AP Physics-B **Kinematics II – Mathematical Analysis of Motion**

Introduction: Everything in the universe is in a state of motion. It might seem impossible to find a simple way to describe and understand the motion of all objects, but this is just what physicists have done! We can describe motion using four quantities – time, displacement, velocity, and acceleration. We will look at "pictures" of these quantities called graphs, we will relate these quantities to each other through formulas, and we will use these formulas to solve problems.

The entire description of *how* an object moves is titled kinematics. Kinematics *does not consider why* an object moves or what causes the motion. Kinematics only describes *how* an object moves.

Performance Objectives: Upon completion of the readings and activities, and when asked to respond either orally or on a written test, you will:

Chapter 3

- ✓ Define the terms: position, distance, displacement, speed, and velocity.
- ✓ Distinguish between distance and displacement and between speed and velocity.
- ✓ Define, compare, and contrast: constant speed, average speed, and instantaneous speed.
- ✓ Define, compare, and contrast: constant velocity, average velocity, and instantaneous velocity.
- ✓ Recognize the graphs of position vs. time for constant and changing velocity. Interpret these graphs in terms of changing position. Calculate the slope of the line and relate it to constant, average, and/or instantaneous velocity.
- ✓ Recognize constant and changing velocity on a velocity vs. time graph. Find the displacement from a velocity vs. time graph.
- ✓ Plot a velocity vs. time graph from a position vs. time graph.
- ✓ Sketch possible graphs to describe given situations.
- ✓ Describe possible situations to accompany given graphs.
- ✓ State the formula for average velocity. Use the formula to solve problems.

Chapter 4

- ✓ Define acceleration. Understand that acceleration is a vector quantity.
- ✓ Recognize constant and changing velocity on a velocity vs. time graph. Calculate acceleration from the slope of the line.
- ✓ Plot an acceleration vs. time graph from a velocity vs. time graph.
- ✓ Find the change in velocity from an acceleration vs. time graph.
- ✓ State the formula for acceleration. Use the formula to solve problems.
- ✓ State the formula for distance traveled during uniform acceleration. Derive the formula. Use the formula to solve problems.
- ✓ State the formula for velocity when distance and acceleration are known. Derive the formula and use it to solve problems.

"Nothing in nature is more ancient than motion, and the volumes that the philosophers have compiled about it are neither few nor small: yet have discovered that there are many things of interest about it that have hitherto been unperceived." -Galileo Galilei (1564 – 1642)

Textbook Reference: Physics: Chapter 2

AP Physics-B **Kinematics – Part II – Describing Motion**

Solve the following problems. Show the basic equations used. Show the steps of your solution in a logical sequence. Don't forget you units! Circle you answer! Recall from Kinematics I that the slope of a position – time graph is equal to the average velocity. $v_{avg} = \Delta x / \Delta t$

1.) If a body has uniform (constant) velocity, what is the relationship among its initial, final, and average velocities? If a body has a uniform (constant acceleration), what is the relationship among its initial, final, and average velocities?

2.) Light from the sun reaches the earth in 8.3 minutes. The speed of light is 3.0×10^8 m/s. In kilometers, how far is the earth from the sun? *1.5×10^8 km*

3.) The distance from home plate to the pitchers mound is 18.5 m. Is a pitcher is capable of throwing a ball at 38.5 m/s (about 83 mph), how long does it take a thrown ball to reach home plate? *0.481 s*

4.) A diver travels the length of the Pennsylvania Turnpike (576 km) in 6 hours and 40 minutes. What is her average speed (a) in km/hr? (b) in m/s (c) in mph? *86.4 km/hr 24 m/s 53mph*

5.) If, while you are driving along at 45 km/hr, your attention wanders for 0.50 s, how far (in meters) do you travel "blind" during that half second? *6.3 m*

6.) A train travels at 100.0 km/hr for 0.52 hours, at 60 km/hr for the next 0.24 hours, and then at 117 km/hr for the next 0.71 hours. What is the average speed? *102 km/hr*

When two objects are moving, you must use an equation to describe the motion of each object.

7.) A bullet is fired at 660 m/s and strikes a target that is 200.0 m from the gun. If the marksman hears the sound of the impact on the target 0.90 s after he fires the gun, what is the speed of sound in this situation?

