Topic 3: Kinematics – Displacement, Velocity, Acceleration, 1- and 2-Dimensional Motion

Source: *Conceptual Physics* textbook (Chapter 2 - second edition, laboratory book and concept-development practice book; CPO physics textbook and laboratory book

Types of Materials: Textbooks, laboratory manuals, demonstrations, worksheets and activities

Building on: With beginning concepts of vectors and measurements, the study of motion will give the lead-in to dynamics, the cause of motion that allows the student to see a logical building of mechanics. Topic one activities have introduced displacement and velocity and will now be enhanced. The instructor should now define displacement, velocity and acceleration. A new displacement activity will use a worksheet and speed vs. velocity will use a worksheet and several additional activities. One-dimensional motion will be studied with labs and two-dimensional motion will be briefly presented but not so in depth that it takes too much time to cut out time for other topics. Finally, an acceleration activity and worksheet will be presented.

Leading to: Once the study of motion is explored in more detail, the teacher will then ask, "What causes motion or the change in motion?" that is presented through activities to begin dynamics, the study of the cause of motion.

Links to Physics: Understanding of motion is fundamental to mechanics including constant or accelerated motion of cars to electrons. Other topics will also require the introduction of motion. Examples include wave motion (as in sound and light), electricity and magnetism (movement of force fields) and celestial movement within the heavens.

Links to Chemistry: Displacement and 1- and 2-dimensional motion may be used in showing conceptual representations of atoms and molecules during reactions. When studying the motion of electrons around the nucleus, velocity and acceleration can be discussed to show how the electron changes speed when it encounters another electron or proton. Motion, especially vibratory motion, also is encountered with the study of states of matter and how the rate of motion changes during phase changes. This is especially evident with gases and the gas laws.

Links to Biology: Displacement and 1- and 2-dimensional motions may be used in animal behavior labs if an animal's position is plotted in relation to a stimulus. This may also occur with plant growth (infrequently) or protist and the movement of pond water organisms to stimulus of light for example. Velocity and acceleration may be determined when discussing blood flow or in observing animal behavior when comparing different velocities of organisms, the fastest and slowest runners for example.

Materials:

(a) Hewitt
Lab 5 – Conceptual Graphing
Lab 2 – The Physics 500
Lab 3 – The Domino Effect
Lab 4 – Merrily We Roll Along
Lab 6 – Race Track
Lab 7 – Bull's Eye

(b) Hsu – CPO Physics
Lab 1A – Time, Distance and Speed

(c) My Labs
C-2: (from Topic 1): Walking Vectors (if this was not done in Topic 1)
C-2: Walk a Number Line
C-3: Velocity and Acceleration
   (a) Constant Motion
   (b) Two-Speed
   (c) Slot Car – Accelerated
   (d) Rollin

(d) Worksheets
Hewitt - Concept-Development Book
2.1 – Motion
2.2 – Speed and Distance
3.2 – Vectors

Hsu
1A: Position vs. Time

My Worksheet
Displacement, Velocity and Acceleration (Graphical Approach)

(e) Demonstration
2-Dimensional Motion

(f) Websites and Videos
ESPN SportsFigures "Tracking Speed" Video Guide (Olympic Decathlon)
1. Mechanical Universe Video Guide: "Falling Bodies"
2. Moving Man Lab Sim (Java)
3. NOVA "Medieval Siege" Video Guide
4. (ESPN SportsFigures "Big Air Rules" Video Guide (Snowboarding)

5. The Buick Launcher Projectile Lab Sim (Flash)

(g) Good Stories
1. Why a Seven-Day Week?
2. Nicolas Copernicus – Renaissance Man
3. The Fastest Airplane in the World
4. Johannes Kepler – A Life of Tragedy
5. Aristotle and Galileo on Early Mechanics

(h) Topic 3: Follow-Up Quiz/Test

Topic 3: C-2 – Walk a Number Line (Displacement Activity)

Purpose: To relate a graphical plot of a student's change in position with the actual change in position along a number line.

Procedure:

1. Place 11 small pieces of electrical tape (about 3 inches long) at 1-m intervals in a straight line along the floor.

2. Make 11 - 3" x 5" index cards labeled, 5 m, 4 m, 3 m, 2 m, 1 m, 0 m, -1 m, -2 m, -3 m, -4 m, -5 m and place them in order at the 11 tape location.

3. Have a student start at 0 m, then move to +2 m, then +5 m, then to +3 m, then to -1 m, then to -3 m, then stay at -3 m, and finally, go to 0 m.

4. Plot a graph of the student's location (in meters) as a function of event (7 in this case). Evenly space the event numbers to represent equal times for each event.

5. Connect the 8 data points using at straight line between the points 0 m to 1 m, 1 m to 5 m, and so on.

6. Study the completed graph of location vs. event and discuss what is happening from start to finish.

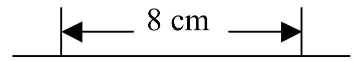
Topic 3: Lab C-3 – Velocity and Acceleration

Purpose: To observe and graphically study various types of motion.

Theory: The change in position (d) divided by the time it takes to change that position (t) is the average velocity.

$$v = \Delta d / \Delta t$$

Example:

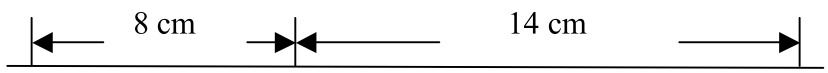


If it takes 2 s to go the 8 cm, then, v = 8 cm/2 s = 4 cm/s

The change in velocity (v) divided by the time it takes to change that position (t) is the average velocity.

$$a = \Delta v/\Delta t = \frac{v_f - v_i}{t_f - t_i}$$

$a = \Delta v/\Delta t$ Example:



If it takes 2 s to go the 8 cm and 2 s to go the 14 cm, then, $a = \frac{14\text{ cm}/2\text{ s} - 8\text{ cm}/2\text{s}}{2\text{ s}} =$ 3 cm/s/s.

Equipment: The main items for equipment for good consistent results are mainly available through science catalogs and Toys "R" Us. The one item that is available, but I feel needs improvement, is a mechanical ticker timer that places dots on a ticker tape. I am working on a refined model and hope to have it available through a soon-to-be established website.

One slow, constant speed vehicle is the electric bulldozer sold through science supply companies like Cenco, Sargent-Welch, etc. The two-speed car is a windup and available at Toys "R" Us. The accelerated car is the HO slot car available at a hobby store or maybe Toys "R" Us.

Procedure:

(A) Bulldozer

1. On a flat surface (table top/floor), place your slow-moving vehicle in front of the ticker timer. Thread the timer tape through the timer and use masking tape to attach the ticker tape to the vehicle. With the timer vibrating, set the vehicle in motion.

2. Ignore about 5 cm at the start of the tape and begin marking off equal distances for equal time intervals. Choose intervals so you have about 10 total and call each interval time 1 s. Record interval distance, total distance and total time in a data

table that you create. Also make a column for average interval velocity.

3. Calculate each interval average velocity by dividing the interval distance by the interval time and record in your table.

4. Plot a total distance vs. total time graph. Explain what it illustrates.

5. Plot an interval average velocity vs. total time graph. Explain what it illustrates.

6. Take the slope of the graph. What does it illustrate?

(B) 2-Speed Windup Car
Repeat 1-6 from (A) using the two-speed windup car.

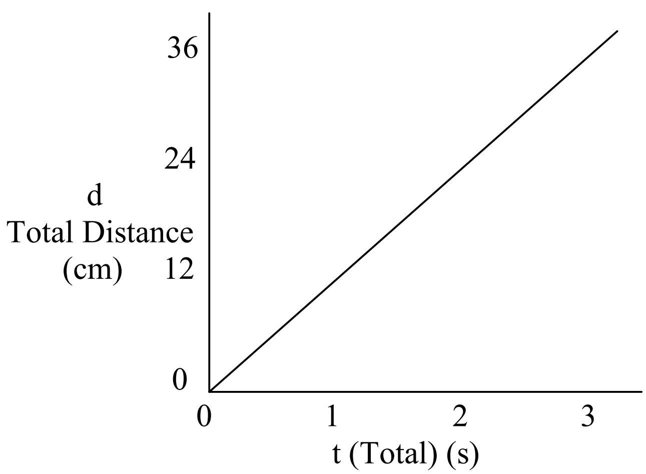
(C) HO Slot Car
Repeat 1-6 from (A) using the slot car.

