Kinematics I

Spring 2005

What you should know

- What is the kinematics?
- Coordinate systems
- The difference between scalar and vector?
- Vector summation method (graphically and mathematically)
- Distance and displacement?
- Speed and Velocity?
- Acceleration?
- Tangential Method (Instantaneous vs. Average)

What is the kinematics?

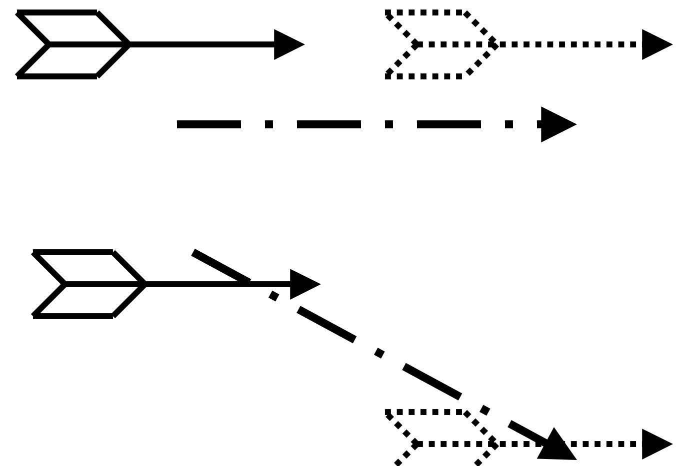
- Descriptions of Motion

Position, Velocity, and Acceleration

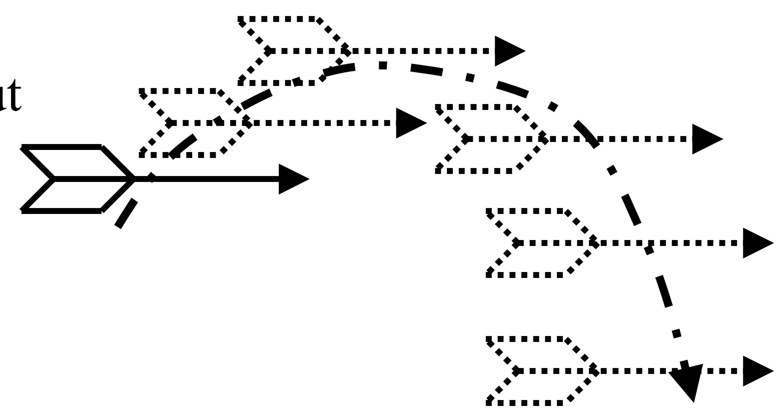
Linear Motion vs. Angular Motion

➔ ***Linear Kinematics and Angular Kinematics***

Linear Motion (=Translation)



- ***Rectilinear***
  - No change in both ________ of motion and ___________ of the object during movement
  - All points on the object move the same distance.
- ***Curvilinear***



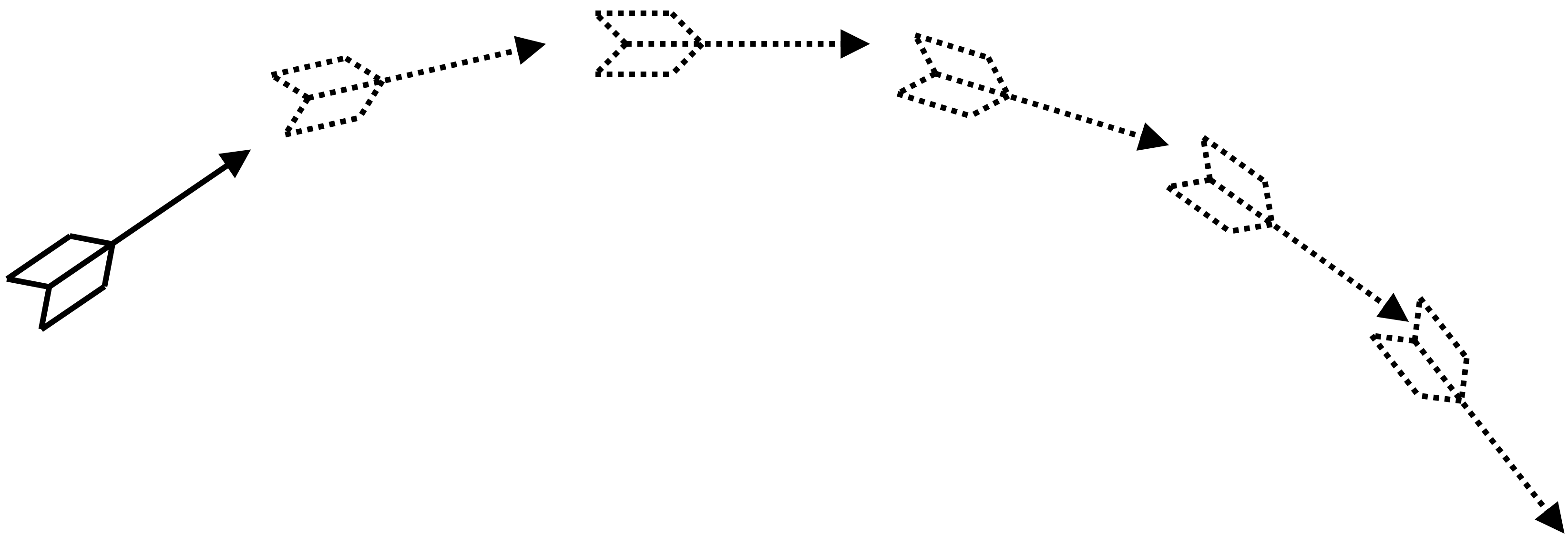
  - Change in direction of motion, but No change in ____________ of the object
  - All points on the object move the same distance

Angular Motion (=Rotation)

- Occur about an ______ within a body or outside of the body.
- Continual change of orientation during movement.
- As the object moves, the paths that each point follows _________ path with having same center or axis

General Motion (Translation+Rotation)

- Combination of linear and angular motions



Descriptions

- **Position** : location in space
- Where is it now? ➔ Need information.
- ____________________________: X & Y-coordinate system with reference point (origin)

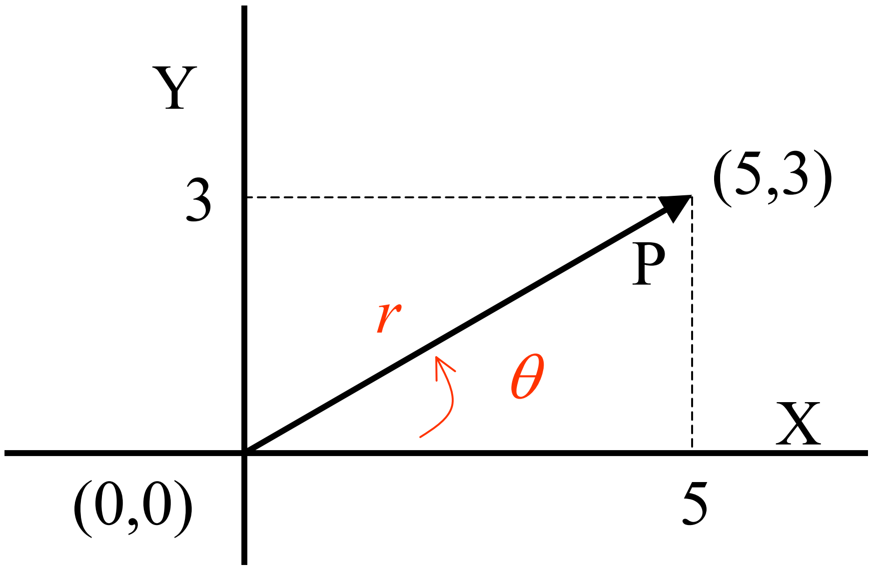
Descriptions

- **______________________________:** Describe the position with ***r* (resultant)** and θ.

