

### Problem Set 3

(due Thursday, January 20)

1. A baseball leaves a pitcher's hand horizontally at a speed of 100 miles per hour. The distance to the batter is 60 ft. (a) How long does it take for the ball to travel the first 30 ft horizontally? The second 30 ft? (b) How far does the ball fall vertically during the first 30 ft of its horizontal travel? (c) During the second 30 ft? (d) Why aren't the answers to (b) and (c) equal? (You may ignore air resistance.)
2. Abel Knaebble, professional stunt-man and amateur physicist, wants to jump the Grand Canyon with his new super-streamlined motorcycle (which is completely immune to the effects of air-resistance). He simply plans to ride his motorcycle horizontally off the north rim, fast enough to land safely on the south rim, which is 320 meters lower. The width of the canyon at the point of his jump is 8 km, the depth of the canyon is 1.6 km, and the mass of the fully loaded cycle (including Abel himself) is 330 kg. How fast does he need to ride in order to make the jump?
3. A basketball player launches a freethrow at an angle of  $55^\circ$  above the horizontal, from a point 7.0 ft above the floor and 13 ft horizontally from the basket. The basket is 10 ft above the floor. With what initial speed should the ball be thrown in order to make the basket?
4. Suppose you throw a rock off a cliff at an angle of  $35^\circ$  above the horizontal. The initial speed of the rock is 15 m/s, and the point of release is 30 m above the valley bottom below. (a) How long does it take for the rock to reach the highest point in its path? (b) How high does it go before it starts to fall? (c) How much time passes before the rock hits the ground?
5. Wile E. Coyote is once again chasing the elusive Roadrunner, assisted by a pair of Acme jet-powered roller skates which provide a constant horizontal acceleration of  $15 \text{ m/s}^2$ . The bird is almost in his claws when they both reach the brink of a cliff, where the Roadrunner quickly turns to the side while the Coyote goes over the edge with a horizontal velocity of 40 m/s. The height of the cliff is 300 m. (a) How far does the coyote travel horizontally before hitting the ground? (b) What is his speed just before impact?
6. An astronaut in training is rotated in a horizontal centrifuge at a radius of 5.0 m. (a) What is the astronaut's speed if the magnitude of her acceleration vector is  $7.0g$ ? (b) How many revolutions per minute are required for this speed and acceleration? (c) What is the period of revolution, that is, the time to go around once?
7. (a) What is the acceleration vector of an object sitting at Earth's equator, due to the daily rotation of the Earth? (b) What would the Earth's period of rotation have to be, for objects at the equator to have an acceleration of magnitude  $g$ ?
8. A boat is traveling upstream at 14 km/hr with respect to the water in a river. The water is flowing at 9 km/hr with respect to the ground. (a) What is the velocity of

the boat with respect to the ground? (b) A child on the boat walks from front to rear at 6 km/hr with respect to the boat. What is the child's velocity with respect to the ground?

9. A transcontinental flight of 2700 miles is scheduled to take 50 minutes longer westward than eastward. The speed of the plane is 600 miles per hour with respect to the air. If the wind blows as scheduled, how fast is it blowing, and in which direction? (Hint: This is a hard problem so don't try to get the answer in one or two steps. Define symbols for all known and unknown quantities, then write all the equations you can to relate these quantities to each other, before you try to solve the equations.)
10. Consider three situations, in which your acceleration vector points (1) to the right, (2) forward, and (3) backward. Your velocity points forward in all three cases. In which situation(s) is your speed (a) increasing, (b) decreasing, and (c) not changing?
11. The two dots below represent the positions of an object at two different times (time 1 and time 3), 1/10 second apart. (The position at time 2, halfway between, is unknown but presumably close to the midpoint between the two dots.) (a) Using a scale in which 1 cm on paper represents a velocity of 10 cm/s, carefully draw the velocity vector of the object at time 2. (b) The acceleration of the object at time 3 is  $3.0 \text{ m/s}^2$ , directly down on the diagram. Knowing this, carefully construct the vector  $\Delta\vec{v}_{24}$ , the change in the object's velocity between time 2 and time 4. (Time 4 is 1/20 second later than time 3.) (c) Carefully draw the velocity vector of the object at time 4. (d) Carefully find and mark the position of the object at time 5, which is 1/10 second after time 3. [Note: If you're patient enough, you can repeat this procedure to construct the entire trajectory of an object, arbitrarily far into the future, working in little steps. All you need is a way of finding out the object's acceleration at any time and place (which we'll learn how to do in a few days). When the acceleration of an object is not constant, this step-by-step procedure is often the only way to predict the object's motion. Fortunately, computers are very patient.]

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## Study Guide

Fundamental definitions:

$$\vec{v} = \frac{\Delta \vec{r}}{\Delta t} = \frac{\vec{r}_f - \vec{r}_i}{t_f - t_i} \quad (\text{definition of velocity})$$

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} \quad (\text{definition of acceleration})$$

If the acceleration vector is constant (in both magnitude and direction), then

$$v_x(t) = v_x(0) + a_x t$$

$$x(t) = x(0) + v_x(0) \cdot t + \frac{1}{2} a_x t^2$$

(and similarly for  $y, z$ )

For a freely flying projectile,  $\vec{a}$  points straight down and has magnitude  $g = 9.8 \text{ m/s}^2$ .

For circular motion at constant speed,  $\vec{a}$  always points directly toward the center of the circle and has magnitude

$$|\vec{a}| = \frac{|\vec{v}|^2}{R}$$

where  $R$  is the radius of the circle.

You should understand the concept of a “frame of reference” and how to transform an object’s velocity from one frame of reference to another (when the frames are moving with respect to each other).