Topic 3: Lab C-3 – Velocity and Acceleration Answer Sheet

(A) Bulldozer
Sample Data Table

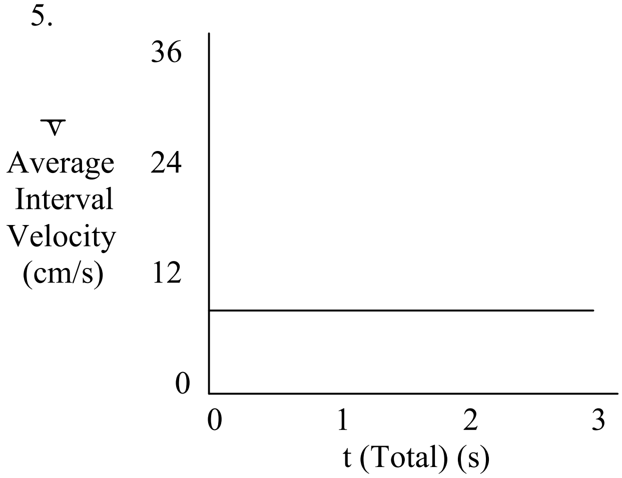
Interval Distance (cm)	Total Distance (cm)	Total Time (s)	Average Interval (cm/s)
12	12	1	12
12	24	2	12
12	36	3	12
↓	↓	↓	↓

4. Total Distance vs. Total Time



This graph shows that the bulldozer moves the same distance in equal times, or constant motion (velocity).

5.



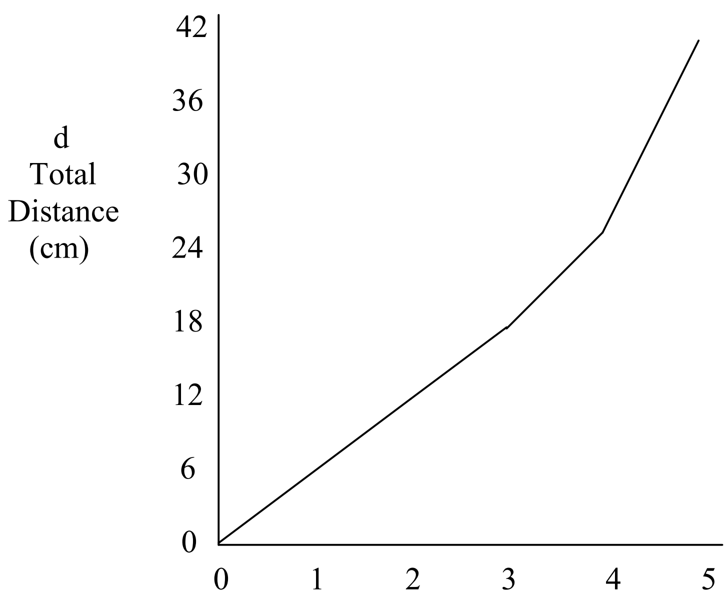
This graph shows that the bulldozer moves at the same rate (velocity) at all times.

6. Slope of the graph in (5) is: $a = (\Delta v)/(\Delta t) = \frac{(12 \text{ cm/s} - 12\text{cm/s})}{3 \text{ s} - 0 \text{ s}} = \frac{0 \text{ cm/s}}{3 \text{ s}} = 0$ cm/s/s, no acceleration

(B) 2-Speed Windup Car:
Sample Data Table

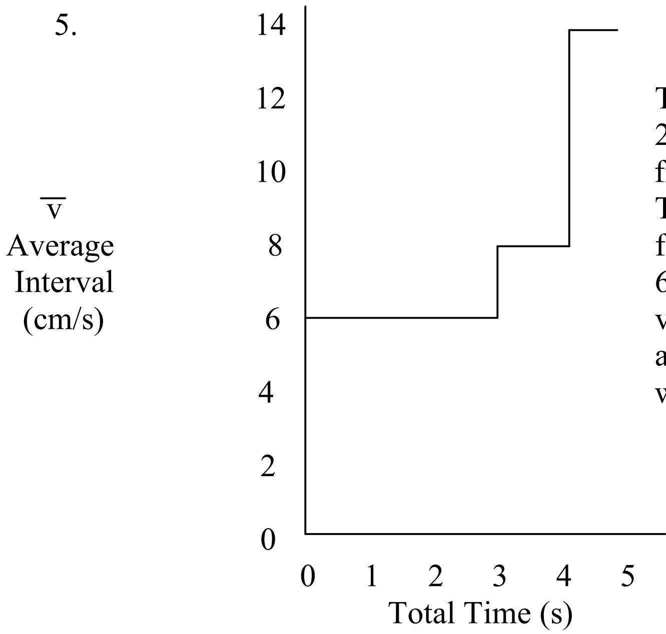
Interval Distance (cm)	Total Distance (cm)	Total Time (s)	Average Interval (cm/s)
6	6	1	6
6	12	2	6
6	18	3	6
8	26	4	8
14	40	5	12
↓	↓	↓	↓

4. Total Distance vs. Total Time



This graph shows the 2-speed car moves equal distance in equal time for the first 3 s, but from 3 s to 5 s, more distance is covered in equal time, showing a greater velocity (also shown by the slope).

5.



This graph shows the velocity of the 2-speed car constant for 3 s, but increases from 3 s to 4 s and even faster from 4 s to 5 s. The graph is misleading from 3 s to 4 s and from 4 s to 5 s because no car can go from 6 cm/s to 8 cm/s or 8 cm/s to 14 cm/s in no velocity time. These data points are only averages and thus don't show a smooth curve when many data points are used.

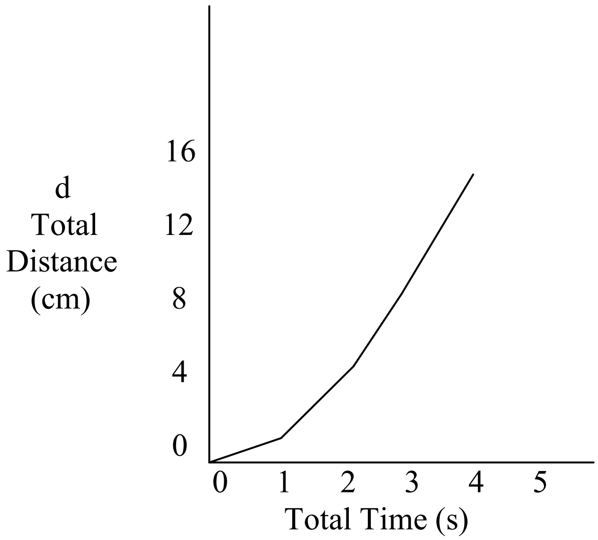
6. Slope of graph is: $a = (\Delta v)/\Delta t) = 0$ from 0 s to 3 s; (8 cm/s – 6 cm/s)/1 s = 2 cm/s/s from 3 s to 4 s = (14 cm/s – 8 cm/s)/1 s = 6 cm/s/s from 4 s - 5 s

   In other words, the acceleration got greater as time went on: first 0, then 2 cm/s/s, then 6 cm/s/s.

(C) HO Slot Car (Accelerated Motion)
Sample Data Table

Interval Distance (cm)	Total Distance (cm)	Total Time (s)	Average Interval Velocity (cm/s)
0	0	0	0
1	1	1	1
3	4	2	3
5	9	3	5
7	16	4	7
↓	↓	↓	↓

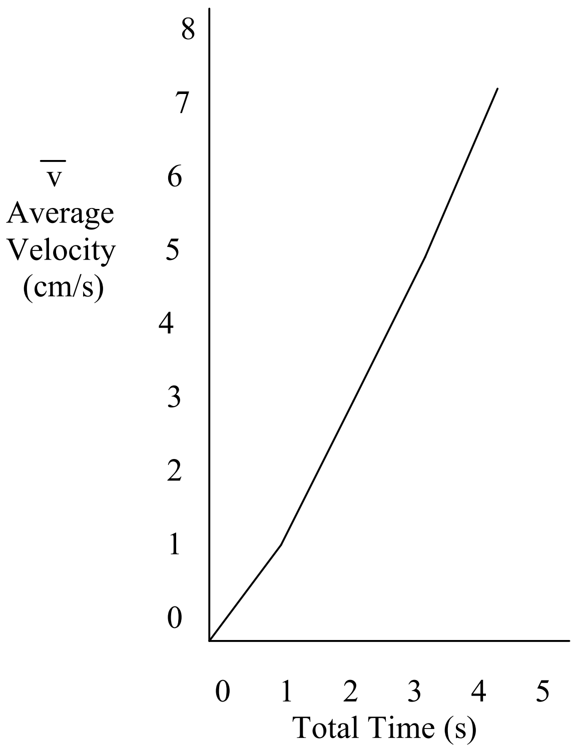
4. Total Distance vs. Total Time



The graph shows continuous accelerated motion. (Larger and larger distances are covered in equal time.)

Velocity is shown by slope that increases.

5. Average Velocity vs. Time



In equal times the slot car gains the same amount of velocity, indicating a constant acceleration.

The slope of the graph is constant.

Or, a = (Δ v)/(Δ t) = (7 cm/s - 1 cm/s) = 6 cm/s/s constant.)

