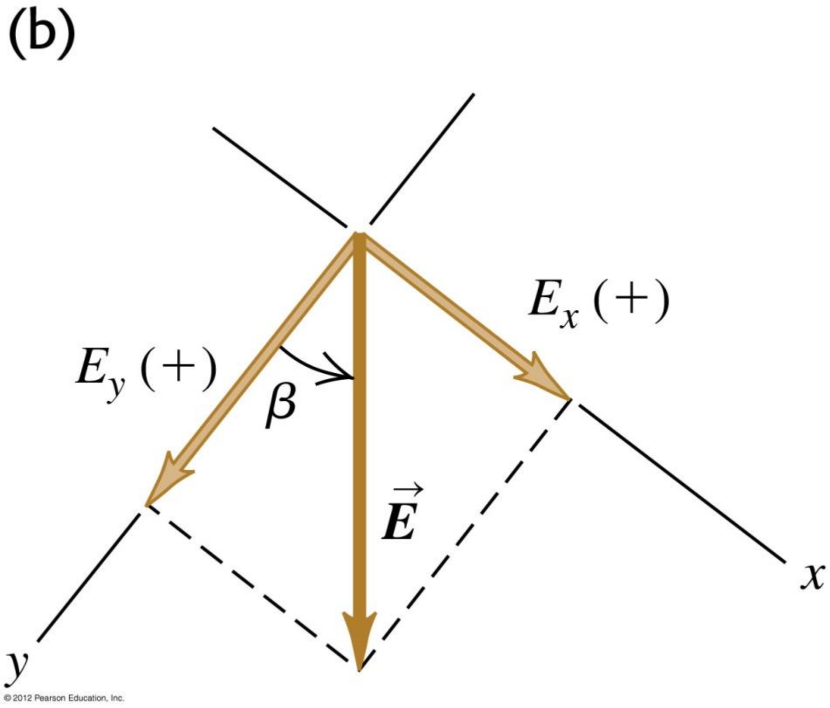
C. $E_x = -E \cos \beta$, $E_y = -E \sin \beta$

D. $E_x = -E \sin \beta$, $E_y = -E \cos \beta$

E. $E_x = -E \cos \beta$, $E_y = E \sin \beta$

Q1.1

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




A. $E_x = E \cos \beta$, $E_y = E \sin \beta$

B. $E_x = E \sin \beta$, $E_y = E \cos \beta$

C. $E_x = -E \cos \beta$, $E_y = -E \sin \beta$

D. $E_x = -E \sin \beta$, $E_y = -E \cos \beta$

E. $E_x = -E \cos \beta$, $E_y = E \sin \beta$

Which of the following statements is correct for *any* two vectors $\vec{A}$ and $\vec{B}$?

A. The magnitude of $\vec{A}+\vec{B}$ is $A + B$

B. The magnitude of $\vec{A}+\vec{B}$ is $A - B$

C. The magnitude of $\vec{A}+\vec{B}$ is greater than or equal to $|A - B|$

D. The magnitude of $\vec{A}+\vec{B}$ is greater than the magnitude of $\vec{A}-\vec{B}$

E. The magnitude of $\vec{A}+\vec{B}$ is $\sqrt{A^2+B^2}$

Q1.2

Which of the following statements is correct for *any* two vectors $\vec{A}$ and $\vec{B}$?

A. The magnitude of $\vec{A} + \vec{B}$ is $A + B$

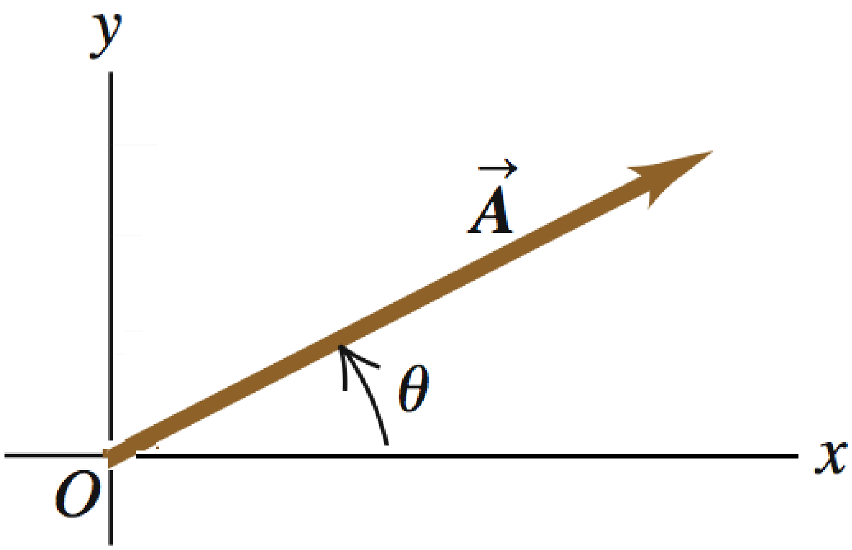
B. The magnitude of $\vec{A} + \vec{B}$ is $A - B$

C. The magnitude of $\vec{A} + \vec{B}$ is greater than or equal to $|A - B|$

D. The magnitude of $\vec{A} + \vec{B}$ is greater than the magnitude of $\vec{A} - \vec{B}$

E. The magnitude of $\vec{A} + \vec{B}$ is $\sqrt{A^2 + B^2}$

Q1.3




The angle $\theta$ is measured counterclockwise from the positive $x$-axis as shown. For which of these vectors is $\theta$ greatest?