$$X = r \cdot \cos\theta, \qquad Y = r \cdot \sin\theta$$

$(15, 80) = [81.4\cos(79.4°), 81.4\sin(79.4°)]$

- Cartesian coordinate vs Polar coordinate



$\sin \theta = 3/r \Rightarrow 3 = r \sin \theta, \; r = 3/\sin \theta$

$\cos \theta = 5/r \Rightarrow 5 = r \cos \theta, \; r = 5/\cos \theta$

Scalar vs. Vector

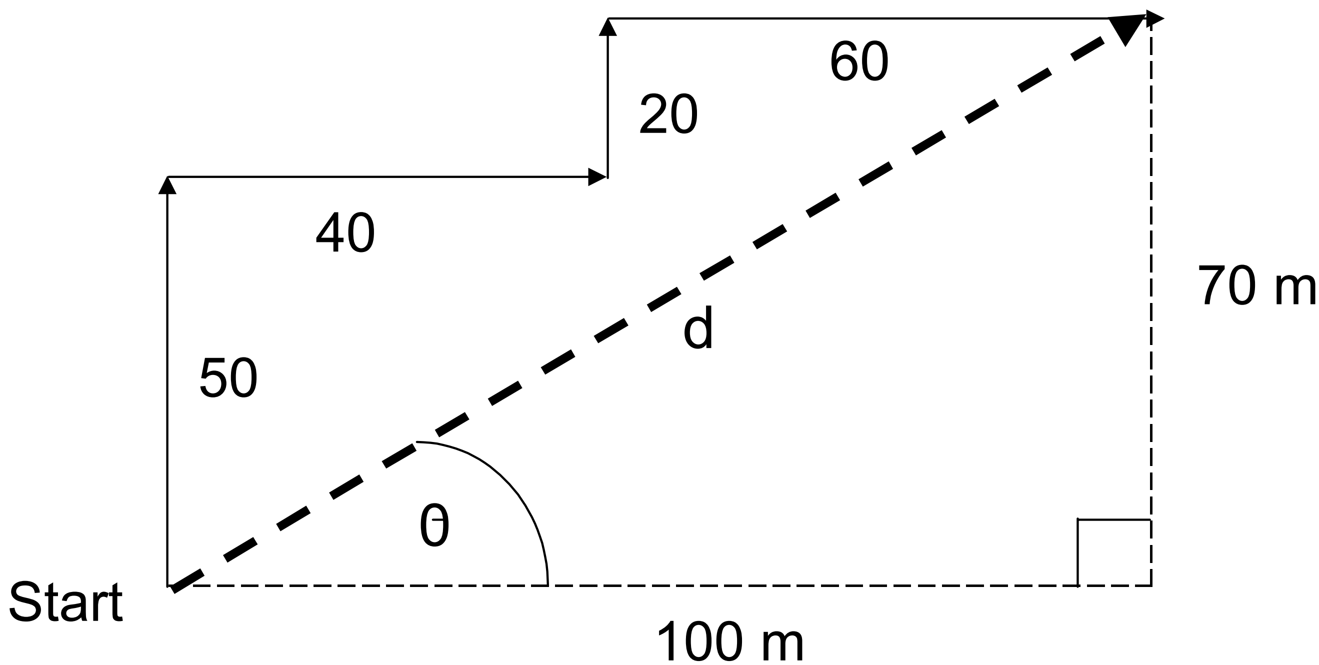
- Scalar: physical quantity that is completely described by its ____________________
- No negative quantity

ex) mass, time, distance, speed, ….

- Vector: physical quantity that possess both __________ and ____________________

ex) displacement, velocity, acceleration,….

Example: Walking north and east, then north and east again:



Overall distance traveled? P

Displacement ("as the crow flies")?

Magnitude d

Direction θ

Examples - Angular distance and displacement.

Diving, gymnastics:

"triple somersault with a full twist"

3.0 revolutions about a transverse axis (somersaulting axis) combined with 1 rev about a longitudinal axis (twisting axis)

transverse axis ϕ =____ θ=______

long. axis ϕ = ______ θ=_______

Discus throw:

Body rotates through ____ rotations prior to discus release.

ϕ = ____ rev θ = ____ rev

Joint range of motion:

The elbow and knee have ROM's of approximately 150 degrees.

ϕ = ________ θ = ________

Typical units - 3 used commonly:

revolutions, radians, degrees

1 rev = 2B rad (i.e., 6.28 rad) = 360 deg

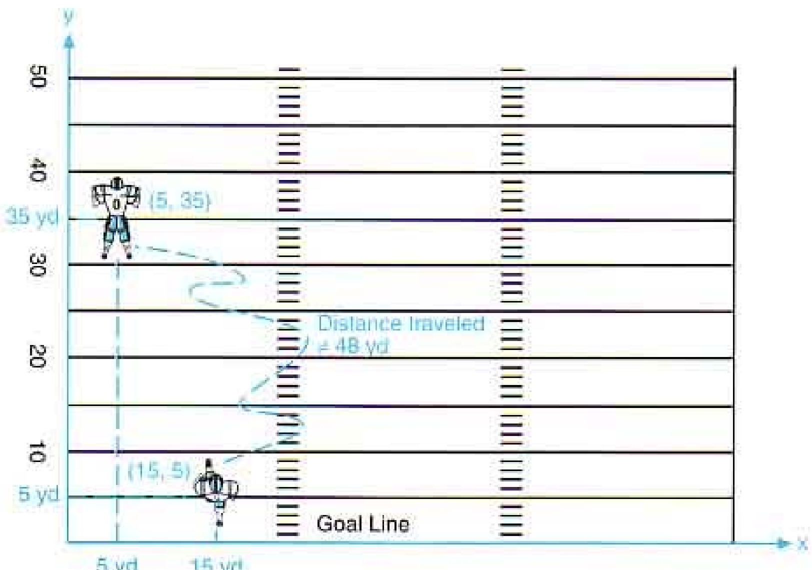
1 rad = 57.3 deg

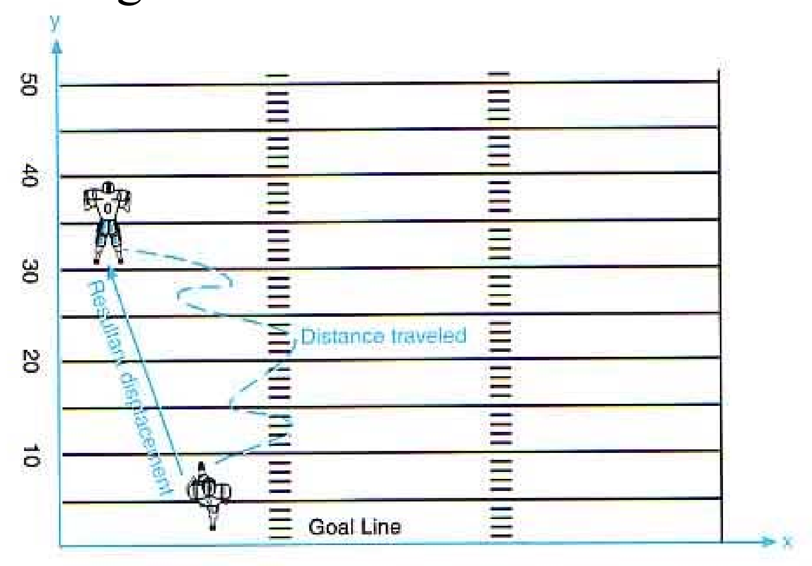
Distance Traveled and Displacement

How far?

- **<u>Distance Traveled</u>**: a measure of the length ______________ followed by the object whose motion is being described, from its starting (initial) position to its ending (final) position.
- Scalar quantity (No direction)
- Symbol = λ

- **<u>Resultant Displacement</u>**: the length _________________ from the initial position to the final position
- Vector quantity
- Symbol = d
- Calculation?
- Negative?





⊄<u>How fast</u>?

Describing rate of change of linear or angular position with respect to (wrt) time

Speed or Velocity: <u>Rate</u> at which a body moves from one position to another

Speed (scalar) Velocity (vector)

Note: *There will be times when it is important to use velocity because of its vector characteristic.*

Linear: Angular:

$$\bar{v} = \frac{d}{\Delta t} \qquad \bar{\omega} = \frac{\theta}{\Delta t}$$

Examples of linear speed or velocity:

Tennis: 125 mph (55.9 m/s) serve
v = 125 mph = 55.9 m/s
Pitching: 90 mph (40.2 m/s) fastball
v = 90 mph = 40.2 m/s

Running:

Marathon (26.2 mi) - 2 hr 10 min (2.17 hr)

$\bar{v}$ = 12.1 mph (5.4 m/s; 4:57 per mile)

Sprinting - 100 m in 9.86 s

$\bar{v}$ = 10.14 m/s = 22.7 mph

Football – “4.6” speed (40 yd in 4.6 s)

$\bar{v}$ = 7.95 m/s = 17.8 mph

Typical units of measurement for v:
m/s, km/hr (kph), ft/s, mph

Examples of angular speed or velocity:

Auto engine speed - 3000 rpm

ω = 3000 rpm

CD ROM drive - 400 rpm

ω = 400 rpm

Cycling cadence - 90 rpm

ω = 90 rpm

Isokinetic dynamometer (Cybex and others) - e.g., 60 deg/s

ω = 60 deg/s

Body segment ω's -

e.g., peak ω of soccer player's knee...

2400 deg/s . 6.7 rev/s

Typical units of measurement for ω:

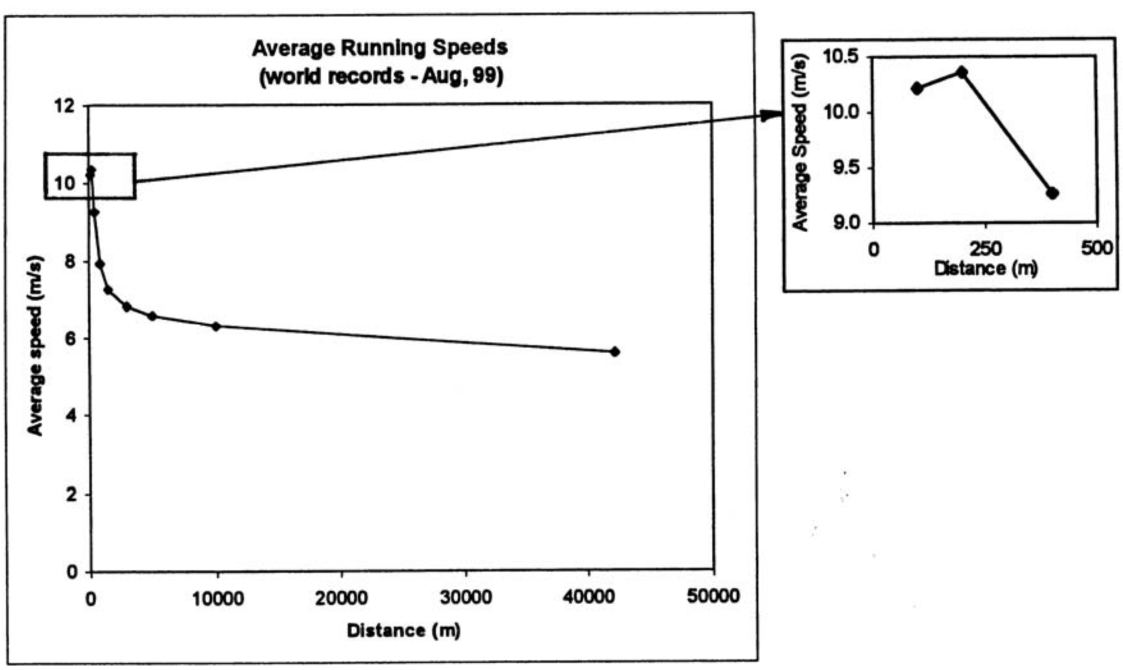
rpm, deg/s, rad/s

<u>Average vs. Instantaneous Velocities</u>

Average speed per race distance:

100 m...marathon

Race that produces highest average speed?



Sometimes $\bar{v}$ over relatively long t is not very informative - reflects need for a "kinematic profile" for more detailed information about performance

e.g., distance running - split times

e.g., sprinting - 1987 T&F World Champ.

Johnson vs. Lewis		
9.83 s	9.93 s	Δ = 0.100 s

Where was race won or lost?

Reaction time:	Δ = 0.067 s
After 10 m:	Δ = 0.100 s

By decreasing t over which we examine velocity and other kinematic information, we approach *instantaneous* estimates of performance - gives more detail about performance.