6. As shown in step 5, the slope is constant at 2 cm/s/s, showing constant acceleration.

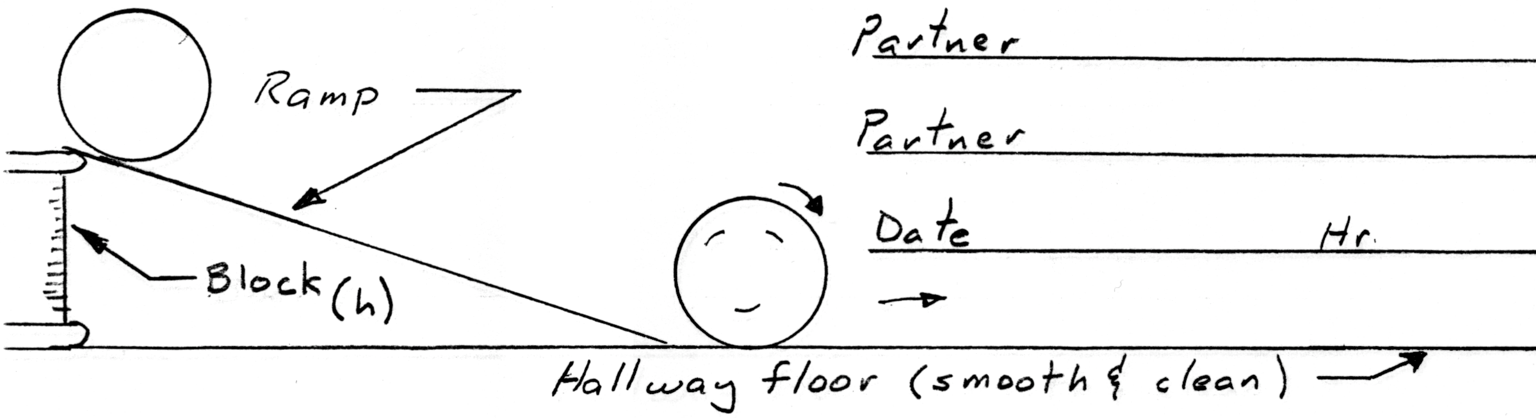
Rollin, Rollin, Rollin . . . *

Name ______________________

Partner ______________________

Partner ______________________

Date ______________ Hr. ______



Procedure:
- Roll the ball down the ramp for Two trials
- Put down markers at 2 second intervals beginning when the ball hits the floor.
- Do for 5 [redacted] second intervals
- Measure and record the distance from the end of the ramp to each marker (d)
- Be sure the initial position and release are the <u>same</u> for each trial.

	d_1	d_2	d_3	d_4	d_5
Trial 1 (Low)					
Trial 2 (High)					

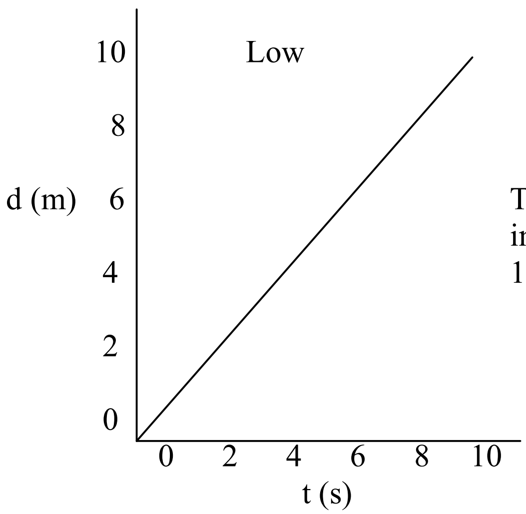
Graph & Analysis on graph paper (1-Page Report)
Think: What is your control variable

* from what movie?

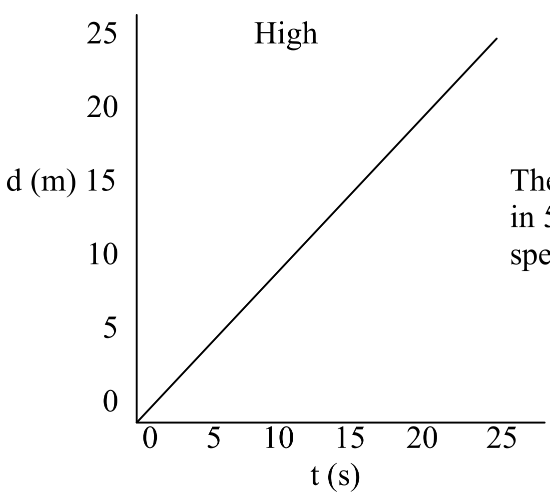
Rollin, Rollin, Rollin . . . Answer Sheet

Sample Data

	d_1	d_2	d_3	d_4	d_5
Trial 1 (Low)	2	2	2	2	2
Trial 2 (High)	5	5	5	5	5



The slope of the graph shows the ball traveling at 1 m in 1 s, 2 m in 2 s, etc., showing a constant speed of 1 m/s.



The slope of the graph shows the ball traveling at 5 m in 5 s, 10 m in 10 s, etc., showing the same constant speed of 1 m/s.

Topic 3: Worksheet D-1 – Displacement, Velocity and Acceleration (Graphical Approach)

(A) Displacement

1. Draw to scale and solve:
   (a) John goes 8 steps north, 3 steps east, 6 steps south, 6 steps west and 2 steps south. What is John's displacement from his starting point?
   (b) Mary hikes east 4 miles, north 2 miles and south 5 miles. What is Mary's displacement from her starting point?

(B) Velocity

1. Draw to scale and solve:
   (a) Juan aims his boat directly across a river flowing at 8 mi/hr. Juan's boat travels at 6 miles/hour in still water. How fast does Juan travel relative to shore?
   (b) Stephanie flies her model airplane at 12 m/s into a headwind of 3 m/s. What speed results as seen from earth?

(C) Acceleration

1. Draw to scale for part (b) and solve:
   (a) Use the $(\Delta v)/(\Delta t)$ average acceleration definition to determine the acceleration of a ball rolling down a hill at 2 m/s and reaches 8 m/s in 2 s.
   (b) Graphically show the vectors to obtain the answer to (a).

(D) Graphical analysis of motion is illustrated by three graphs, and three graphical items show the details of that motion.

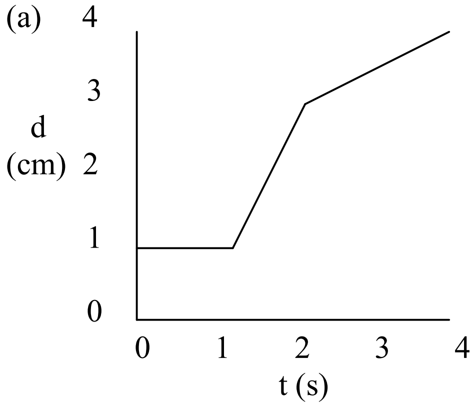
1. Direct readings:
   For a position-time graph, direct reading shows your position at a given time.
   For a velocity-time graph, direct reading shows your velocity at a given time.
   For an acceleration-time graph, direct reading shows your acceleration at a given time.

2. Slope:
   The slope of a position-time graph shows the velocity of an object within a given time interval.
   The slope of a velocity-time graph gives the acceleration of an object within a given time interval.
   The slope of an acceleration-time graph shows nothing.

3. Area:
   The area beneath a position-time graph shows nothing.
   The area beneath a velocity-time graph shows displacement within a given time interval.
   The area beneath an acceleration-time graph shows velocity within a given time interval.

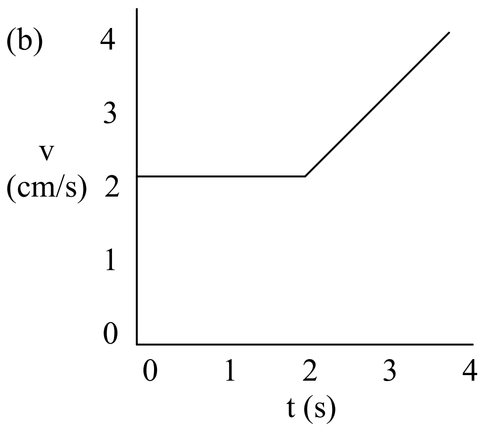
Use this information to answer questions about the following graphs for an object:

(a)



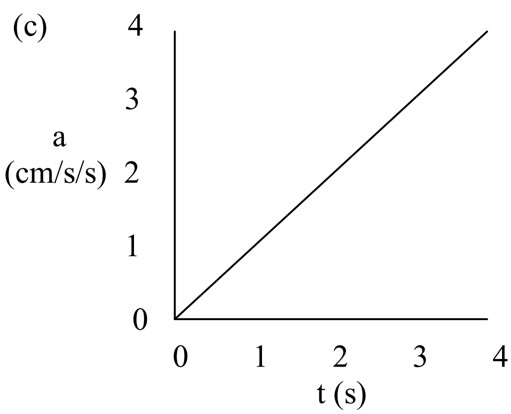
1. Where is the object at 0.5 s?
2. Where is the object at 2 s?
3. Where is the object at 3 s?