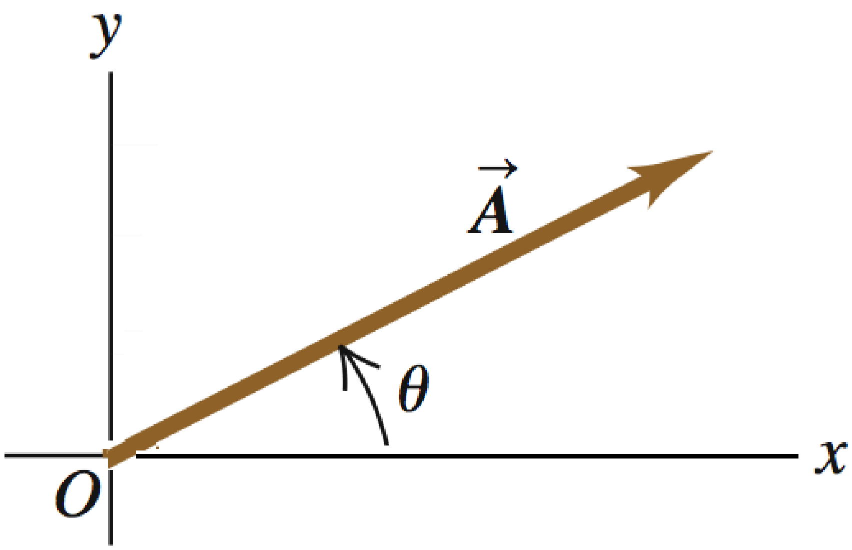
A. $24\hat{\boldsymbol{i}} + 18\hat{\boldsymbol{j}}$

B. $-24\hat{\boldsymbol{i}} - 18\hat{\boldsymbol{j}}$

C. $-18\hat{\boldsymbol{i}} + 24\hat{\boldsymbol{j}}$

D. $-18\hat{\boldsymbol{i}} - 24\hat{\boldsymbol{j}}$

Q1.3




The angle $\theta$ is measured counterclockwise from the positive *x*-axis as shown. For which of these vectors is $\theta$ greatest?

A. $24\hat{\boldsymbol{i}} + 18\hat{\boldsymbol{j}}$

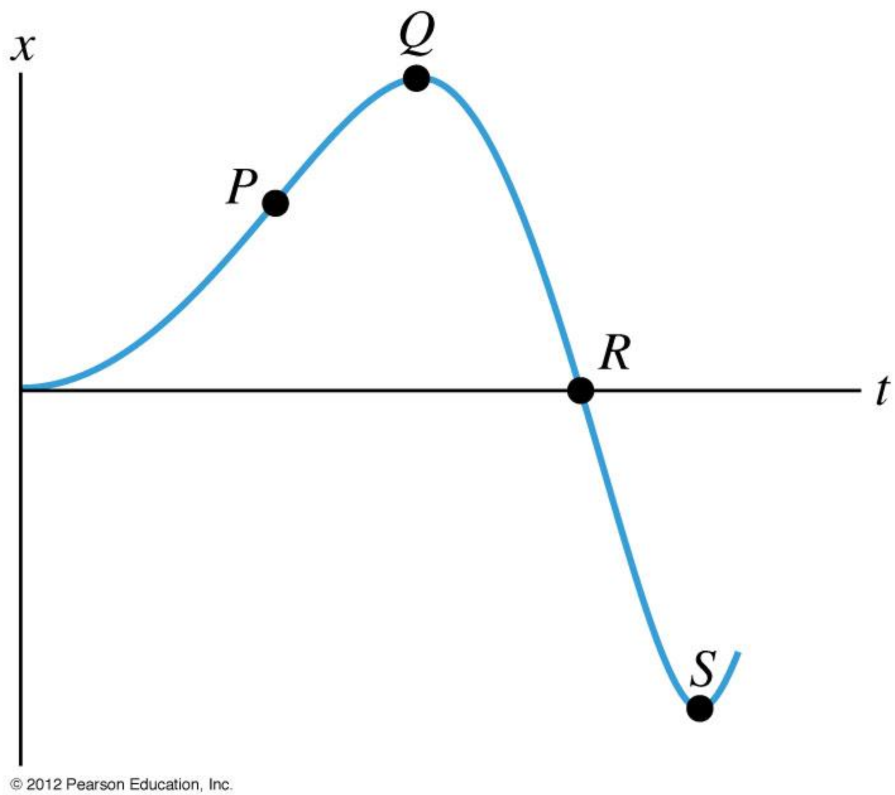
B. $-24\hat{\boldsymbol{i}} - 18\hat{\boldsymbol{j}}$

C. $-18\hat{\boldsymbol{i}} + 24\hat{\boldsymbol{j}}$

D. $-18\hat{\boldsymbol{i}} - 24\hat{\boldsymbol{j}}$

# Motion in 2D

Q2.3




This is the *x*-*t* graph of the motion of a particle. Of the four points *P, Q, R,* and *S*, the acceleration $a_x$ is greatest (most positive) at