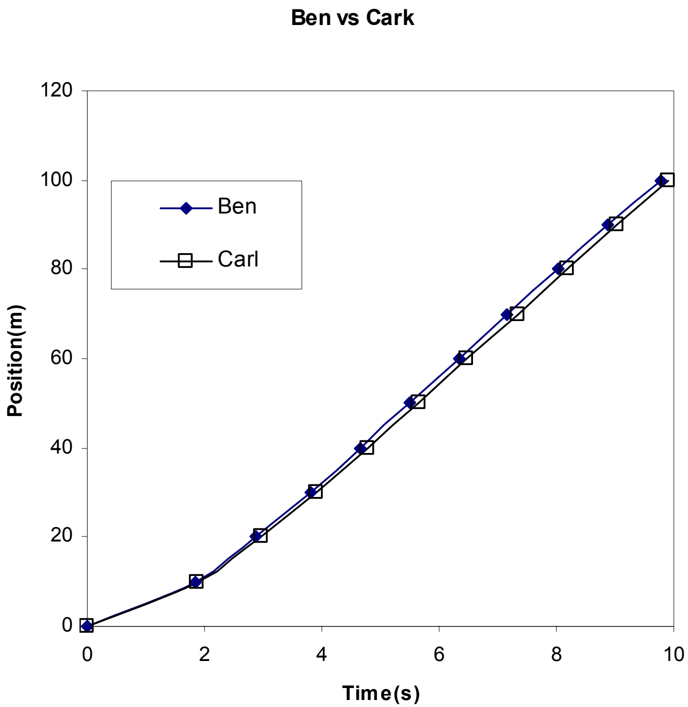
e.g., during a soccer kick (next page):

Ben vs. Carl

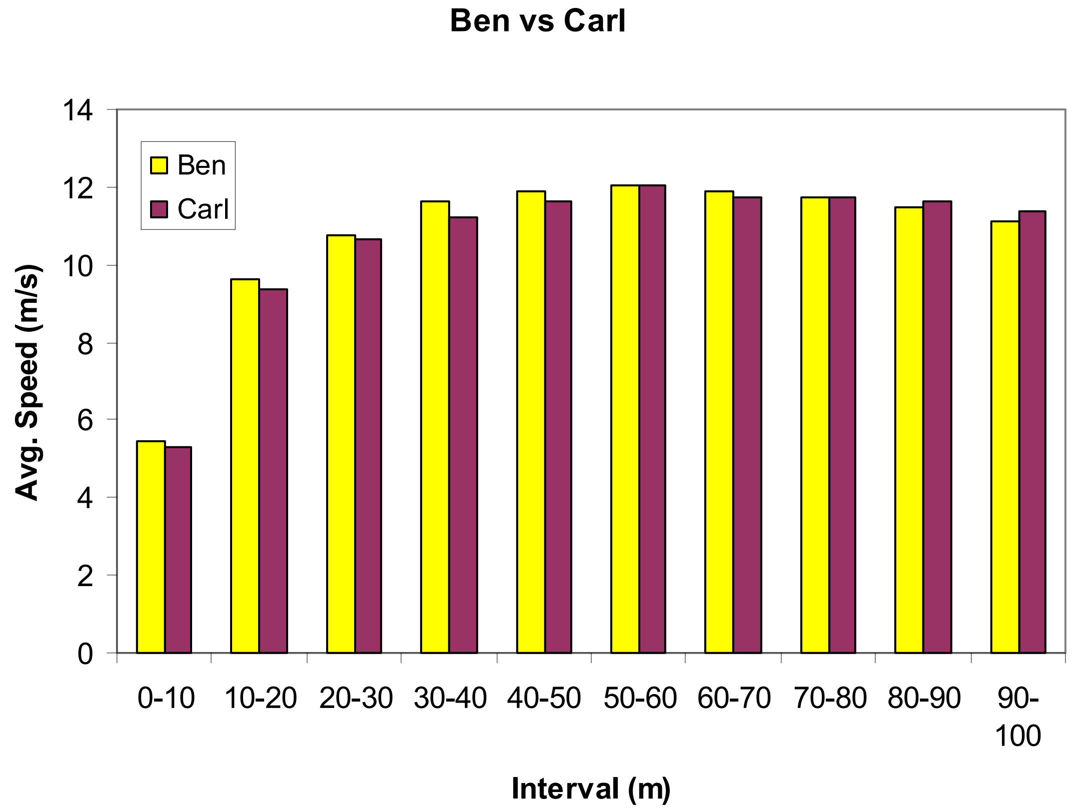
Table 5.1 & 5.2 Result of 1988 Seoul Olympics

	Ben Johnson		Carl Lewis						
Position (m)	Elapsed time(s)	Interval time (s)	Elapsed time(s)	Interval time(s)	Elapsed time diff(s) (Ben - Carl)	Interval time diff	Interval (m)	Ben Avg. Speed (m/s)	Carl Avg. Speed (m/s)
0	0		0						
10	1.83	1.83	1.89	1.89	-0.06	-0.06	0-10	5.46	5.29
20	2.87	1.04	2.96	1.07	-0.09	-0.03	10-20	9.62	9.35
30	3.8	0.93	3.9	0.94	-0.1	-0.01	20-30	10.75	10.64
40	4.66	0.86	4.79	0.89	-0.13	-0.03	30-40	11.63	11.24
50	5.5	0.84	5.65	0.86	-0.15	-0.02	40-50	11.9	11.63
60	6.33	0.83	6.48	0.83	-0.15	0	50-60	12.05	12.05
70	7.17	0.84	7.33	0.85	-0.16	-0.01	60-70	11.9	11.76
80	8.02	0.85	8.18	0.85	-0.16	0	70-80	11.76	11.76
90	8.89	0.87	9.04	0.86	-0.15	0.01	80-90	11.49	11.63
100	9.79	0.9	9.92	0.88	-0.13	0.02	90-100	11.11	11.36