(b)



1. How fast is the object moving at 1 s?
2. How fast is the object moving at 3 s?

(c)



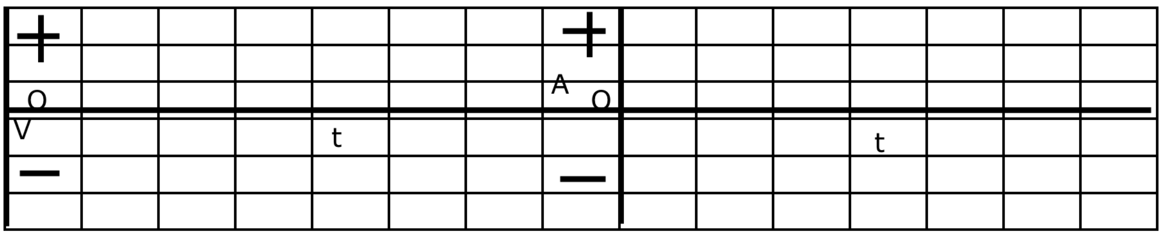
1. What is the acceleration of the object at 2 s?
2. What is the acceleration of the object at 4 s?

(d) Use graph (a) for the following questions:
1. What is the value and meaning of the slope from 0 s–1 s?
2. What is the value and meaning of the slope from 1 s–2 s?
3. What is the value and meaning of the slope from 2 s–4 s?
4. What is the value and meaning of the area beneath 0 s–1 s?
5. What is the value and meaning of the area beneath 1 s–2 s?
6. What is the value and meaning of the area beneath 2 s–4 s?

(e) Use graph (b) for the following questions:
1. What is the value and meaning of the area beneath the graph from 0 s–2 s?
2. What is the value and meaning of the area beneath the graph from 2 s–4 s?
3. What is the value and meaning of the slope between 0 s–2 s?
4. What is the value and meaning of the slope between 2 s–4 s?

(f) Use graph (c) for the following questions:
1. What is the value and meaning of the slope during 0 s–4 s?
2. What is the value and meaning of the area during 0 s–4 s?

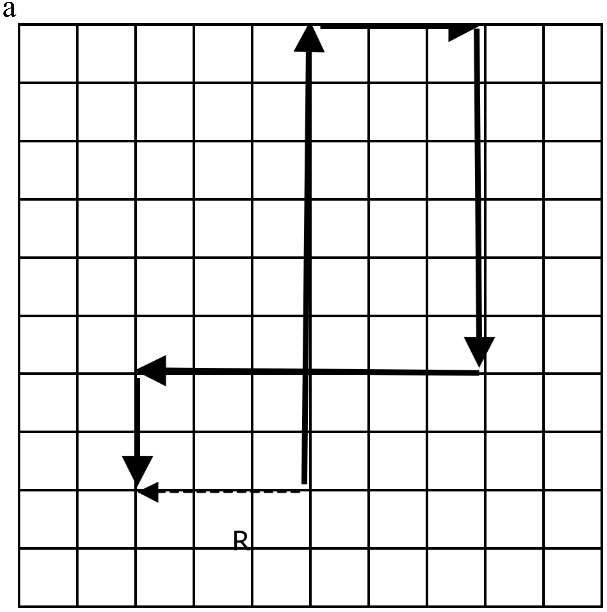
Sketch a velocity-time and acceleration-time graph for each of the following:
Sample Graphs



1. A car starting from rest moves a few hundred yards down a road and slows to a stop at the corner.
2. A tennis ball rolls across a tennis court.
3. An airplane taxis to the end of a runway, stops for a moment, turns around and then takes off.
4. A book falls from a desk and hits the floor.
5. A student walks up a hill to mail a letter and returns down the hill.

Topic 3: D-1 Worksheet Answer Sheet:

A1a

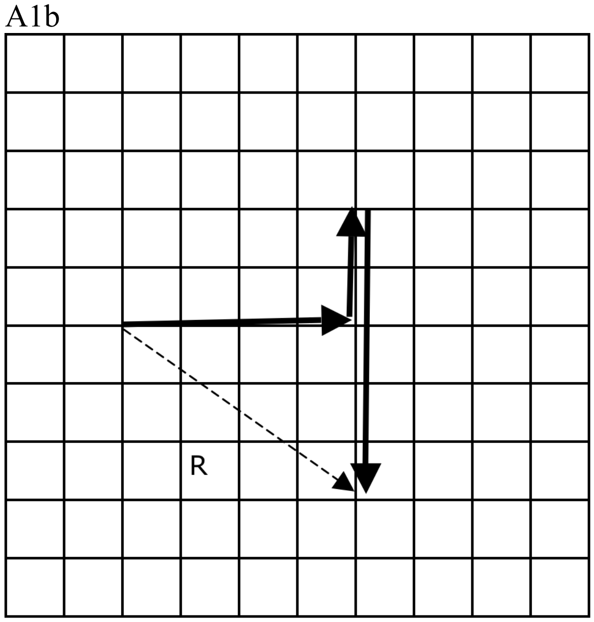


steps

R = 3 steps, W

steps

A1b

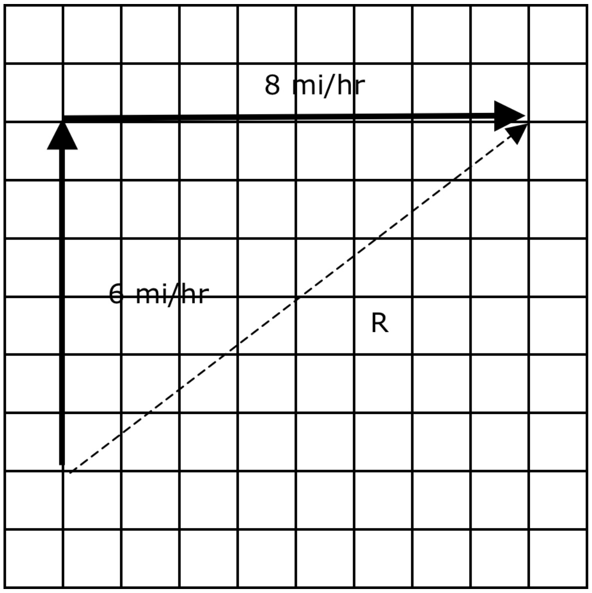


steps

R = 5 steps, SE

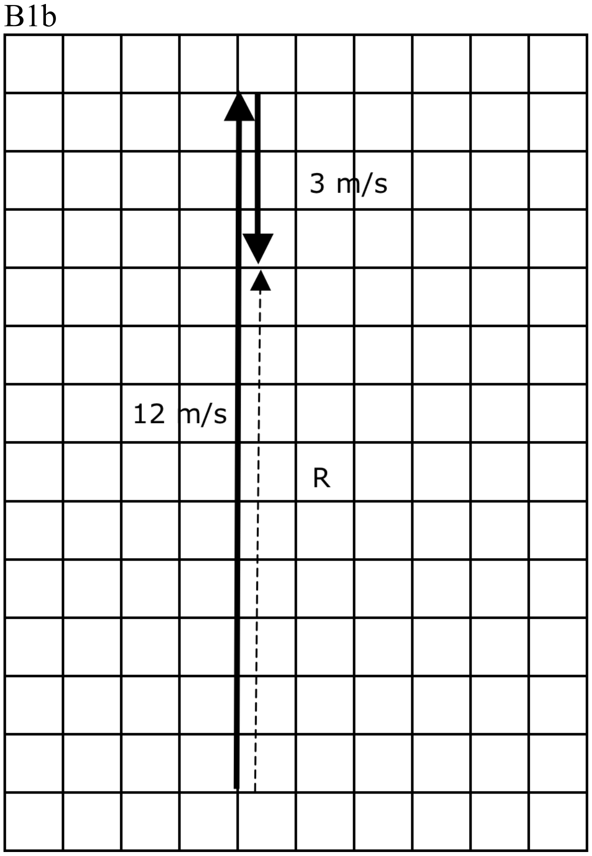
steps

B1a



R = 10 mi/hr downstream

B1b

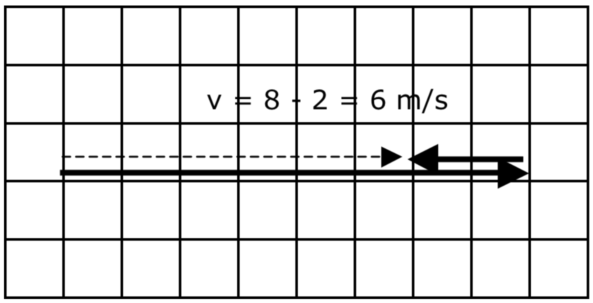


R = 9 m/s into the wind

C1a

$$a = \frac{8\text{ m/s} - 2\text{ m/s}}{2\text{s}} = 3\text{ m/s/s}$$

C1b



So, a = 6 m/s / 2 s = 3 m/s/s

Da1. At 1 cm
Da2. At 3 cm
Da3. At 3.5 cm

Db1. 2 cm/s
Db2. 3 cm/s

Dc1. 2 cm/s / 2 s = 1 cm/s/s
Dc2. 4 cm/s / 4 s = 1 cm/s/s

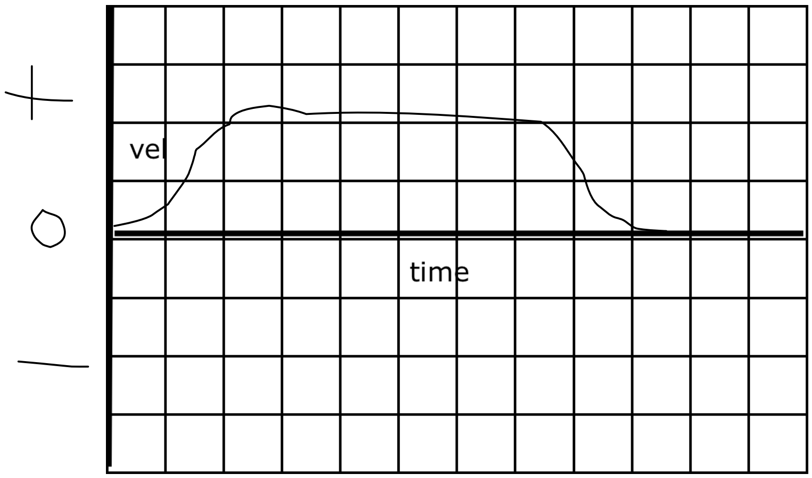
Dd1. Shows velocity, so slope = v = 0
Dd2. Shows velocity, so slope = v = 2 cm/1 s = 2 cm/s
Dd3. Shows velocity, so slope = v = 1 cm/2 s = 0.5 cm/s
Dd4. Shows nothing
Dd5. Shows nothing
Dd6. Shows nothing

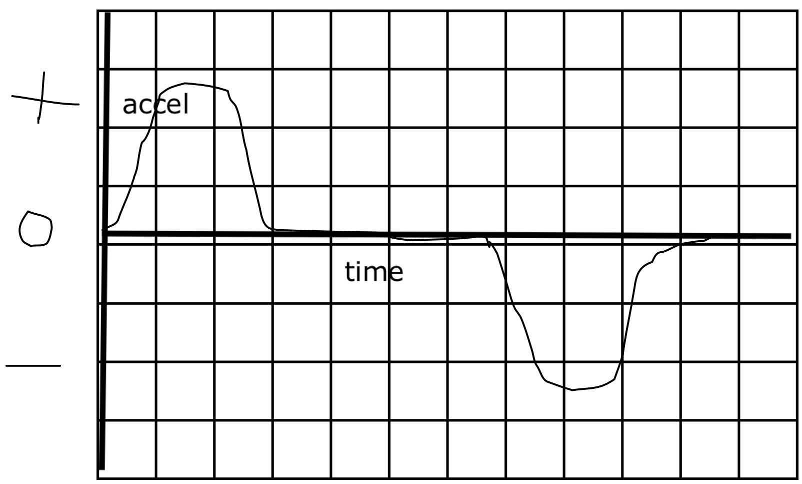
De1. Shows displacement, so d = 2 x 2 = 4 cm
De2. Shows displacement, so d = 2 x 2 + 0.5 x 2 x 2 = 6 cm
De3. Shows acceleration, so a = 0
De4. Shows acceleration, so a = 2 cm/s / 2 s = 1 cm/s/s

Df1. Slope shows nothing.
Df2. Area shows velocity, so 0.5 x 4 cm/s/s x 4 s = 8 cm/s at 4 s.

v-t graphs and a-t graphs:

1.





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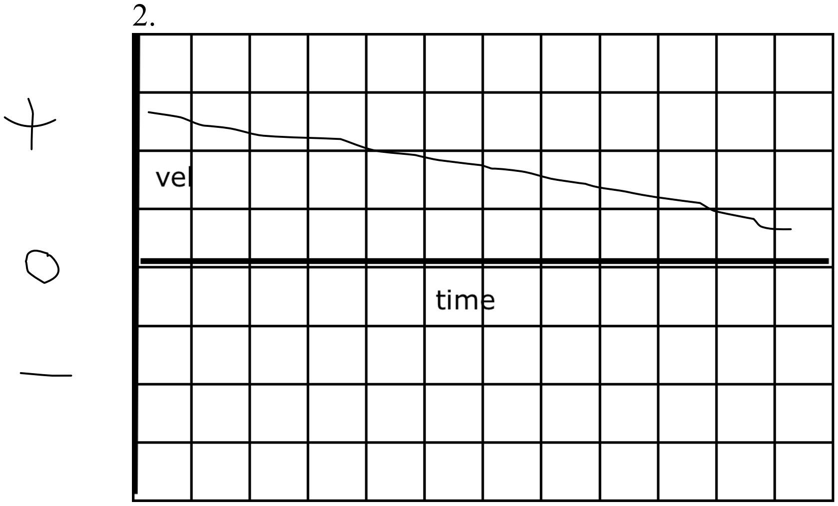

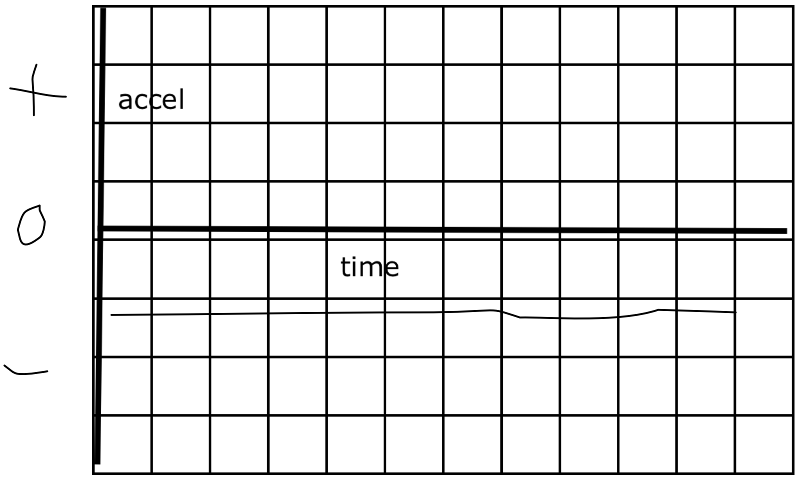

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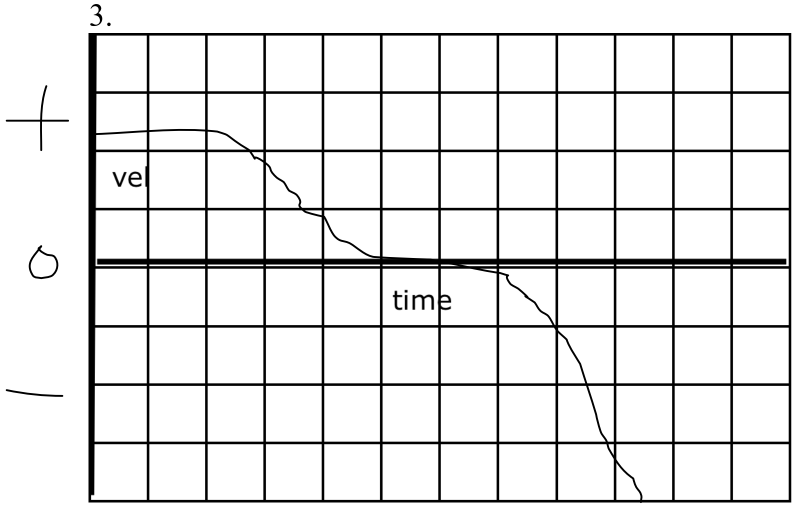

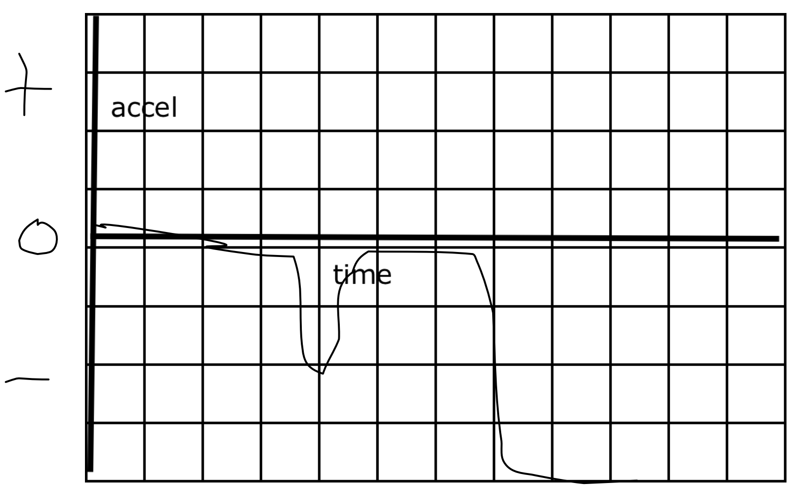

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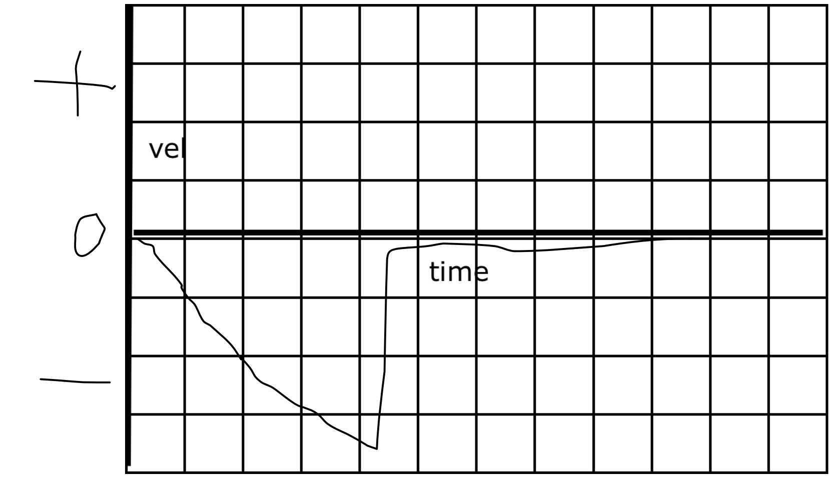