A. point *P.*

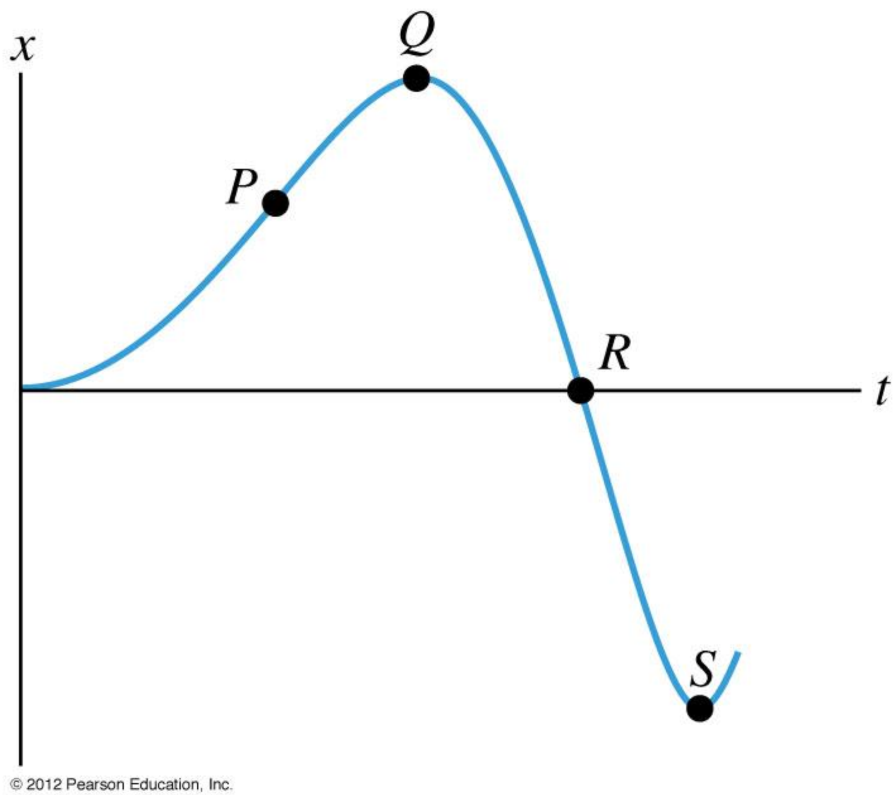
B. point *Q.*

C. point *R.*

D. point *S.*

E. not enough information in the graph to decide

Q2.3




This is the *x*-*t* graph of the motion of a particle. Of the four points *P, Q, R,* and *S*, the acceleration $a_x$ is greatest (most positive) at

