AP Physics-B **Motion in 2-D – Projectile and Circular Motion**

Projectile Motion: Projectiles in physics are objects that are launched into the air by an external net force and then allowed to travel through the air with only the forces of gravity and air resistance acting on it. The path that the projectile follows is called a trajectory. Remember that velocity is a vector quantity and vectors can be resolved into perpendicular components. For a projectile launched other than straight up or straight down, the object is moving in both the "x" and "y" directions at the same time. Recall that vectors add together to give a net result, but act independently of each other. Keep this in mind when analyzing the motion of a projectile. If air resistance is neglected, the horizontal component has no net force acting upon it and the vertical component has only the force of gravity acting upon it. The instantaneous velocity at any time can be found by adding the horizontal and vertical velocities using the Pythagorean Theorem. These are actually kinematic problems, so go back and find that old reliable list of kinematic formulas that we built up in the kinematics unit!

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

- ✓ Display an understanding of the independence of the vertical and horizontal velocities of a projectile. Apply this knowledge in solving problems involving projectiles.
- ✓ Illustrate an understanding of projectiles fired at an angle by solving problems associated with such projectiles.
- ✓ List the equations for centripetal acceleration and centripetal force.
- ✓ Solve problems for circular motion in the horizontal and vertical planes.

Textbook Reference: Chapter 3

1.) A ball is thrown vertically upward with a velocity of 24 m/s from a railroad flatcar moving horizontally with a velocity of 4.0 m/s. Describe the path of the ball as seen a.) by an observer on the flatcar, and b.) by an observer on the ground nearby.

2.) A football is kicked into an oncoming wind. a.) Sketch its path (trajectory) of travel. b.) How would its trajectory look different if air resistance could be ignored? Make a second sketch of this new trajectory. c.) …for this second sketch, draw vectors representing the "x" and "y" components of velocity at five different locations along the football's trajectory. I.) When it leaves the ground. II.) When it's halfway up. III.) When it's at the peak of its trajectory. IV.) When it's halfway down. and V.) At the instant before it hits the ground.

3.) A sailor drops his pocketknife from the top of a mast on a ship sailing eastward at 7 m/s. The mast is 21 m high. Where does the knife hit the deck?

4.) Why does a high jumper approach the jump at a relatively slow running speed where as a long jumper runs as fast as possible for the jump?

5.) Divers at Acapulco dive from a cliff that is 61 m high. If the rocks below the cliff extend outward for 23 m, what is the minimum horizontal velocity a diver must have to clear them? *6.5 m/s*

6.) A cannon ball is fired horizontally with a velocity of 350 m/s from the top of a cliff 85 m high. a.) In what time will it strike the plane at the foot of the hill? b.) At what distance from the foot of the cliff will it strike? c.) With what velocity will if strike? *4.2 s* *1470 m* *352 m/s*

7.) A plane drops a raft to the survivors of a shipwreck. The plane is flying at a height of 1960 m and at a speed of 90.0 m/s. The raft lands next to the survivors. How far away from the shipwreck was the plane when the raft was dropped. *1800 m*

8.) An arrow is fired directly (horizontally) at the bull's eye of a target 60.0 m away. The arrow has a speed of 89 m/s when it leaves the bow. When it is fired, the arrow is 1.0 m above the ground. How far short (in front of) of the target does it stride the ground? *19.8 m*

9.) A famous motorcyclist plans to jump across a canyon, 0.35 km wide. To do this, the cyclist plans to leave a 30-degree ramp on one side of the canyon at a speed of 19.6 m/s. If the motorcycle can attain this speed, where does the cycle touch down? Assuming that the top of the ramp is at the same level as the opposite side of the canyon, does the motorcycle reach the other side of the canyon on the jump? If it does not reach the other side, then at what initial velocity would the motorcycle need to leave the same ramp to make the jump a success? *No*