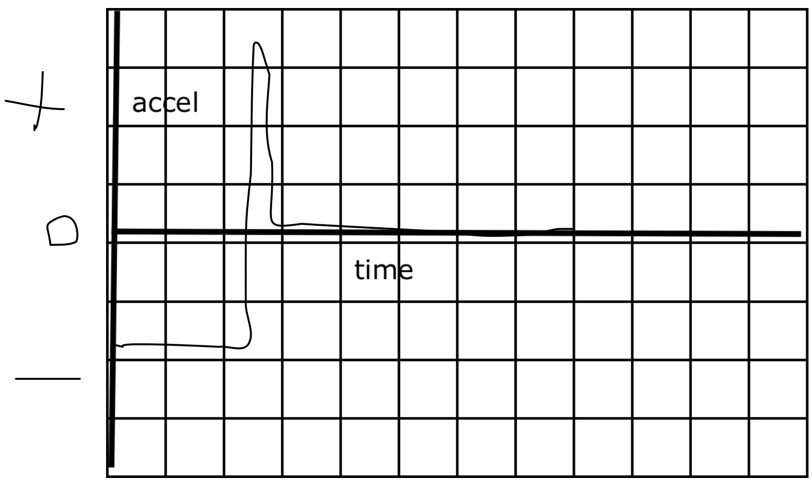

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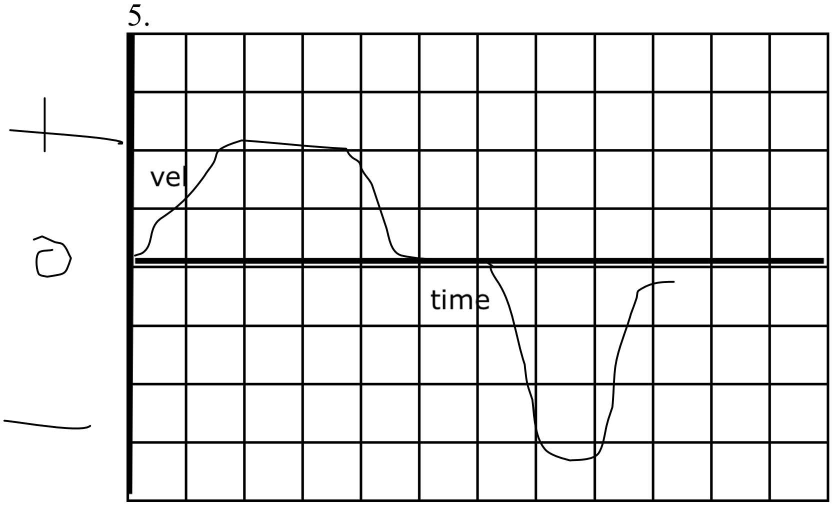
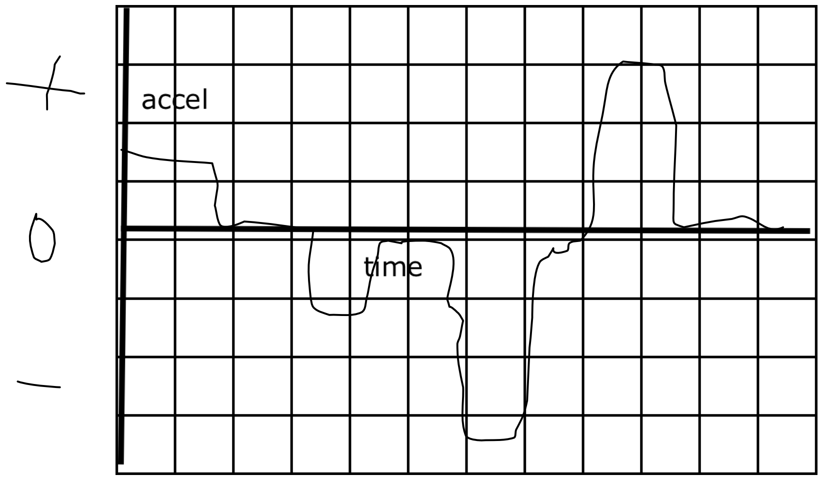




accel
time

Topic 3: Demo – 2-D Projectile Motion

Purpose: To analyze the horizontal and vertical components of 2-dimensional motion.

Apparatus: Digital movie camera, computer with a media player, screen or projection surface on which to use erasable marker, felt tip markers (whiteboard type), ruler, bright-colored ball (baseball).

Procedure:

1. Mount the camera in a fixed position.
2. Record the ball traveling in a projectile path.
3. Transfer the video clip to the computer.
4. Play back onto a CRT screen or project onto a blackboard (whiteboard).
5. Mark the position of the ball at several uniform locations using the timeline slider of the media player.

Analysis: Draw vertical lines through the marked points. The space between the lines shows that the equal spacing indicates that the horizontal motion is uniform.

Draw horizontal lines through the marked points. The unequal spacing of the lines indicates that the motion in the vertical dimension is changing. Close analysis will show that the ball slows down on the way up equally as the ball going down speeds up.

Caution: Unless pixel height and width are equal, actual measurements from the screen will be unreliable.

There are several methods for importing video graphics to the computer.

1. Direct input to the computer from the camera using a "FireWire," USB or RCA mini-plugs. (RCA mini-plugs typically allow for analog input only; analog works although the screen resolution is less.)

2. Record the 2-D motion on videocassette, minidisk or memory card. Import the video clip, using step 1.

3. Most operating systems have a media player such as Windows Media Player built in with a control for advancing the timeline.

Why a Seven-Day Week?

The ancient Greeks had no week; the Romans had an eight-day week. When the seven-day week was adopted is not clear. The number seven seems to have universal appeal. Rome was built on seven hills, the Japanese have seven gods of happiness and the Bible refers to the Sabbath as the seventh day of creation. Somewhere around the third century the Romans were on a seven-day schedule. This does not seem to be the result of any governmental action.

The National Convention of the French Revolution set up a committee on calendar reform. This committee was composed of a mathematician, a poet, an educator and the great astronomer, La Place. They produced a calendar of rational symmetry. In 1792 the decimal calendar replaced the seven-day week with a ten-day week, the decade. Three decades comprise one month, twelve months in one year. The day was divided into ten hours, each minute into one hundred seconds. This system required five days plus a leap day to be added to the end of the twelve-month cycle. These additional days were dedicated to holidays and sports. The new decimal calendar was designed to loosen the grip of the church on daily life. This new calendar system ended thirteen years later when Napoleon became the ruler of France. He restored the Gregorian calendar with its traditional saints days and holidays.

In 1929 the Soviet Union aimed to dissolve the Christian year by replacing the Gregorian calendar with the Revolutionary calendar. The week had five days, four for work and one for rest. Each month had six weeks. Holidays made up the required number for a solar year. The Gregorian month names were retained but the days were simply numbered 1, 2, 3, 4 and 5. By 1940 the Soviet Union had returned to the Gregorian calendar.

Nicolas Copernicus – Renaissance Man

Nicolas Copernicus was born in northern Poland in 1473. At the age of ten his father had died and the Church became his home. Nicolas was appointed canon at age 24 and held that position until he died in 1543. He studied mathematics, astronomy, medicine, church law and painting. The picture typically associated with Copernicus is a self-portrait. He lived in the time of Michelangelo, Leonardo da Vinci, Gerrard Mercator and Christopher Columbus. Copernicus was truly a Renaissance man.

Copernicus became interested in the fact that, since its beginning, the Julian calendar, instituted in 45 B.C., showed a difference of ten days between the predicted and the actual spring equinox. He turned to the writings of Ptolemy. Ptolemy took Aristotle's geocentric universe and explained planetary motion using a system of epicycles and deferents. As complicated as the system was, it did a reasonably good job of describing the paths of the planets through the heavens. So good in fact that Ptolemy's Almagest wasn't seriously challenged for over a millennia.