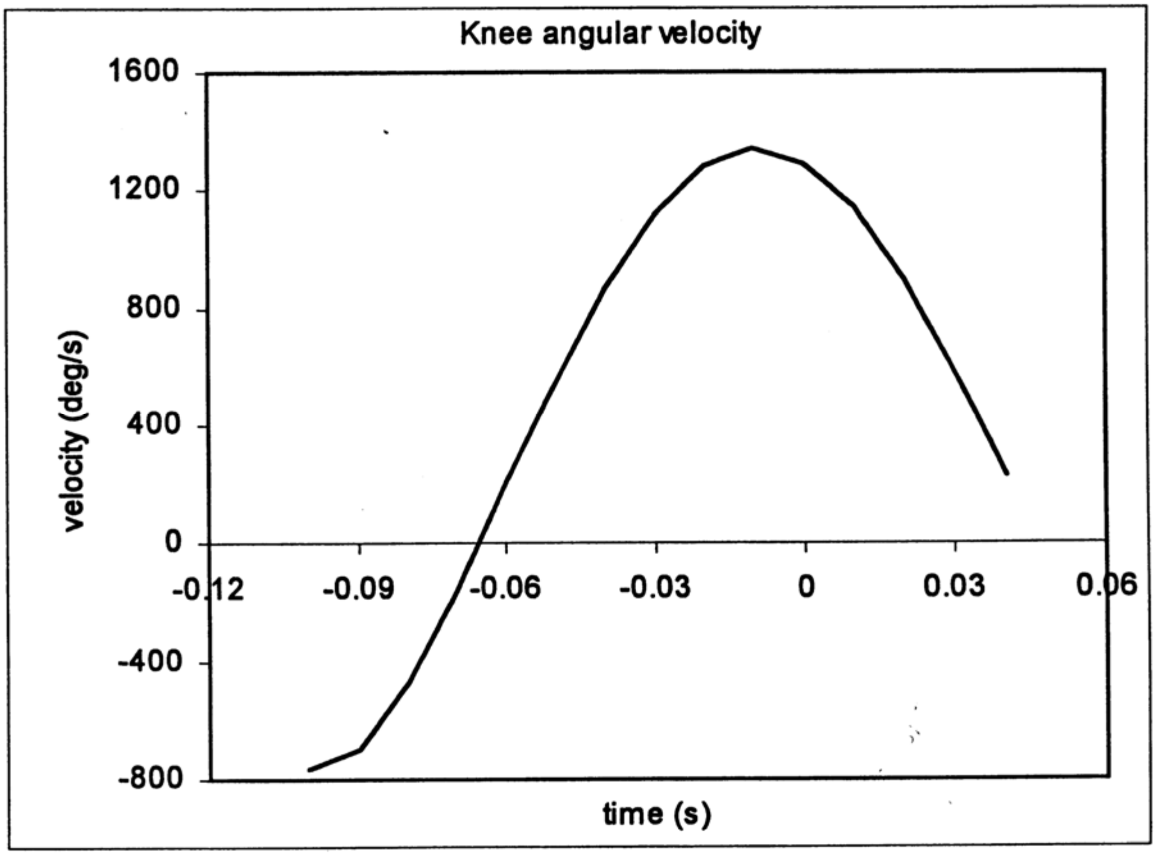
Ben vs. Carl



Ben vs Cark
120
100
80
60
40
20
0
Position(m)
0
2
4
6
8
10
Time(s)
Ben
Carl



Ben vs Carl
14
12
10
8
6
4
2
0
Avg. Speed (m/s)
Ben
Carl
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
Interval (m)



⊄Acceleration

Describing the rate of change of linear or angular velocity wrt time

Vector only - no scalar equivalent

Linear:

Angular:

Typical units of measurement for acceleration:

Linear - m/s^2, ft/s^2

Angular - deg/s^2, rad/s^2

<u>Example - linear</u>

An athlete described as being “quick” or having “good acceleration” - same as being fast?

<u>No</u>, acceleration describes a person’s ability to <u>change speed or direction</u>; doesn’t describe top speed.

<u>Example - angular</u>

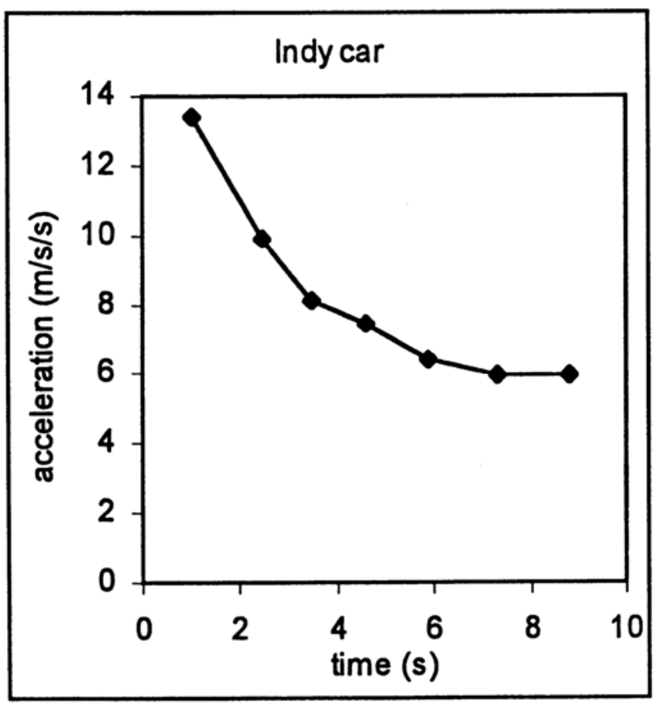
Throwing a baseball

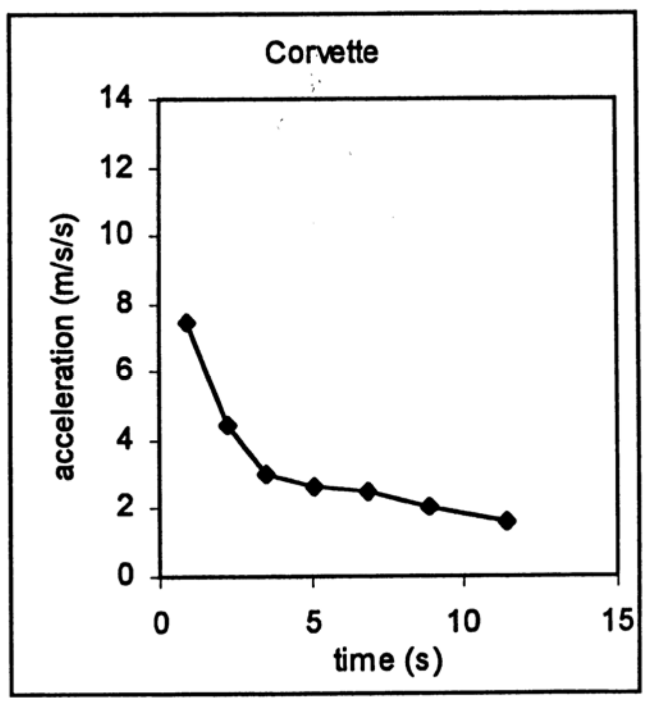
Angular speed of shoulder internal rotation increases from zero to 1800 deg/s in 26 ms just prior to release...

Ball velocity at release correlates strongly (r=.75) with shoulder internal rotation speed at release (Sherwood, 1995).

<u>Example – linear</u>:
Auto accelerations - Indy car vs. Corvette

Indy car				Corvette			
Δmph	Δm/s	Δt (s)	$\overline{a}$ (m/s^2)	Δmph	Δm/s	Δt (s)	$\overline{a}$ (m/s^2)
0-60	0-26.8	2.0	13.42	0-30	0-13.4	1.8	7.45
60-80	26-8-35.8	0.9	9.94	30-40	13.4-17.9	1.0	4.47
80-100	35.8-44.7	1.1	8.13	40-50	17.9-22.4	1.5	2.98
100-120	44.7-53.7	1.2	7.45	50-60	22.4-26.8	1.7	2.63
120-140	53.7-62.6	1.4	6.39	60-70	26.8-31.3	1.8	2.48
140-160	62.6-71.6	1.5	5.96	70-80	31.3-35.8	2.2	2.03
160-180	71.6-80.5	1.5	5.96	80-90	35.8-40.3	2.8	1.60





_____When is speed or velocity highest for Indy car?

_____When is acceleration highest for Indy car?

_____Is the speed or velocity of the Indy car changing approximately 6-8 seconds after the start?

<u>Link between position, velocity, and acceleration</u>:

<u>Velocity</u> - rate of change of <u>position</u> wrt time

<u>Acceleration</u> - rate of change of <u>velocity</u> wrt time

X Instantaneous <u>velocity</u> is reflected by the *slope* of the <u>position</u> curve at some instant in time.

X Instantaneous <u>acceleration</u> is reflected by the *slope* of the <u>velocity</u> curve at some instant in time.