10.) A player kicks a football from ground level with a velocity of magnitude 27.0 m/s at an angle of 30.0° above the horizontal. Find: a.) it's "hangtime," that is, the time the ball is in the air. b.) the distance the ball travels before it hits the ground. and c.) it's maximum height. *2.76 s 64.6 m 9.3 m*

11.) The kicker now kicks the ball with the same speed as before, but this time at an angle of 60.0° from the horizontal. Find: a.) Hangtime b.) downfield distance (range) and c.) maximum height. What do you answers reveal about the ranges of projectiles launched at these angles? *4.78 s 64.5 m 27.9 m*

12.) A baseball is hit at 30.0 m/s at an angle of 53.0° with the horizontal. Immediately, an outfielder runs 4.00 m/s toward the infield and catches the ball at the same height it was hit. What was the original distance between the batter and the outfielder? *108.3 m*

13.) A broad jumper takes off at an angle of 20 degrees above the horizontal and jumps 0.6 m high. a.) What is his forward velocity? b.) How far does he jump? *9.42 m/s 6.6 m*

14.) A projectile is fired at 200 m/s at an angle of 53° with the horizontal. Calculate a.) the time the shell remains in the air, and b.) the horizontal distance it travels. *32.6 s 3924 m*

15.) While standing on an open bed of a truck moving at 35 m/s, an archer sees a duck flying directly overhead. The archer shoots an arrow straight up at the duck and misses. The arrow leaves the bow with a vertical velocity of 98 m/s. a.) How long does it remain in the air? b.) The truck maintains a constant speed of 35 m/s and does not change its direction. What horizontal distance does the arrow travel while it is in the air? c.) Where does the arrow finally land (ignore air resistance)?

16.) A diver takes off with a speed of 8.0 m/s from a diving board 3.0 m high, at an angle of 30° above the horizontal. How much later does he strike the water? *1.3 s*

17.) A ball thrown by a boy in the street is caught 2.00 seconds later by another boy on the porch of a house 14.7 m away and 4.9 m above the street level. What was the speed of the ball and the angle above the horizontal at which it was thrown? *14.3 m/s*

18.) A projectile is fired into the air from the top of a 200.0 m cliff above the valley. Its initial velocity is 67 m/s at an angle of 60° with the horizontal. Neglecting air resistance, where does the projectile land? *489.1 m*

19.) A batted baseball leaves the bat at an angle of 37° above the horizontal and with a velocity of 40.0 m/s. The ball is caught by a spectator in the outfield bleachers at a horizontal distance of 128 m from home plate. How far above the level at which the ball was struck was it caught? *17.7 m*

20.) A ball thrown by a boy in the street is caught 2.00 seconds later by another boy on the porch of a house 14.7 m away and 4.9 m above street level. What was the speed of the ball and the angle above the horizontal at which it was thrown? *14.3 m/s*

Circular Motion: Circular motion results when a net force constantly acts at a right angle to the direction in which the mass is moving. This constant net force perpendicular to the motion of the body is called the centripetal force. Both the centripetal acceleration **($a_c = v^2/r$)** and the centripetal force **($F_c = m \cdot a_c = m \cdot v^2/r$)** are always directed toward the center of the circle. If a body travels through the same circle more than once, then circular motion can be an example of periodic motion. **Uniform Circular Motion** occurs when the speed of the object in the circular path is constant. The time it takes the mass to complete one complete circle is known as the period (T). Frequency (f) – on the other hand – is the number of circular paths / cycles / events / vibrations / oscillations completed by the mass in a specific amount of time (i.e. – I watch NHL Hockey 7 times a week is an example of the frequency at which I watch NHL Hockey). If the specific amount of time at which these 'cycles' have taken place in is measured in seconds, then the unit of frequency is Hertz (Hz) which translates to 'per second' or 1/s. Period is the inverse of Frequency – or: **$T = 1/f$.**

21.) A 1.0 kg mass is attached to a string and moves in a horizontal circle with a radius of 1.0 m at a rate of 4.0 rev/s. a.) Find the centripetal acceleration of the mass. b.) Calculate the magnitude of the centripetal force acting on the mass. c.) What is the direction of the centripetal force? *632 m/s^2 632 N Center of Circle*