8.) An experimental rocket car moves along a straight track at a constant speed of 90.0 m/s. The car passes a group of officials, travels a distance of 270.0 m and then explodes. If the officials hear the sound of the explosion 3.8 s after the car passes their position, what is the speed of sound on that day? *337.5 m/s*

Recall from Kinematics I that the slope of a velocity – time graph gives the acceleration. $a = \Delta v / \Delta t$

9.) Each of the following changes in velocity takes place in a 10 second - interval. What is the magnitude, the algebraic sign, and the direction of the average acceleration in each interval?

a.) At the beginning of the interval, a body is moving toward the right at 5 m/s and, at the end, it is moving toward the right at 20 m/s. *+1.5 m/s^2 right*

b.) At the beginning it is moving toward the right at 20 m/s and, at the end, it is moving toward the right at 5.0 m/s. *-1.5 m/s^2 left*

c.) At the beginning it is moving toward the left at 5.0 m/s and, at the end, it is moving toward the left at 20 m/s. *-1.5 m/s^2 left*

d.) At the beginning it is moving toward the left at 20 m/s and, at the end, it is moving toward the left at 5.0 m/s. *+1.5 m/s^2 right*

e.) At the beginning it is moving toward the right at 20 m/s and, at the end, it is moving toward the left at 20 m/s. *-4.0 m/s^2 left*

f.) At the beginning it is moving toward the left at 20 m/s and, at the end, it is moving toward the right at 20 m/s. *+4.0 m/s^2 right*

g.) In which of the above instances has the body decelerated? *b, d, e, and f*

10.) A uniformly accelerated body is moving with a velocity of 3.0 m/s south. 5.0 seconds later, it has a velocity of 7.0 m/s north. What is the acceleration? *2.0 m/s^2 north*

11.) An airplane starting from rest has a uniform acceleration of 4.0 m/s^2. What is the velocity at the end of 30.0 s if this acceleration is maintained? *120 m/s*

12.) During an interval of 10.0 seconds, a train on a straight track changes its velocity from 15.0 km/hr to 20 km/hr. Determine the acceleration and the average velocity during that period assuming that the change occurred uniformly. *0.50 km/hr-s or 0.138 m/s^2* *17.5 km/hr*

13.) A snail traveling at a snail's pace (12 m/day) decides to slow down to only 5.0 m/day, and allows itself 2.0 minutes in which to make the change. (a) Express its initial velocity in km/hr, cm/yr, and m/s (b) Compute the acceleration in m/day-min and in m/s^2.
5.0 x 10^{-4} km/hr *438,000 cm/yr* *1.4 x 10^{-4} m/s* *-3.5 m/day-min* *-6.8x10^{-7} m/s^2*

Other kinematics formulas can be derived from the graphs and algebraic substitution.

$$v_{avg} = (v_i + v_f) / 2 \qquad \Delta x = v_0\Delta t + \tfrac{1}{2}a\Delta t^2 \qquad v_f^2 = v_i^2 + 2a\Delta x$$

14.) Nolan Ryan pitched a baseball that that traveled from the pitcher's mound to home plate (a distance of 18.5 m) in 0.411 s. (a) What was the speed of the ball in km/hr? (b) in mph? (c) If the catcher allowed his mitt to recoil backward 0.075 m while catching the ball, what was the acceleration of the ball while it was being slowed down by the catcher? *162 km/hr* *100mph* *-13,500 m/s^2*

15.) A spacecraft increases speed at a rate of 0.02 km/s^2. How much time is required for the speed to increase from 7.0 km/s to 8.0 km/s? How far does it travel during this time? How far will it travel during the ninth second? *50 sec* *375 km* *7.17 km*

16.) A train has an acceleration of 3.0 m/s^2 in a direction opposite to that of its motion. (a) How long a time will the train require to stop if it is initially going 30.0 m/s? (b) How far does it travel during this time period?
10.0 sec *150 m*

17.) A body moving with constant acceleration covers the distance between two points 60.0 m apart in 6.0 seconds. Its velocity as it passes the second point is 15 m/s. (a) What is its velocity at the first point? (b) What is the acceleration? *5.0 m/s* *1.6 m/s^2*

18.) A bus traveling along a straight street at 16.7 m/s increasing its speed at the rate of 1.33 m/s each second. (a) Find the distance covered in 6.00 s. (b) If its speed is decreasing at the rate of 1.33 m/s each second, find the distance traveled in 6.00 seconds and the time it takes to come to rest. *124 m* *76.3 m* *12.8 sec*

Free Falling Objects

Experiment shows that all objects, no matter what their mass, density, or shape will fall to earth from a given release point with the same free–fall acceleration, "g". Free fall means falling in a vacuum, so that the frictional resistance and buoyant effect of the air do not affect the motion. The quantity "g" is often referred to as the acceleration due to gravity.