See soccer kick - angular position, velocity, and acceleration graphs next page

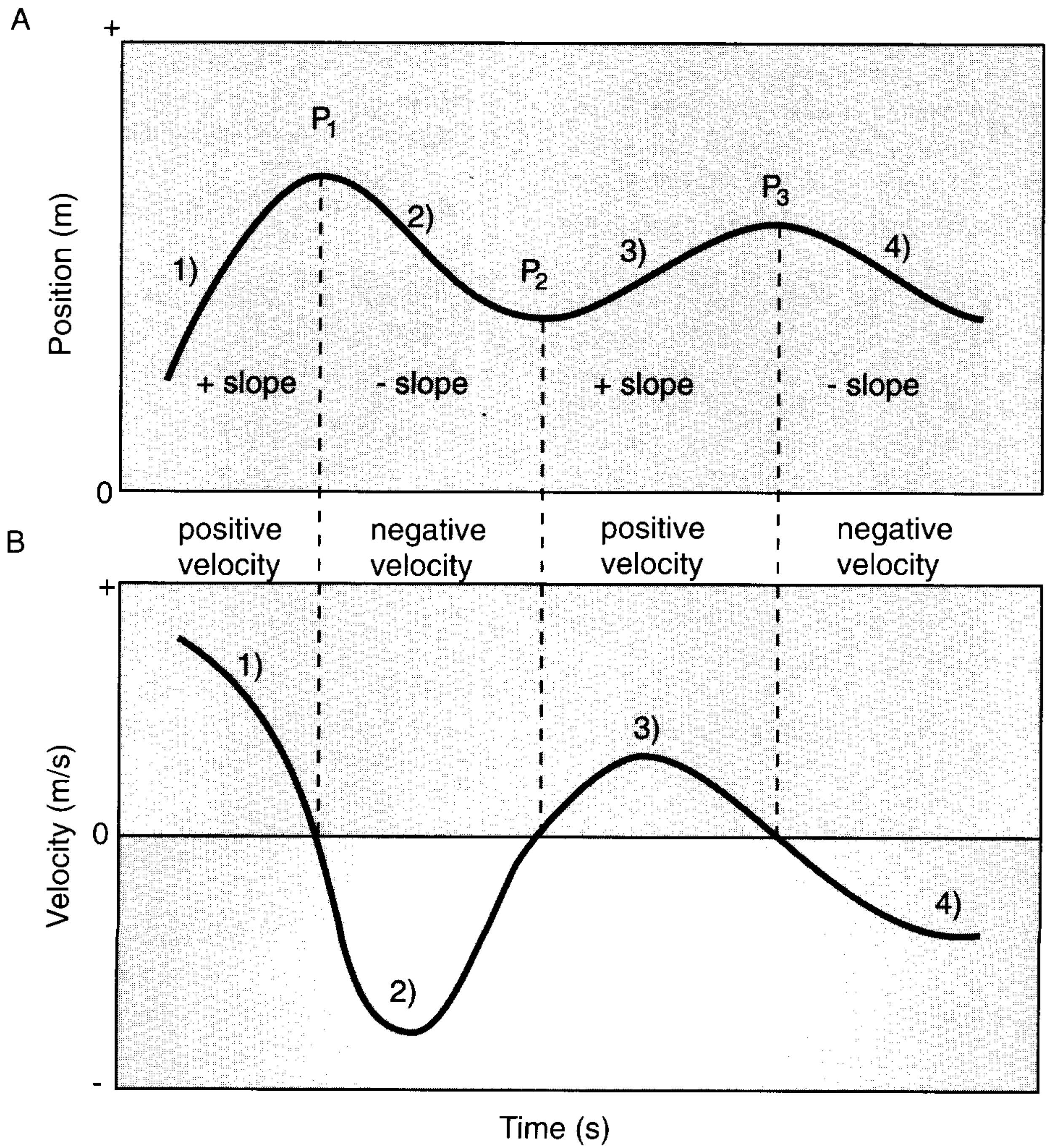
Tangential Method (Displacement → Velocity)

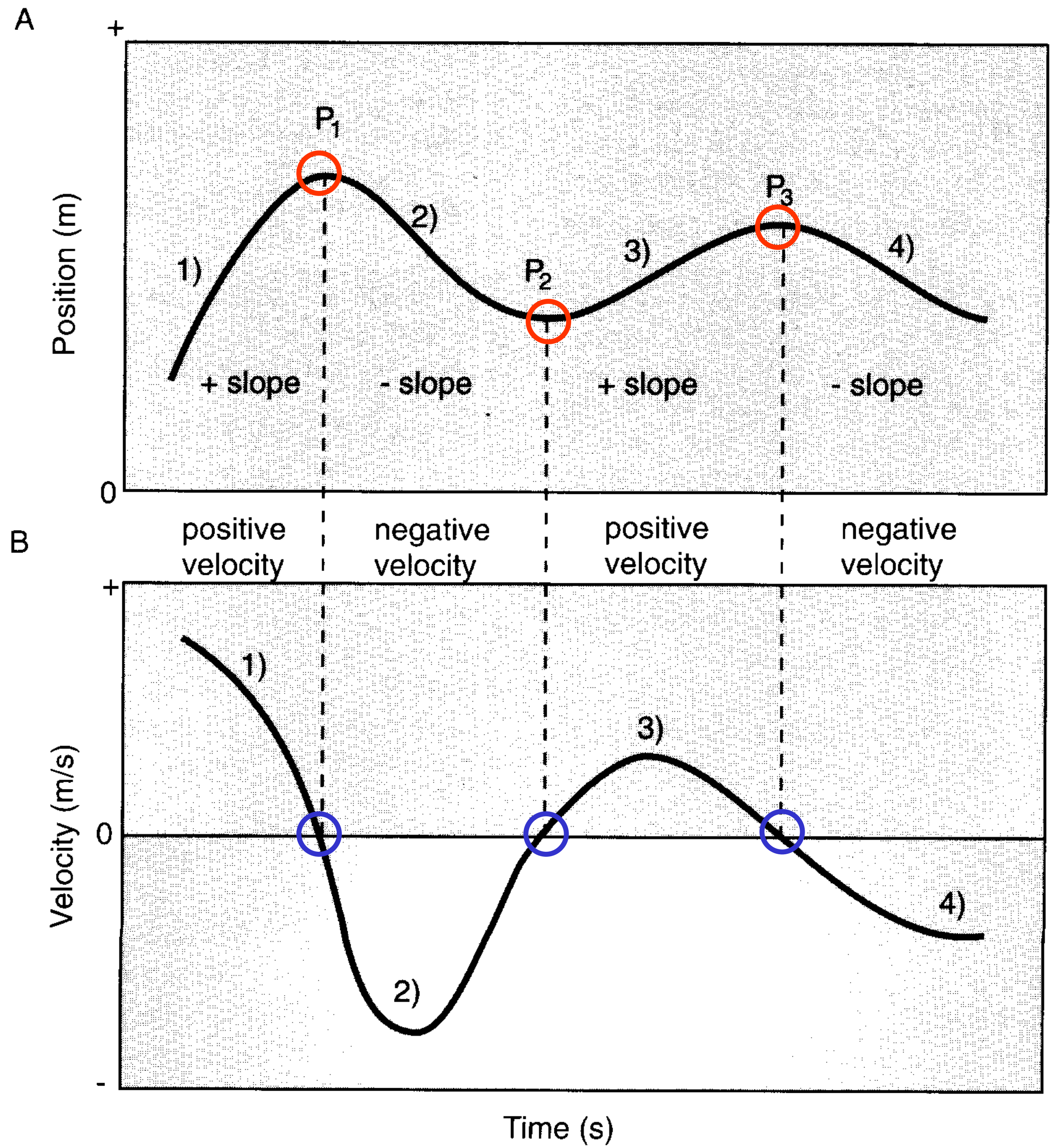
1. Find out "______________" **(slope + to – or – to +)**
   - Mark the instance (the specific time)
   - Velocity = 0 at the instance

