Name: ____ Hr: ________

Unit 1 – Free-Fall & Further Practice with Uniform Acceleration Problems

Vocabulary **Free Fall:** the movement of an object in response to a gravitational attraction

When an object is released, it falls toward the earth due to the gravitational attraction the earth provides. As the object falls, it will accelerate at a constant rate of 9.8 m/s^2 regardless of its mass. However, to make calculations more expedient and easier to do without a calculator, this number is often written as g = 10 m/s^2.

There are many different ways to solve free fall exercises. The sign convention you use is up to you. In the examples below, the downward direction will be positive, and anything falling downward will be written with a positive velocity and position. Anything moving upward from an initial position would then need to be represented with a negative velocity and negative position. Remember: Whichever sign convention used, the acceleration of an object due to gravity, g, will *always be down*, regardless of which direction the object is moving.

Review of Equations

When an object is not accelerating, or when an average velocity is known, the following equation can be used.

$v_{avg} = \frac{d}{t}$

When an object is accelerating, that acceleration is defined by the following equation:

$a = \frac{v_f - v_i}{t}$

This equation is often rewritten in terms of velocity as

$v_f = v_i + a \cdot t$

Average velocity can then be written in terms of the initial velocity, v_i, and the final velocity v_f.

$v_{avg} = \frac{v_i + v_f}{2}$

By substitution, it can be shown that the displacement of an accelerating object in a given amount of time is written as

$d = v_i t + \frac{1}{2}at^2$

Also by substitution, it can be shown that the relationship between displacement and velocity of an accelerating object can be written as

$v_f^2 = v_i^2 + 2ad$

Putting it all together, we have **five fabulous formulas** of motion.

[1] $v_{avg} = \frac{d}{t}$

[2] $a = \frac{v_f - v_i}{t}$

[3] $v_{avg} = \frac{v_i + v_f}{2}$

[4] $d = v_i t + \frac{1}{2}at^2$

[5] $v_f^2 = v_i^2 + 2ad$

Helpful Hints The equation used in any particular problem will be chosen because of its usefulness or the ease with which the problem can be solved based on the information given in the problem. For example, if the velocity is needed for an object accelerating for a given time, equation [2] would be useful. If the displacement of an object is needed when it changes velocity from some initial to final velocity, equation [5] would be used. Remember that you cannot solve an equation when there are two unknowns.

Regardless of what quantity you are solving for, it is best practice to rearrange the equation being used prior to substituting quantities with their units. This practice will save time & work, help to see relationships between quantities and how units cancel, and reduce errors.

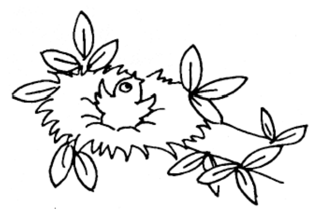
Note that the term 'g' is used for the acceleration due to gravity ($g = 9.8\ m/s^2$ downward). If a problem involves something freely falling (moving up or down), the acceleration 'a' is replaced by 'g' with the value of $9.8\ m/s^2$.

It is common to neglect air resistance in most free fall exercises, although in real life, air resistance is a factor that must be taken into account.

Finally, unless otherwise stated, it is also assumed that when an object is dropped or begins to fall, its initial velocity is zero.

Solved Examples

Example 1: A baby blue jay sits in a tall tree awaiting the arrival of its dinner. As the mother lands on the nest, she drops a worm toward the hungry chick's mouth, but the worm misses and falls from the nest to the ground in 1.50 s. how high up is the nest?



Given: $v_i = 0\ m/s$
$g = 9.8\ m/s^2$
$t = 1.50\ s$
Unknown: $d = ?$
Original equation: $d = v_it + \frac{1}{2}at^2$
Solve: $d = v_it + \frac{1}{2}gt^2 = (0\ m/s)(1.50\ s) + \frac{1}{2}(9.8\ m/s^2)(1.50\ s)^2 = 11.0\ m$

Example 2: King Kong carries Fay Wray up the 321-m-tall Empire State Building. At the top of the skyscraper, Fay Wray's shoe falls from her foot. How fast will the shoe be moving when it hits the ground?