So how could Copernicus improve upon or replace such a system? Even though the Ptolemaic system was extremely complicated and confusing, it was never Copernicus' intention to correct the Almagest. As a purely academic exercise he proposed an aesthetic alternative. Copernicus postulated no new theory; he collected no data nor formulated any new mathematics or offered any proof. He merely posed the question, "What If?" What if the stationary earth were replaced with a moving earth? The resulting heliocentric did not replace the epicycle, nor could it predict the position of the planets with any greater accuracy than Ptolemy's theory. The appeal and acceptance of the Copernican system was its simplicity and elegance, an idea whose time was right in Renaissance Europe.

The Fastest Airplane in the World

The Air Force SR-71, Blackbird, has a cruise speed of mach 3.2 (over 2200 mph). This speed is about 3500 feet per second, faster than a 30-06 rifle bullet. A turning pilot pulling 3 G's requires 20 miles just to make a right turn. The SR-71 acquired the official name Blackbird because of the special paint that covers the plane. The paint absorbs radar and also radiates heat from the airframe, which, due to air friction, can reach up to 900 degrees F. The black color also acts as camouflage at high altitude where its silhouette blends into the darkness of inner space. The paint also allows the plane to run about 75 degrees F cooler.

In order to withstand extreme temperatures, the airframe is made from 99 percent titanium composite. The landing gear was the largest titanium forging in the world. The United States, needing titanium, bought all it needed from the Russians. In addition to airframe modifications to fend off heat, the tires are impregnated with aluminum and filled with Nitrogen. Exhaust temperatures can reach upwards of 3200 degrees F.

It is not until after take off that the Blackbird can take on a full tank of fuel. Until the Blackbird reaches operating temperatures the skin panels of the plane do not expand enough to seal causing the fuel tanks to leak. This is also a problem when refueling. The Blackbird must slow down and therefore cool, again, causing the tanks to leak.

Over 1,000 missiles have been launched at the Blackbird; the black plane has out run them all. The SR-71 Blackbird had no digital gages and was designed without the aid of a computer; the primary design tool was the slide rule.

Johannes Kepler – A Life of Tragedy

Johannes Kepler was born premature in Weil der Stadt, Germany on December 27, 1571. Son of Heinrich and Katherine, Heinrich was a vicious, quarrelsome mercenary of the Duke of Alba. Kepler's mother, Katherine, was the daughter of an innkeeper and raised by an aunt who was burned at the stake for witchcraft. Kepler's mother, who had a vile temper, dabbled in the occult, was arrested, imprisoned and nearly burned at the stake herself. By the age of three Johannes contracted smallpox and his hands were left crippled. His grandfather raised him in a small cottage crowded with more than a dozen family members. Johannes was bestowed at birth with the gift of genius at a time when the rest of his brothers and sisters suffered from severe mental and physical handicaps. Kepler himself was not immune from the family curse of physical infirmity, for he was bowlegged, frequently covered with boils, and suffered from congenital myopia and multiple vision. Unfit for physical labor Kepler prepared for a life as a religious clergy. Three of Kepler's children died, at least one from smallpox, and his first wife was claimed by typhus. Throughout Kepler was kept on the move trying to avoid wars or religious reformations. His genius as a mathematician would soon become apparent.

Kepler studied the Greek astronomers in an attempt to make a real science out of astrology. He also attempted to use astrological techniques to solve Biblical mysteries. He worked out the date of creation to be 3992 B.C. and placed the birth of Christ at five years earlier than the accepted date. Johannes supported himself in part by casting astrological horoscopes for various noblemen. He became interested in the "music of the spheres" first studied by Pythagoras where exact musical notes would correspond to planetary cycles.

Galileo and Aristotle on Early Mechanics

In an older high school physics textbook (1970's, *Project Physics* or *Harvard Project*), historical development of kinematics by Aristotle and Galileo and others is presented. This is explored in Chapter 2 (pp. 37-60) of the 1975 edition, especially about Galileo's work. A short summary of this historical presentation is given below:

Aristotle "the Philosopher" was well informed on topics of biology, psychology, politics and literature. Aristotle was thought to be born in 384 BC; he thought that a heavy object falling toward the center of earth is an example of "natural" motion, and the heavier the body, the faster it would fall. Also, objects reach a final speed based on the amount of "content" within a body.

Other Aristotle ideas state that a "violent" motion must be caused by a force, so the bigger the force the faster the motion. Also, Aristotle believed that mathematics played little value in describing terrestrial phenomena and these ideas were still accepted into the 15th and 16th centuries until Galileo and others questioned some of Aristotle's teachings.

Galileo described mathematically the motion of ordinary objects, horses moving falling stones and balls rolling on inclines. This intellectual revolution is now considered modern science. Galileo read from Euclid and Archimedes and that changed his interest from medicine to physical sciences. He was appointed professor of mathematics at Pisa at age 26 and began challenging older professors, making enemies. Also, he supported the sun-centered theory of the universe and brought on a lot of enemies, also immortal fame.

When a light and heavy body drop from rest, they fall side by side and almost hit at the same time. The important point is not that the time of arrival is slightly different, but that they are very nearly the same! Galileo attributed the difference due to air resistance. Galileo saw that to study freely falling objects is the key to understanding all observable motions of all bodies in nature. Galileo chose to define uniform acceleration as the motion in which the change in speed definition matches the real behavior of moving bodies.

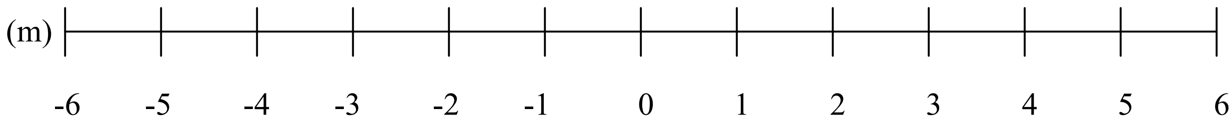
Since Galileo had no accurate timepiece, he used mathematics to derive relationships that could be tested. Specifically, for uniform acceleration from rest, the distance traveled is proportional to the square of the time elapsed.

Tests of this hypothesis of freely falling bodies do exhibit just such motion. Galileo went further in stating that if the same relationship would hold for a ball down an incline, the acceleration would just be less. This indirect test took place on a 12 cubit wooden ramp (1 cubit = 20 inches) repeating trials often to obtain consistent data. Graphing his data, Galileo proved that freely falling bodies uniformly accelerate, but at a lesser value on a ramp.

Galileo learned that an effective way to do scientific research is to make a general observation, hypothesis, mathematical analysis or deduction from the hypothesis, experimental test of deduction and revision of deduction.

Topic 3: Follow-Up Quiz/Test

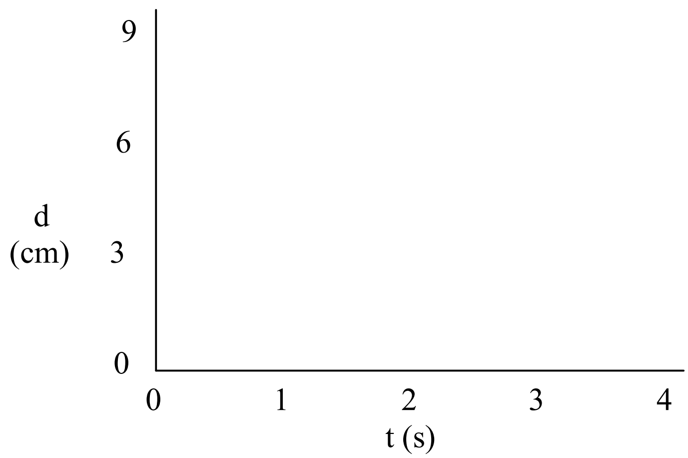
1. (a)



Draw a displacement vector starting at 2 m on the above number line for a positive 2 m length. Continue where you left off with a second displacement going a negative 6 m. Finally, go a positive 1 m. From your starting point, what is the resulting displacement vector?

(b) For constant motion, a body will travel equal distances in __________________________.