A. point *P.*

B. point *Q.*

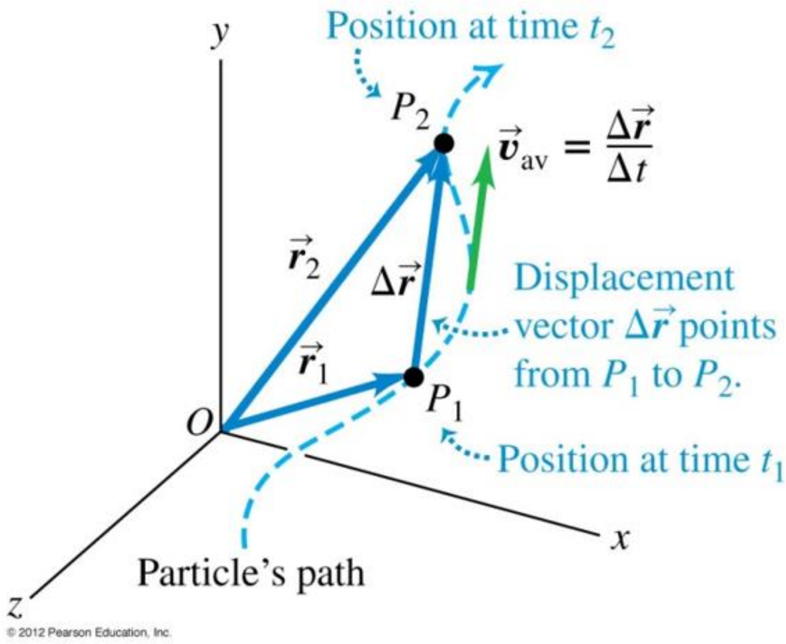
C. point *R.*

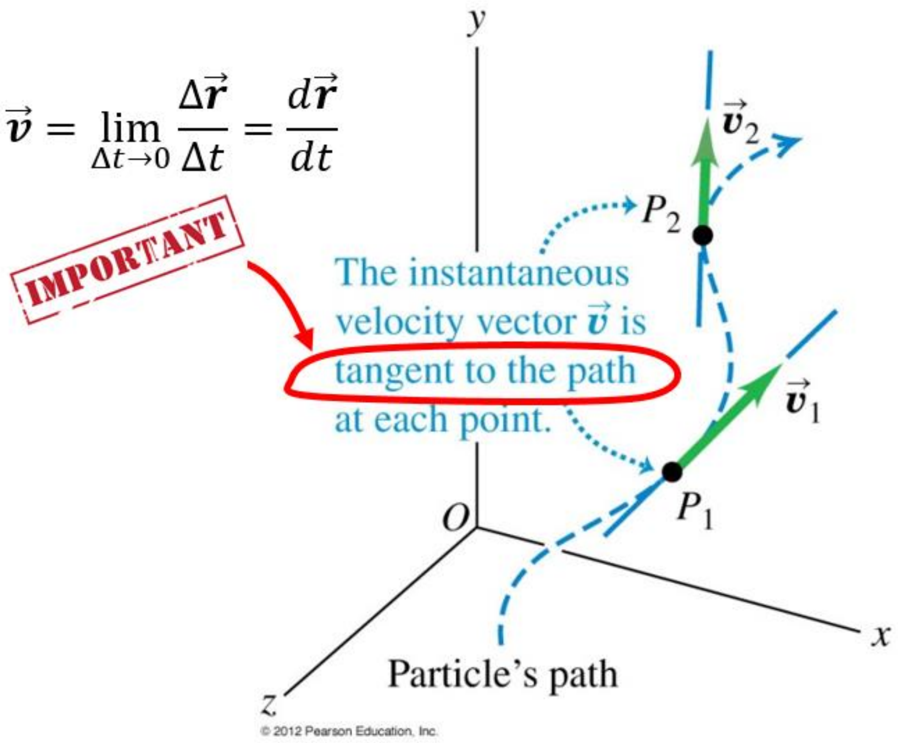
D. point *S.*

E. not enough information in the graph to decide

# Displacement and velocity vectors

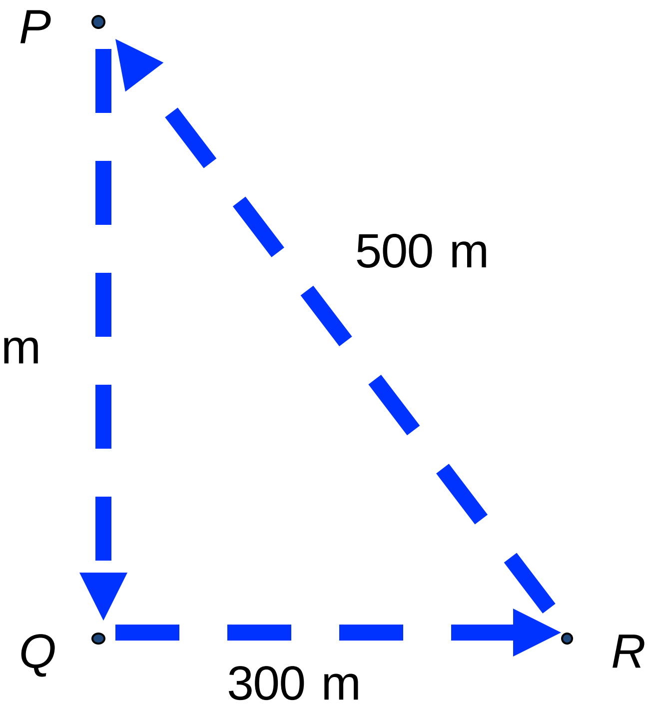
Distance and speed – scalars
Displacement and velocity – vectors



Q3.1

A bicyclist starts at point *P* and travels around a triangular path that takes her through points *Q* and *R* before returning to point *P*. What is the magnitude of her net displacement for the entire round trip?




A. 100 m

B. 200 m

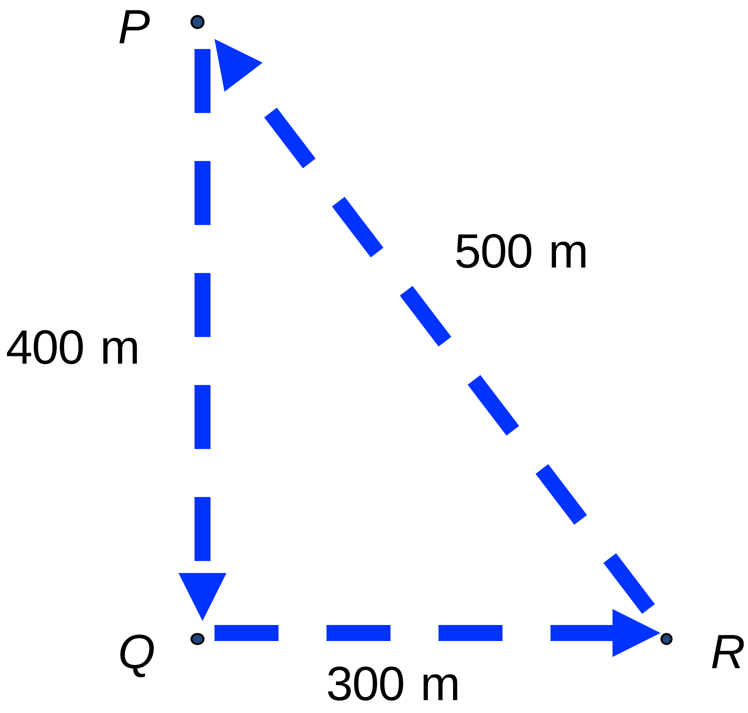
C. 600 m

D. 1200 m

E. zero

Q3.1

A bicyclist starts at point *P* and travels around a triangular path that takes her through points *Q* and *R* before returning to point *P*. What is the magnitude of her net displacement for the entire round trip?