22.) A 2.0 kg mass is attached to a string and swings in a circle with a radius of 1.0 m parallel to the horizontal. The mass goes around once each 0.8 s. a.) What is its centripetal acceleration? b.) What is the magnitude of the centripetal force acting on the mass? c.) What is the direction of the centripetal force acting on the mass?
62 m/s^2 124 N

23.) It takes a 600 kg racing car 10.0 s to travel at a uniform speed around a circular racetrack of 50.0 m radius. a.) What force must the tires exert against the track to maintain its circular motion? b.) What is the acceleration of the car? c.) How can this car be accelerating if it is traveling at a uniform speed?
11,844 N 19.7 m/s^2

24.) The radius of the moon's orbit about the earth is about 3.6×10^8 m. The moon's period is 2.3×10^6 seconds (27.3 days). Find the centripetal acceleration of the moon. *0.0027 m/s^2*

25.) A coin is placed on a stereo record revolving at 33-1/3 revolutions per minute 10.0 cm from the center of the record. The mass of the coin is 20.0 kg. What is the centripetal force provided by friction to the coin? What is the direction of this force?

Non-Uniform Circular Motion occurs when the speed of the object in a circular path varies. An object in a circular path in a vertical plane changes speed because of the force of gravity. The object accelerates on the downward part of its path and decelerates on the upward part of its path. Its speed is a minimum at the top of the circle and a maximum at the bottom.

26.) A body rests in a pail that is moved in a vertical circle of radius 2.0 m. What is the least speed the body must have so as not to fall out when at the top of the path. *4.4 m/s*

27.) The breaking strength of a string 2.0 m long is 17 N. A 1.0 N body is attached to the string and whirled in a vertical circle. Find the maximum speed that can be given to the body without breaking the string. *17.7 m/s*

28.) A car goes over the crown of a hill whose radius is considered to be the arc of a circle in a vertical plane of radius 40.0 m. With what maximum speed may the car travel and not move tangentially off the road? (The car is at the top of the circle with only the downward force of gravity.) *19.8 m/s*

29.) The human body can safely stand acceleration 9 times that due to gravity – that is – having a force APPLIED to you that is nine times larger than you weigh! With what minimum radius of curvature may a pilot safely turn his plane upward at the end of a dive in which the plane travels at a speed of 220 m/s? *617 m*

30.) The pilot of a dive bomber who has been diving at a velocity of 179 m/s pulls out of the dive by changing his course to a circle in a vertical plane. A.) What is the minimum radius of the circle in order that the acceleration at the lowest point shall not exceed 7 "g's"? B.) How much does an 800 N pilot apparently weigh at the lowest point of the pullout? *545 m* *5600 N*

Placing A Satellite In Orbit: A satellite's weight provides the centripetal force to maintain its circular motion. A satellite's mass does not affect its orbital velocity.

31.) a.) At what speed must a satellite of mass M be launched horizontally at the surface of the earth (radius = 6400 km) if its orbit is to be a circle just grazing the highest mountains? (assume no air resistance) b.) How much time would elapse between successive passes of this imaginary satellite? *7920 m/s* *about 5000 s*

32.) Calculate the velocity at which a satellite must be launched in order to achieve an orbit about the earth. Use 9.8 m/s^2 as the acceleration due to gravity and 6500 km as the radius of the orbit. *7980 m/s*

33.) During the lunar landings, the command module orbited the moon while waiting for the lunar module to return from the moon's surface. If the diameter of the moon is 3570 km and the acceleration of gravity on the moon is 1.6 m/s^2, at what velocity did the command module orbit the moon? *1.7 km/s*

34.) Calculate the velocity at which Viking I orbited Jupiter. The acceleration of gravity on Jupiter is 5800 m/s^2. The diameter of the planet is 142,200 km. *645 km/s*