2. Find out "_______________" **(slope ↑ & ↓ or ↑ &↓)**
   - Mark the instance (the specific time)
   - Velocity = peak at the instance (flexion point of velocity)

3. Categorize positive and negative slope area
   - d uphill → V positive, d downhill → V negative
   - Watch out deflexion point!!

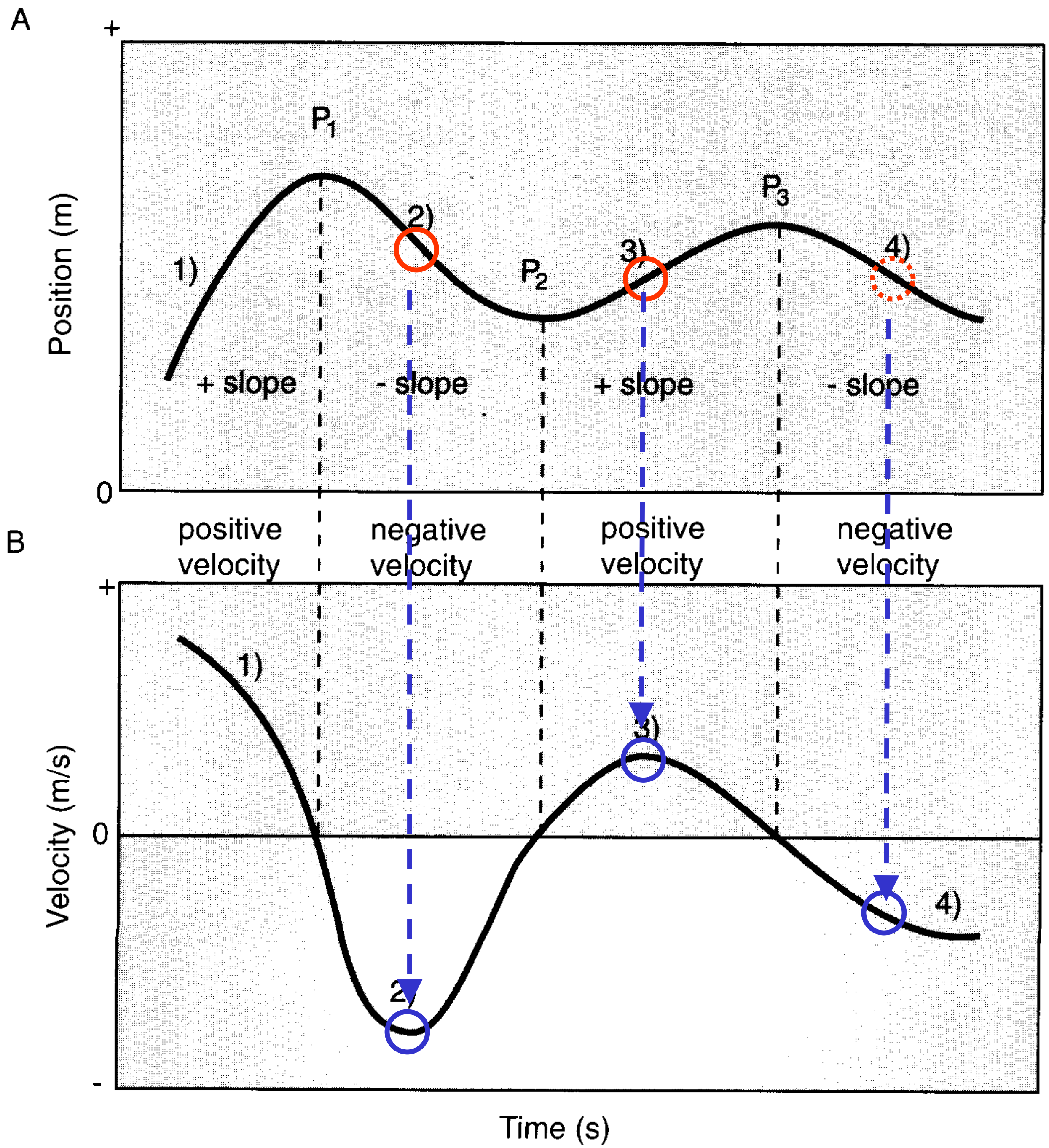
4. Create the velocity curve based on the slope of displacement graph.


A
B
+
0
-
Position (m)
Velocity (m/s)
Time (s)
P1
P2
P3
1)
2)
3)
4)
+ slope
- slope
+ slope
- slope
positive velocity
negative velocity
positive velocity
negative velocity