The direction of "g" at any given point determines the direction of the vertical at that point; it defines what we mean by "down." Although the magnitude of "g" varies from point to point on the earth's surface, and also with elevation, its average value at sea level and mid–latitudes is 9.8 m/s^2 (about 32 ft/s^2). We will use this value for the problems in this unit.

19.) A 1.0 kg stone is dropped from a tall building. What is its displacement after it falls freely for 3.0 sec?
-44.1 m

20.) A small object is given an initial downward velocity of 3.0 m/s. (a) What is its velocity after it falls freely for 5.0 s? (b) What is its displacement from the initial position? *-52 m/s* *-137.5 m*

21.) A ball dropped from a bridge requires 5.0 s to strike the ground below. How high is the bridge in meters? *122.5 m*

22.) With what upward speed should a package be thrown in order to be caught easily be a person on a balcony 6.0 m above the ground? *10.8 m/s*

23.) A ball is thrown vertically upward to a height of 19.6 m and allowed to strike the ground. If it loses one fourth of its speed while in contact with the ground, how high does it rise on the rebound? *11.025 m*

24.) A ball is thrown nearly vertically upward from a point near the corner of a tall building. It just misses the edge on the way down, and passes a point 50.0 m below its starting point 5.0 s after it leaves the throwers hand. (a) What was the initial velocity of the ball? (b) How high did it rise above its starting point? (c) What were the magnitude and direction of its velocity at the highest point?

25.) A pitcher throws a baseball straight up, with an initial speed of 25 m/s. (a) How long does it take to reach the highest point? (b) How high does the ball rise above its release point? (c) How long will it take for the ball to reach a point 25 m above its release point? *2.6 s* *32m* *1.4 sec and 3.7 sec*

When two objects are moving at the same time and you are comparing them relative to each other, the two equations used to describe the motions of the objects must be solved simultaneously.

26.) Just as a traffic light turns green, a waiting car starts off with a constant acceleration of 6.0 m/s^2. At the instant the car begins to accelerate, a truck with a constant velocity of 21 m/s passes in the next lane. (a) How far will the car travel before it overtakes the truck? (b) How fast will the car be traveling when it overtakes the truck? *147 m* *42 m/s*

27.) At the instant the traffic light turns green, an automobile that has been waiting at an intersection starts ahead with a constant acceleration of 2 m/s^2. At the same instant, a truck, traveling with a constant velocity of 10 m/s, overtakes and passes the automobile. (a) How far (time – wise) beyond the starting point will the automobile overtake the truck? (b) How fast will it be traveling? *10 s* *20 m/s*

28.) An automobile and a truck start from rest at the same instant, with the automobile initially at some distance behind the truck. The truck has a constant acceleration of 2.0 m/s^2 and the automobile, an acceleration of 3.0 m/s^2. The automobile overtakes the truck after the truck has moved 75 m. (a) How long does it take the automobile to overtake the truck? (b) How far was the auto behind the truck initially? *8.7 s*

29.) A car and a truck are each traveling at 20.0 m/s, and the car is 25 m behind the truck. The car driver decides to pass the truck, and he steps on the gas, producing an acceleration of 3.0 m/s^2. (a) How long will it be before the car is alongside the truck? (b) How fast will the car be moving relative to the truck when they are side by side? (c) How far will the car travel while reaching the truck? (d) How far will the truck travel in the same time?
4.1 s *12.3 m/s* *107 m* *82m*

30.) A late passenger, sprinting at 8.0 m/s, is 30.0 m away from the rear of the train when it starts out of the station with an acceleration of 1.0 m/s^2. Can the passenger catch the train if the platform is long enough? (This problem requires the solution of a quadratic equation. Explain the significance of the two values you get for the time.) *YES!! ☺*

31.) A pedestrian is running at the maximum speed of 6.0 m/s to catch a bus stopped by a traffic light. When she is 25 m from the bus, the light changes and the bus accelerates uniformly at 1.0 m/s^2. Find either (a) How far she has to run to catch the bus, or (b) Her frustration distance (closest point that he reaches). Do this with the use of a graph or by solving the appropriate equations. *7.0 m*

32.) The engineer of a passenger train traveling at 30.0 m/s sights a freight train whose caboose is 200.0 m ahead on the same track. The freight train is traveling in the same direction as the passenger train with a velocity of 10.0 m/s. The engineer of the passenger train immediately applies the brakes, causing constant deceleration of 1.0 m/s^2, while the freight train continues at constant speed. (a) Will there be a collision? (b) If so, where will it take place? *Yes…☹* *400 meters from where the passenger train first noticed the freight train.*