A. 100 m

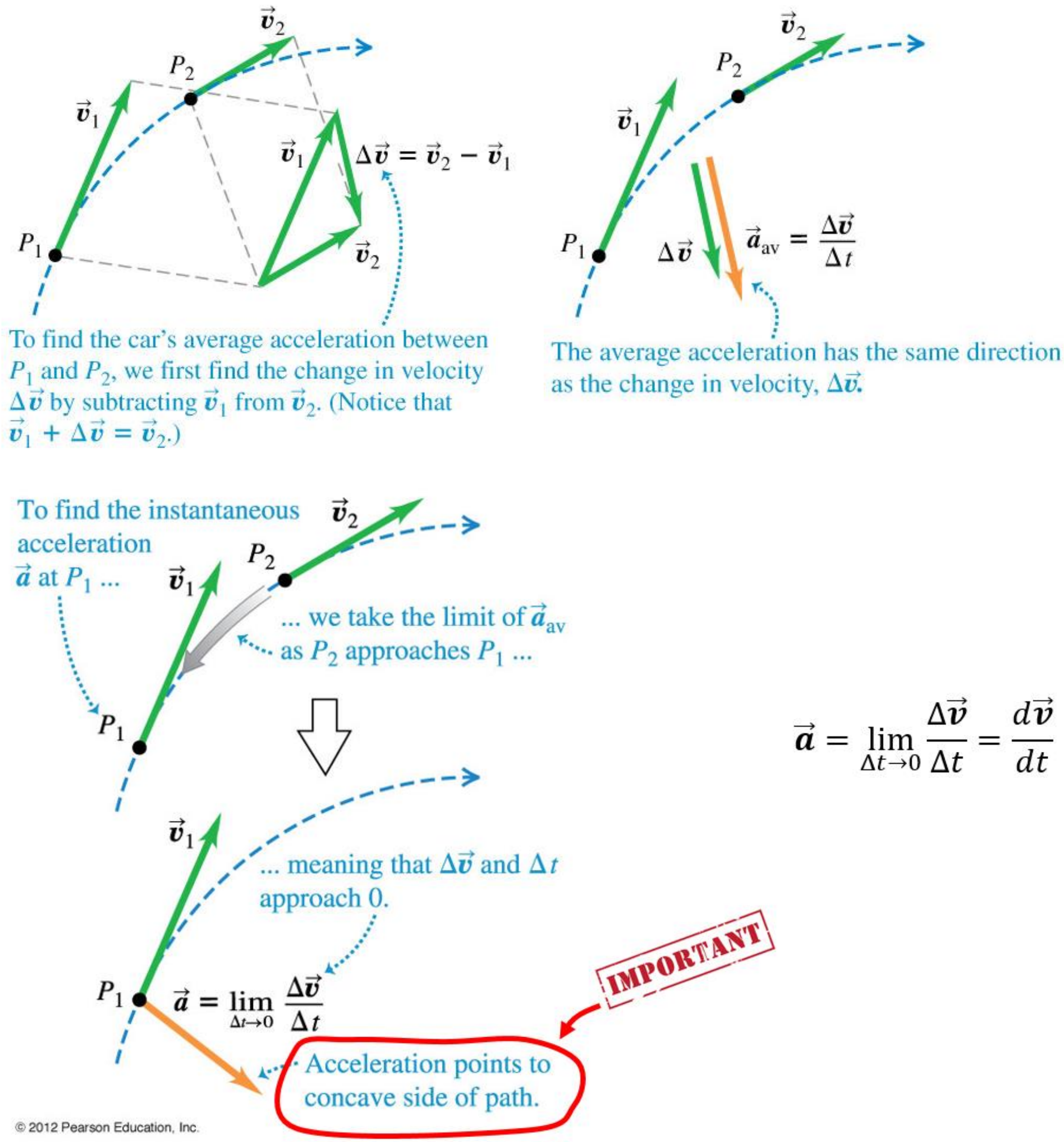
B. 200 m

C. 600 m

D. 1200 m

E. zero

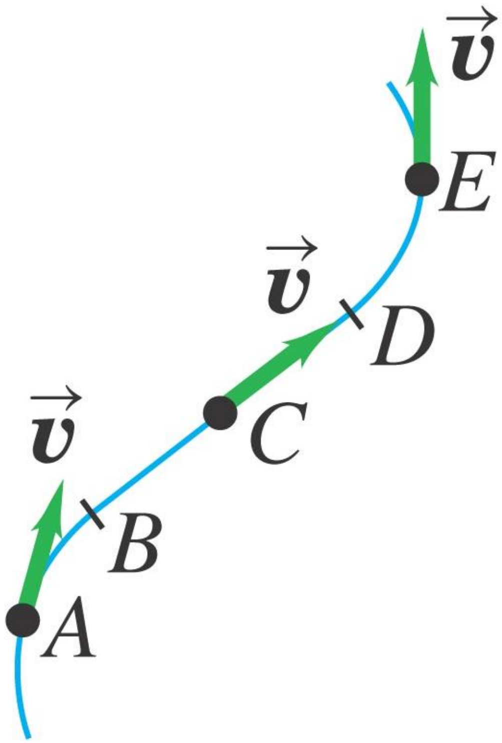
# Acceleration vector




$$\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta\vec{v}}{\Delta t} = \frac{d\vec{v}}{dt}$$

Q3.3

The motion diagram shows an object moving along a curved path at constant speed. At which of the points *A, C,* and *E* does the object have *zero* acceleration?