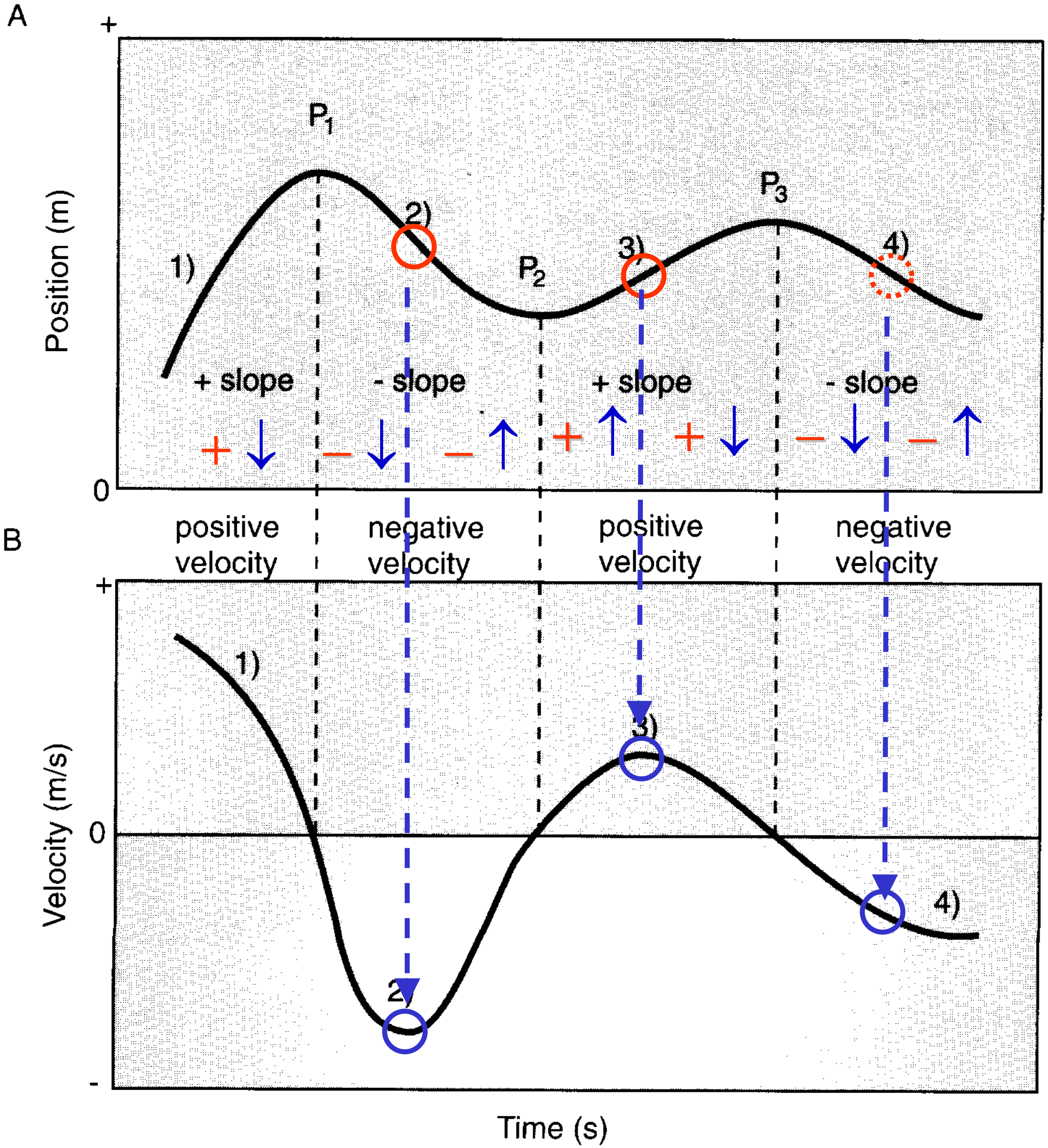
A
+
P1
2)
1)
P3
3)
4)
P2
Position (m)
+ slope
- slope
+ slope
- slope
0
positive velocity
negative velocity
positive velocity
negative velocity
B
+
1)
3)
Velocity (m/s)
0
4)
2)
-
Time (s)

Return

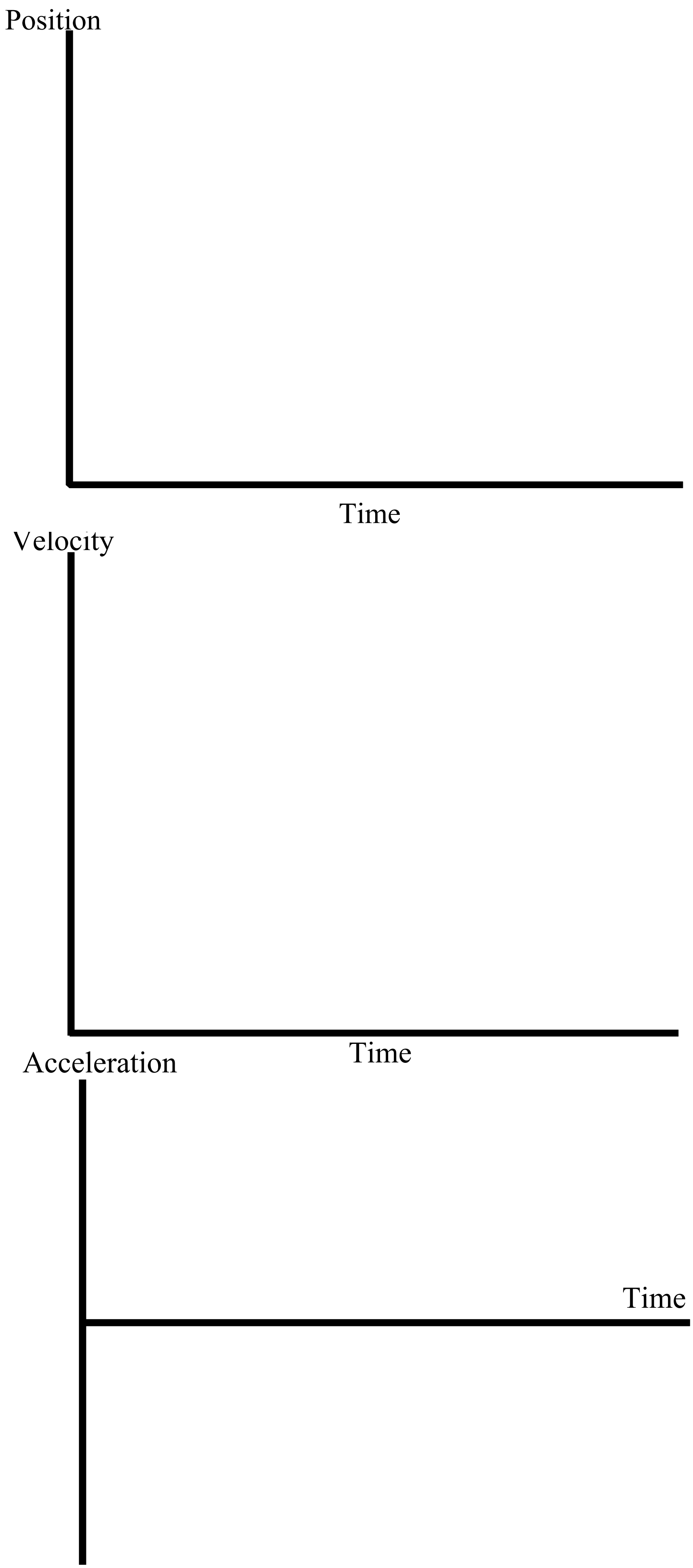


A
B
Position (m)
Velocity (m/s)
Time (s)
+
0
-
P1
P2
P3
1)
2)
3)
4)
+ slope
- slope
+ slope
- slope
positive velocity
negative velocity
positive velocity
negative velocity

Return


A
B
+
0
-
Position (m)
Velocity (m/s)
Time (s)
P1
P2
P3
1)
2)
3)
4)
+ slope
- slope
+ slope
- slope
positive velocity
negative velocity
positive velocity
negative velocity

Return



Can you deduce the position vs. time and acceleration vs. time profiles based on the velocity profile of a hand reaching for a glass of water?

Six Cases of Acceleration					
Case	Change in Speed	Starting Direction	Ending Direction	Δv	Accel. ($\Delta v/\Delta t$)
1	Speeding up				
2	Slowing down				
3	Speeding up				
4	Slowing down				
5	Reversing directions				
6	Reversing directions				

Notes:

1. Speeding up in the positive direction =______ acceleration
2. Slowing down in the positive direction = ______ acceleration
3. Speeding up in the negative direction = ______ acceleration
4. Slowing down in the negative direction = ______ acceleration
5. *Reversing directions* from positive to negative = ______ acceleration
6. *Reversing directions* from negative to positive = ______ acceleration.