Name: ____ Date: __________________

Freefall PreLab

Instructions: Prepare for this first lab experience by answering the following questions. Note that this is a PreLab, and that PreLabs must be turned in at the start of the lab period. Time will not be given in lab to perform PreLab activities; after the start of lab activities PreLabs will not be accepted. In the *Student Lab Handbook* (see http://www.phy.ilstu.edu/slh/), read the following sections and then answer the questions below. Restrict your responses only to the space provided; think carefully before you write.

- *Dimensional Analysis*
- *Error Propagation*

1. Conduct a dimensional analysis for the function $s = f(a, t)$ to find the expected form of the relationship. In this relationship distance, *s*, is expressed in meters, where acceleration, *a*, is expressed in meters per second squared, and time, *t*, is expressed in seconds. Your final equality should contain only the variables *s*, *a*, and *t*, and the constant of proportionality *k*.

2. Given the relationship $F = ma$, show that a small error in the value of mass equal to Δm and a small error in the value of acceleration equal to Δa, results in an error of force, ΔF, equal to $m\Delta a + a\Delta m$.

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Freefall Lab Guidelines

Objectives: At the conclusion of this lab activity, the student should be able to clearly and accurately:

- collect and interpret data relating to freefall.
- linearize data using *Graphical Analysis.*
- create a physical model for the relationship between distance and time.
- perform dimensional analysis based on the relationship $s = f(a, t)$.
- find the acceleration due to gravity.
- demonstrate error propagation using instrumental error as a basis.
- show that the measured value of the acceleration due to gravity falls within a predictable range resulting from instrumental error.
- determine whether or not the mass of a falling ball bearing affects the rate of acceleration.

Task I. Determine the relationship between distance and time of fall.

a. To get an intuitive "feel" for the relationship between the time and distance of fall for an object, drop one of the metal balls provided to you paying particular attention to the qualitative relationship between time and distance. Drop the same ball from great and small heights and make a mental measure of the time required for the fall.

Q1. What is the approximate relationship between distance fallen and time? (Based on your observations alone, give a qualitative relationship. e.g., As distance increases…)

b. If you have not done so or don't recall your results from the PreLab, conduct a dimensional analysis for the function $s = f(a, t)$ where distance, s, is expressed in meters, where acceleration, a, is expressed in meters per second squared, and time, t, is expressed in seconds.

Q2. What is the expected nature of the relationship between s, a, and t based on your dimensional analysis in PreLab? Your equality should contain only the variables s, a, and t, and the constant of proportionality k.

c. Using the freefall apparatus provided, determine the actual relationship between the height of a ball drop (same ball each time) and the time required for it to hit the switch at the end of its fall. Repeatedly collect and average appropriate data and create a suitable graph of distance versus time. Plot the <u>independent variable</u> on the y-axis. Be certain to label axes with variables and units. Use as wide a range of data as possible. Label this graph "**Graph 1**." Print both data table and the graph using landscape view on one sheet of paper.

d. Examine Graph 1 carefully. Determine the approximate nature of the form. Using *Graphical Analysis'* "column formula", linearize your graph so that your data points appear in a straight line. Using an appropriate regression equation, create a physical interpretation for this relationship (e.g., the shown regression line *must* pass through the origin). Label this graph "**Graph 2**." Print both data table and the graph using landscape view on one sheet of paper.

Q3. What is the model of the physical relationship between distance and time in the freefall situation assuming that $t = 0$ when $s = 0$?

Q4. What value did you get for your slope in the above model of the physical relationship?

Q5. What are the units on the above slope?

Task II. Determine the acceleration due to gravity.

a. Note that the units on the slope given in response to Q5 are those of acceleration. The value of the constant, however, is not that of the acceleration due to gravity. According to theoretical considerations, the true form of the relationship between distance, time, and acceleration due to gravity is the following:

$$s = \frac{1}{2}gt^2$$

b. Given the following relationship, $k = \frac{1}{2}g$, find the value of g.

Q6. What value and units did you arrive at experimentally for the acceleration due to gravity?

Q7. Assuming that the actual local value of the acceleration due to gravity is $9.81 m/s^2$, what is the percent error in your experimental determination?

Task III. Error in determination of the acceleration due to gravity.

a. Your value of the acceleration due to gravity probably wasn't very precise for a variety of reasons, not the least of which is <u>instrumental error</u>. That is, your measurements of the time and distance of fall were probably no better than the accuracy of the instruments used to measure them – the freefall apparatus and the meter stick.

b. Using the theoretical formula under Task II, part a, take a series of measurements at a *fixed* distance. Do these six times. Record your data in the table found on the Answer Sheet.

Distance of fall, *s*.	**Time of fall, *t*.**		
	Obsv 1:	Obsv 3:	Obsv 5:
	Obsv 2:	Obsv 4:	Obsv 6:

Q8. What is the <u>absolute uncertainty</u> due to instrumental error in the value of s (also known as Δs)?

Q9. What is mean value of t?

Q10. What is the <u>absolute uncertainty</u> due to instrumental error in the mean value of t (also known as Δt)?

Q11. Based upon the above mean data, what is the calculated value of g?

c. Determine whether or not the absolute uncertainties resulting from instrumental error can account for the fact that your experimentally determined value of g differs from the given value of 9.81 m/s^2. To do this, conduct a study of error propagation.

Q12. Given an absolute error in s of Δs, and an absolute error in t of Δt, prove that the *maximum* error in the expected value of g, Δg, is given by the following relationship. Show all work starting with $s = \frac{1}{2}at^2$.

$$\Delta g_{max} = g\left(\frac{\Delta s}{s}\right) + 2\frac{\Delta t}{t}$$

Q13. Given your mean and calculated values of *s*, *g*, *t*, what is the expected maximum error in *g*?

Q14. Given the maximum absolute error in *g* from Q12, what is the expected range of *g* (i.e., $g + \Delta g$ to $g - \Delta g$) based on your experiment?

Q15. Does your measured value of *g* based on multiple observations at one height fall within this range? Yes or no? If no, explain what sort of errors outside of instrumental error might account for the deviation.

Task IV. Rate of acceleration as a function of mass

a. We must now address the question of how the mass of the falling ball bearing affects its acceleration. Before you begin experimenting, make a prediction. For all intents and purposes, in this experiment with the small speeds and the relatively aerodynamic form of the ball bearing, we can neglect wind resistance.

Note that the mass of the smaller ball bearing is approximately 16*g* whereas the mass of the larger ball bearing is on the order of 28*g*.

Q16. How will the different masses of the two ball bearings affect the rate of acceleration of each?

Q17. If you feel that the bearings will fall at the same rate, explain why; if you believe that the ball bearings will fall at different rates, state which will fall faster and why.

b. Using the same general approach as before, determine experimentally whether or not the mass of a falling ball bearing has a significant effect (say greater than a few percentage points difference) on the rate of acceleration.

Q18. What are the accelerations of the two ball bearings? Give the acceleration of the less massive ball bearing (~16*g*) first and the more massive ball bearing (~28*g*) second.

Q19. What is the percent difference between the acceleration of the two ball bearings?

Q20. Does the mass of the ball bearing appear to make a significant difference on the rate of their fall under the specified conditions?