A. point *A* only

B. point *C* only

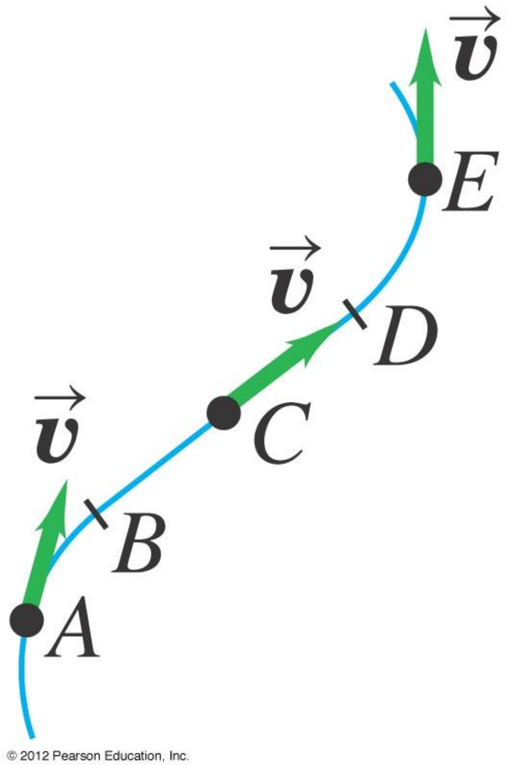
C. point *E* only

D. points *A* and *C* only

E. points *A, C,* and *E*

Q3.3

The motion diagram shows an object moving along a curved path at constant speed. At which of the points *A, C,* and *E* does the object have *zero* acceleration?




A. point *A* only

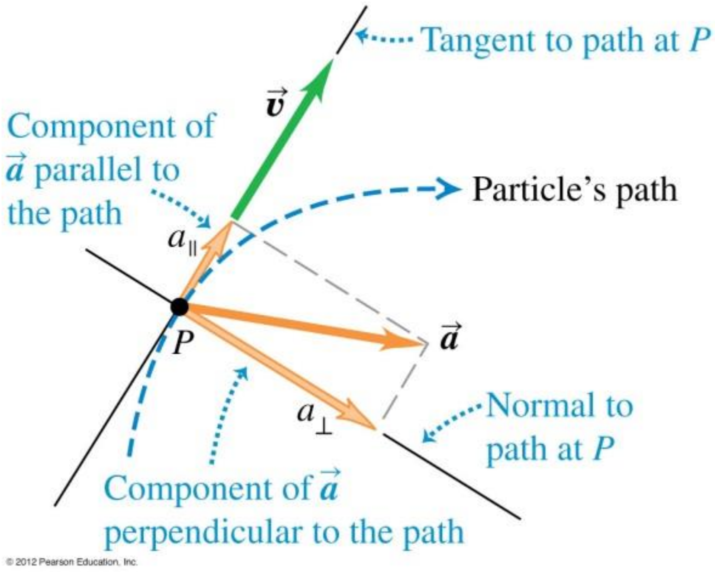
B. point *C* only

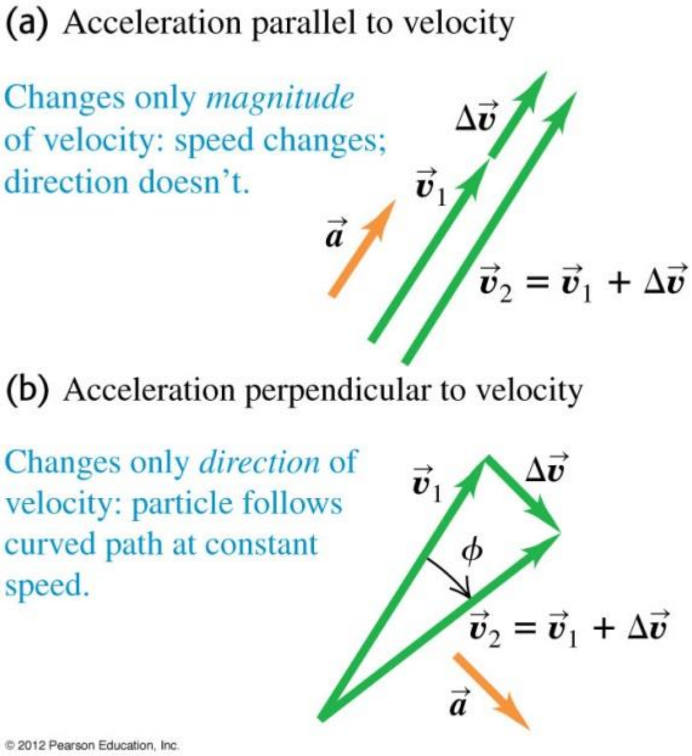
C. point *E* only

D. points *A* and *C* only

E. points *A, C,* and *E*

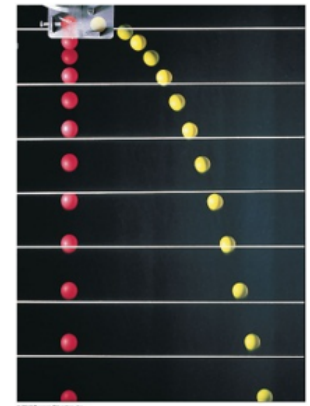
Resolve into parallel (or <u>tangential</u>) $a_{\parallel}$, and perpendicular (or <u>radial</u>) $a_{\perp}$ components



**Projectile**

Principle: $x$ and $y$ motions are independent



Vertical motion of red and yellow balls are identical – at the same height at any time