Given: $v_i = 0\ m/s$
$d = 321\ m$
$g = 9.8\ m/s^2$
Unknown: $v_f = ?$
Original Equation: $v_f^2 = v_i^2 + 2ad$
Solve: $v_f = \sqrt{v_i^2 + 2gd} = \sqrt{(0\ m/s)^2 + 2(9.8\ m/s^2)(321\ m)} = 79.3\ m/s$

Example 3: The Steamboat Geyser in Yellowstone National Park, Wyoming is capable of shooting its hot water up from the ground with a speed of 48.0 m/s. How high can the geyser shoot? Solution: Remember, the geyser is shooting **up**. Therefore it must have a negative initial velocity.

Given: $v_i = -48.0$ m/s
$v_f = 0$ m/s
$g = 9.8$ m/s^2
Unknown: $d = ?$
Original equation: $v_f^2 = v_i^2 + 2ad$
Solve: $d = \frac{v_f^2 - v_i^2}{2g} = \frac{(0 \text{ m/s})^2 - (-48.0 \text{ m/s})^2}{2(9.8 \text{ m/s}^2)} = -115 \text{ m}$

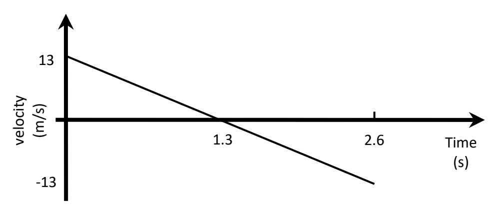
As you might expect, the final answer has a negative displacement. This means that the position of the water at its highest point (when $v_f = 0$ m/s) is above the ground.

Example 4: A giraffe, which stands 6.00 m tall, bites a branch off a tree to chew on the leaves, and he lets the branch fall to the ground. How long does it take the branch to hit the ground?

Given: $d = 6.00$ m
$v_i = 0$ m/s
$g = 9.8$ m/s^2
Unknown: $t = ?$
Original equation: $d = v_i t + \frac{1}{2}at^2$
Solve: $t = \sqrt{\frac{2d}{g}} = \sqrt{\frac{2(6.00 \text{ m})}{9.8 \text{ m/s}^2}} = 1.11 \text{ s}$

Example 5: Mr. Konichek, when he finds out he has just won the Crystal Apple Award for excellence in teaching, throws his red pen up into the air at 13 m/s. How long is the pen in the air? Construct a graph showing the velocity of the pen from when he throws it to when it returns to his hand. For this problem, we will say that up is positive, and say that $g = -10$ m/s^2.

Given: $v_i = 13$ m/s
$v_f = -13$ m/s
$g = -10$ m/s^2
Unknown: $t = ?$
Original Equation: $a = \frac{v_f - v_i}{t}$
Solve: $t = \frac{v_f - v_i}{g} = \frac{(-13 \text{ m/s}) - (13 \text{ m/s})}{-10 \text{ m/s}^2} = 2.6 \text{ s}$



Exercises: Show ALL work, including formulas, plugged-in numbers, units, and circled answers!

1: Billy, a mountain goat, is rock climbing on his favorite slope one sunny spring morning when a rock comes hurtling toward him from a ledge 50.0 m above. Billy ducks and avoids injury. a) How fast is the rock traveling when it passes Billy? b) How does this speed compare to that of a car traveling down the highway at a speed limit of 55 mph?

2: Reverend Northwick climbs to the church belfry one morning to determine the height of the church. From an outside balcony he drops a book and observes it takes 2.00 s to strike the ground below. a) How high is the balcony of the church belfry? b) Why would it be difficult to determine the height of the belfry balcony if the Reverend dropped only one page out of the book?

3: a) How long is Tina, a ballerina, in the air when she leaps straight up with a speed of 1.8 m/s? b) Construct a graph of velocity vs. time for Tina while she is in the air.

4: In order to open the clam it catches, a seagull will drop the clam repeatedly onto a hard surface from high in the air until the shell cracks. If a seagull flies to a height of 25 m, how long will the clam take to fall?

5: A unique type of basketball is played on the planet Zarth. During the game, a player flies above the basket and drops the ball in from a height of 12 m. If the ball takes 5.0 s to fall, find the acceleration due to gravity on Zarth.

6: A race car's velocity increases from 4 m/s to 88 m/s over a 4 second time interval. a) What is its acceleration? b) How far does the car travel during this time? c) Construct a graph of velocity vs. time.

7: A drag racer accelerates uniformly from rest, traveling 400 meters in 6.5 seconds. a) What is the car's final velocity? b) What is the car's average velocity? c) Construct a graph of position vs. time.