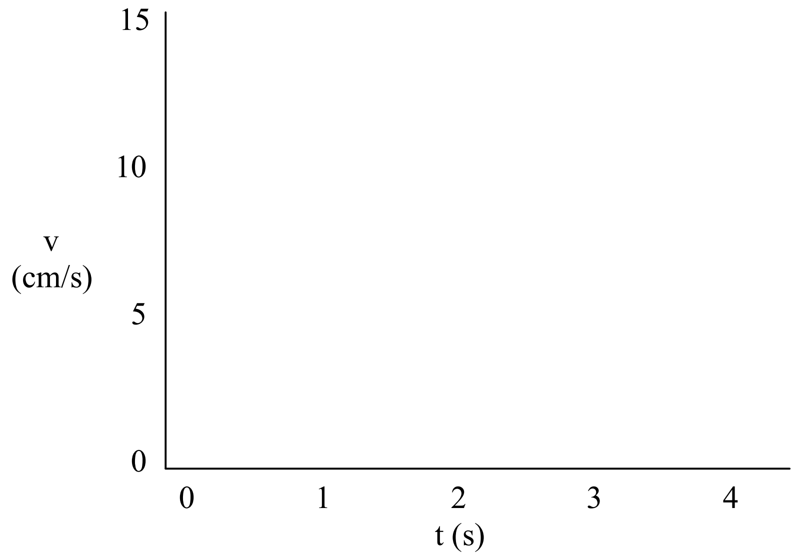
(c)



1. Use a solid line on the above position-time graph to show a body's constant motion at 2.0 cm/s.

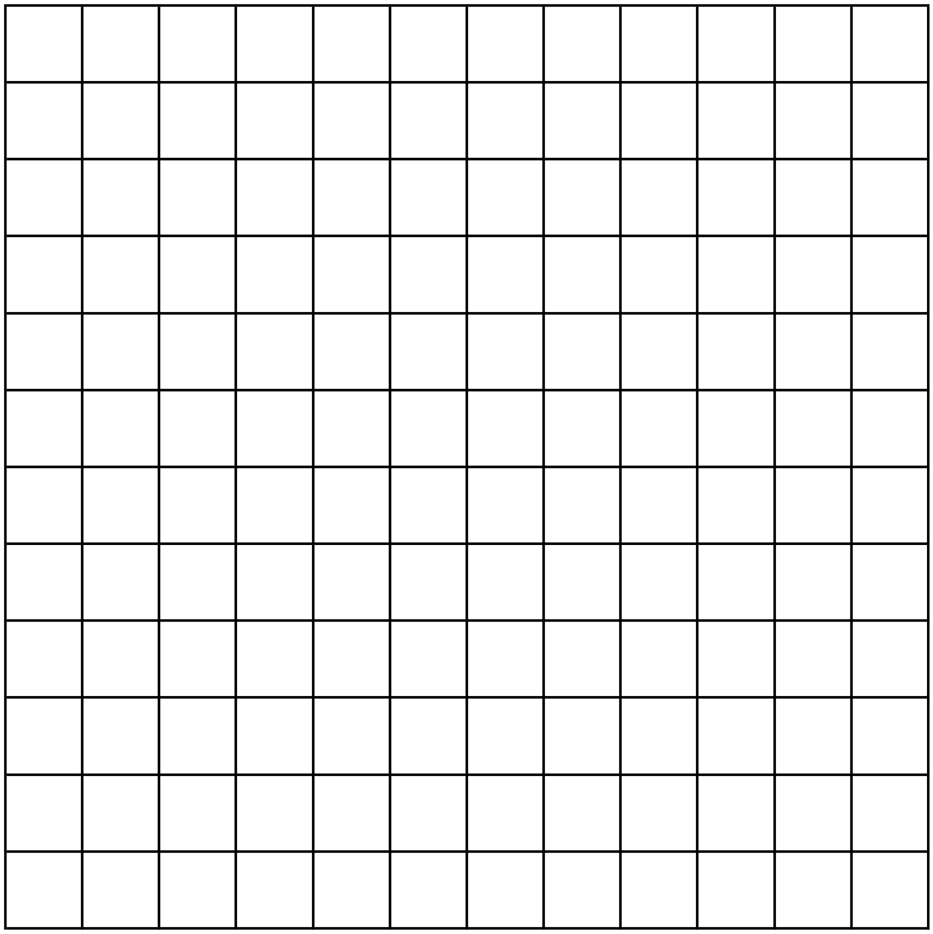
2. Use a dotted line on the above position-time graph to show no motion.

(d)



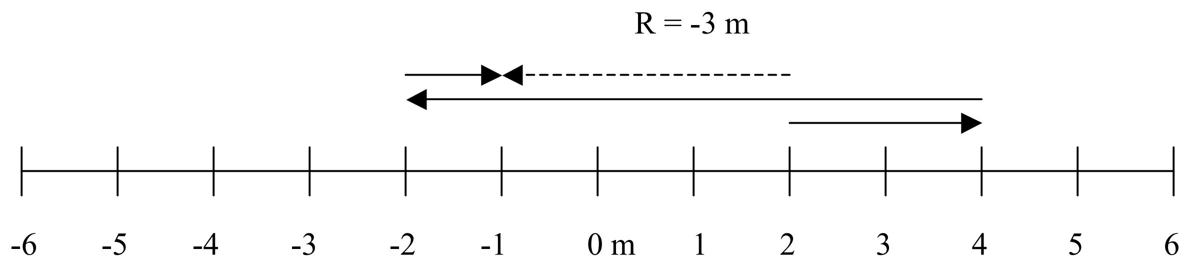
1. A body that accelerates at a constant rate changes ______________________ in equal times.
2. Sketch a curve on the graph using a dotted line to show a body at rest.
3. Sketch a curve on the graph using a solid line for a body accelerating at 5 cm/s/s.

2. Using proper graphing techniques, sketch a curve on the blank graph below the following event: A turtle moves at a constant rate at 10 cm in 2 s for a period of time of 3 s. Then the turtle uniformly gains speed to 15 cm/s in 3 s.



Topic 3: Follow-Up Quiz/Test Answer Sheet

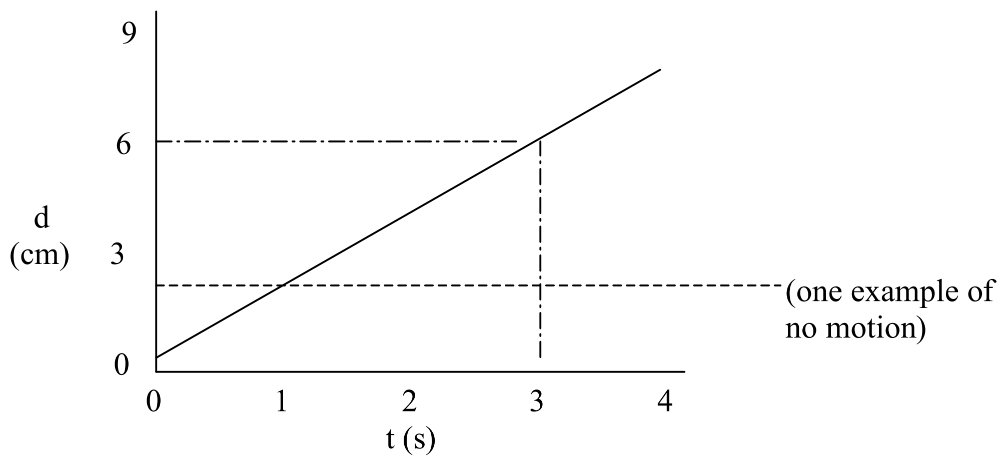
1. (a)



Draw a displacement vector starting at 2 m on the above number line for a positive 2 m length. Continue where you left off with a second displacement going a negative 6 m. Finally, go a positive 1 m. From your starting point, what is the resulting displacement vector?

(b) For constant motion, a body will travel equal distances in <u>equal times</u>.

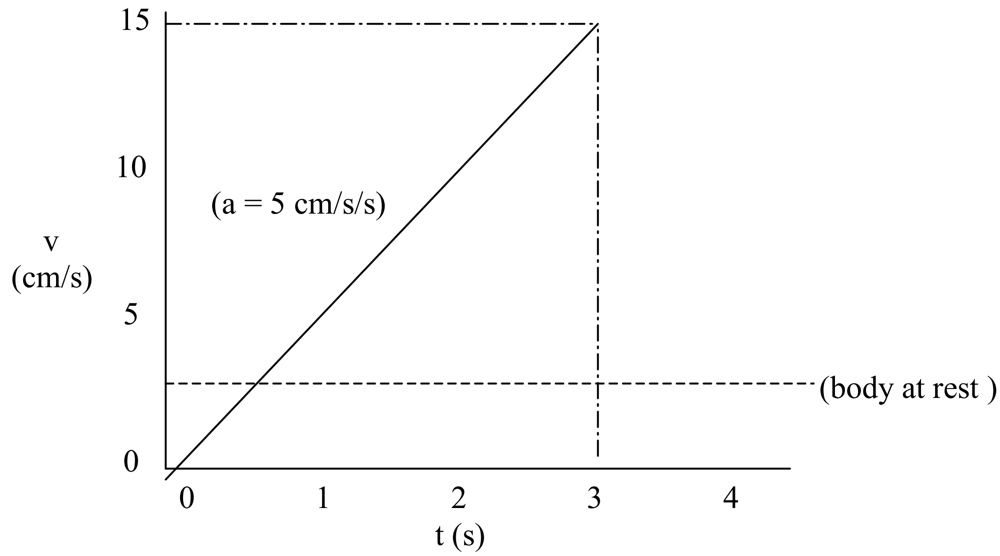
(c)



1. Use a solid line on the above position-time graph to show a body's constant motion at 2.0 cm/s.

2. Use a dotted line on the above position-time graph to show no motion.

(d)



1. A body that accelerates at a constant rate changes equal velocities in equal times.
2. Sketch a curve on the graph using a dotted line to show a body at rest.
3. Sketch a curve on the graph using a solid line for a body accelerating at 5 cm/s/s.

2. Using proper graphing techniques, sketch a curve on the blank graph below the following event: A turtle moves at a constant rate at 10 cm in 2 s for a period of time of 3 s. Then the turtle uniformly gains speed to 15 cm/s in 3 s.