$\vec{\boldsymbol{a}} = a_x\hat{\imath} + a_y\hat{\jmath} = -g\hat{\jmath}$, i.e., $a_x = 0, a_y = -g$

Recall from high school: rectilinear motion with uniform acceleration $a$

$$v = v_0 + at$$
$$x - x_0 = v_0 t + \frac{1}{2}at^2$$
$$v^2 = v_0^2 + 2a(x - x_0)$$

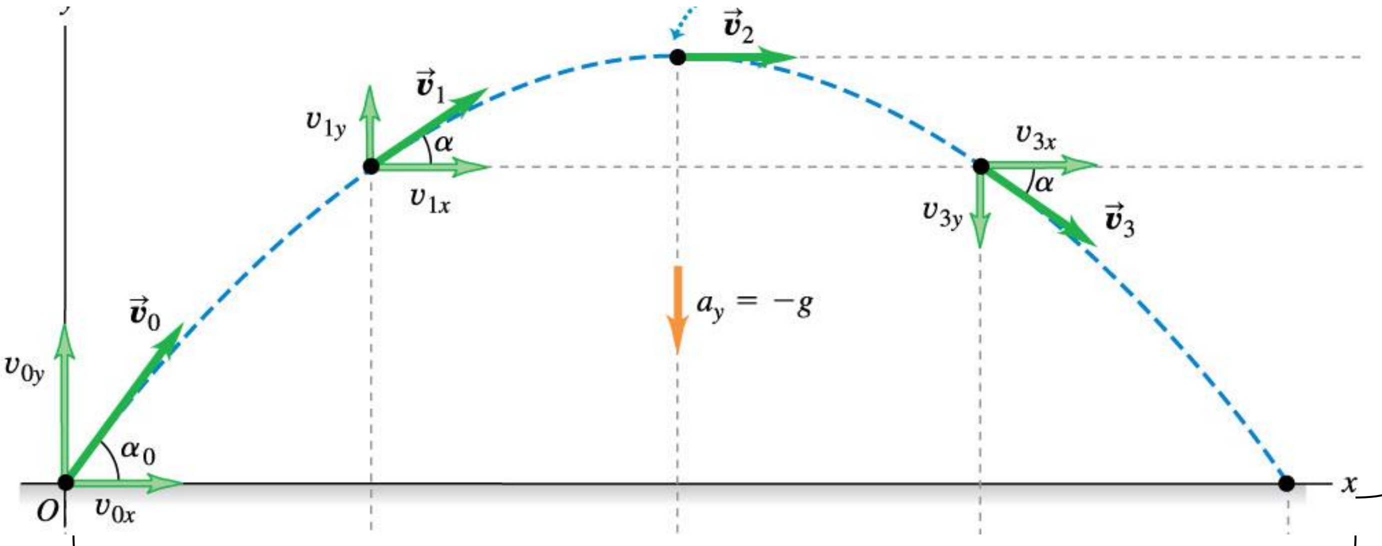
Trajectory: $x(t) = v_0 \cos\alpha_0\, t,\ y(t) = v_0 \sin\alpha_0\, t - \frac{1}{2}gt^2$

Eliminate $t \Longrightarrow \quad y = (\tan\alpha_0)x - \dfrac{g}{2v_0^2\cos^2\alpha_0}x^2$

i.e. $y = bx - cx^2$ a parabola 抛物線

A typical projectile: at the top, $0 = v_y = v_0 \sin\alpha_0 - gT$

$\Rightarrow T = v_0 \sin\alpha_0 / g$




$y$ motion with uniform downward acceleration $g$,

max. height

$= v_0 \sin\alpha_0 T - \frac{1}{2} g T^2$

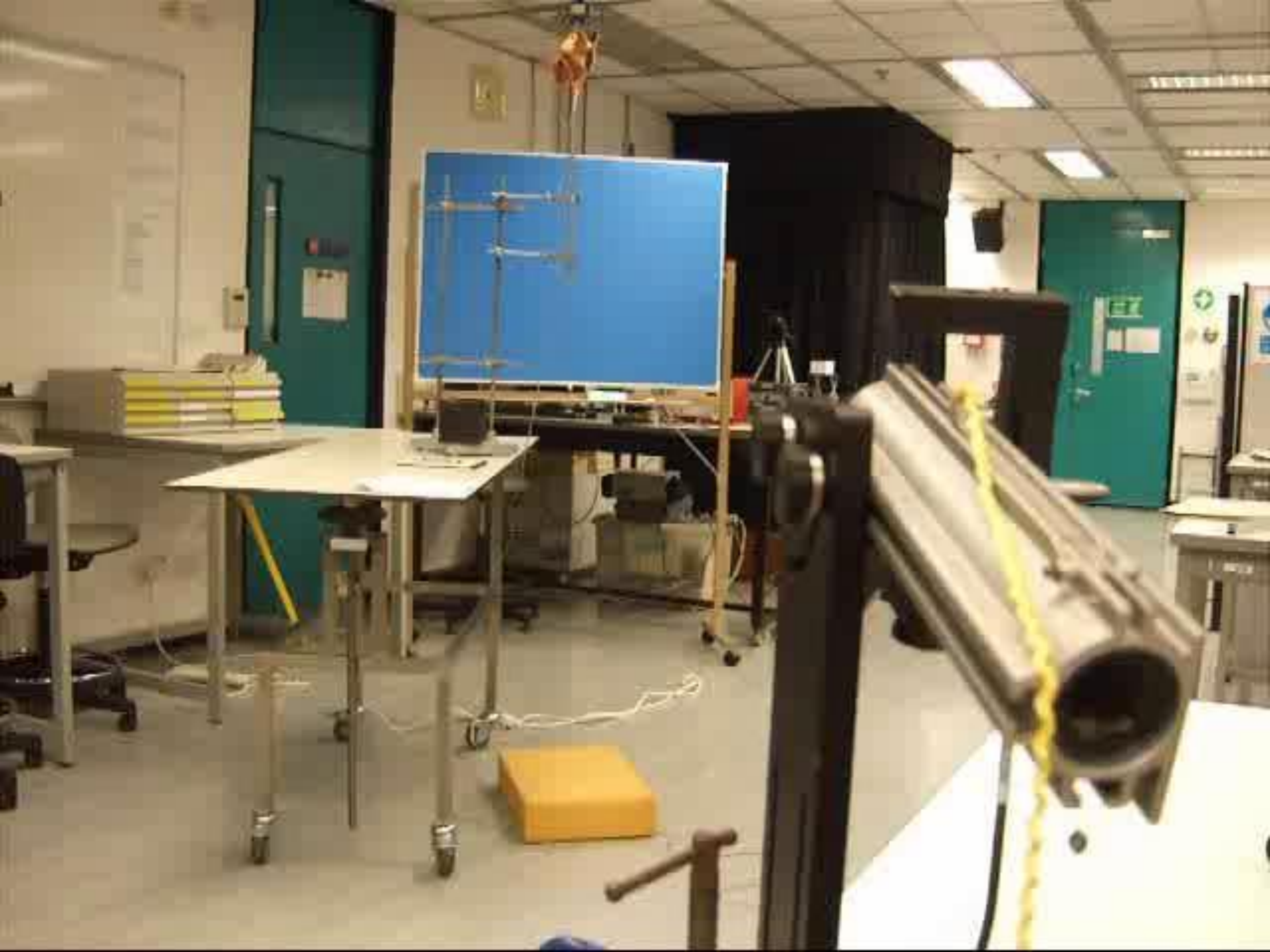
$= \dfrac{v_0^2 \sin^2 \alpha_0}{2g}$

$x$ motion, no acceleration, range $= v_0 \cos\alpha_0 (2T) = 2 v_0^2 \sin\alpha_0 \cos\alpha_0 / g$

Demonstration: a ball fired at the same instant when the monkey is dropped

Ball *always* hit the monkey, *AMAZING!!*

See textbook for a proof.



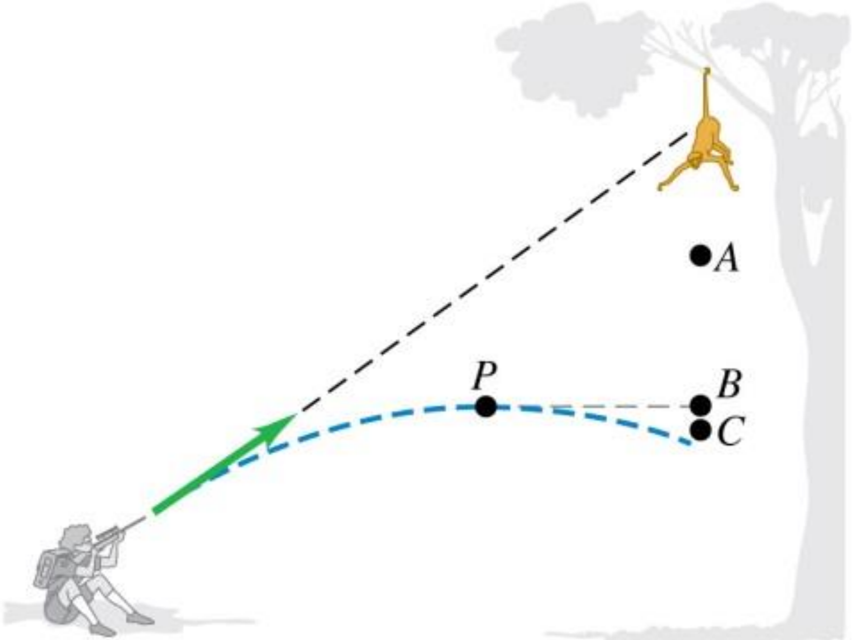
# Question

When the ball is at its highest point *P*, the monkey will be at

(i) point *A* (higher than *P*)

(i) point *B* (at the same height as *P*)

(i) *C* (lower than *P*)



Q3.10

A projectile is launched at a 30° angle above the horizontal. Ignore air resistance. The projectile's acceleration is greatest

A. at a point between the launch point and the high point of the trajectory.

B. at the high point of the trajectory.

C. at a point between the high point of the trajectory and where it hits the ground.

D. misleading question—the acceleration is the same (but nonzero) at all points along the trajectory

E. misleading question—the acceleration is zero at all points along the trajectory

Q3.10

A projectile is launched at a 30° angle above the horizontal. Ignore air resistance. The projectile's acceleration is greatest

A. at a point between the launch point and the high point of the trajectory.

B. at the high point of the trajectory.

C. at a point between the high point of the trajectory and where it hits the ground.

D. misleading question—the acceleration is the same (but nonzero) at all points along the trajectory

E. misleading question—the acceleration is zero at all points along the trajectory