Name: ____________________
Student ID# _______________
Date: ________ Time: _______
Lab Instructor: _____________

Physics 104 Lab Exam – SAMPLE (with answers)

Instructions: *Work individually to complete each exercise to the best of your ability, show all your work, and clearly explain your answers in the spaces provided or on the back of these papers. Be sure to record all measurements (in SI units) and show all calculations. For items that require a numerical result, write your answer as you would for a formal lab report, including a meaningful* ***label*** *to identify a value. Your answer will be graded based on the* ***accuracy*** *of your result and proper reporting of* ***uncertainty***, ***significant figures***, *and* ***units***. *Once the lab exam begins, you are not permitted to receive any assistance from your TA or other students. However, you may use your lab manual, graded lab reports, notes, and textbook as resources for this exam. The questions may be answered in any order, so adjust your work according to the availability of the lab equipment, and* ***do not spend more than 20 minutes at any one lab exam station*** *so that every student has an equal opportunity to complete the exercises.*

Honor Pledge: ***All work presented here is my own.*** ______________________________

1. A simple pendulum is known to have a period of oscillation $T = 1.55$ s. Student A uses a digital stopwatch to measure the total time for 5 oscillations and calculates an average period $T = 1.25$ s. Student B uses an analog wristwatch and the same procedure to calculate an average period for the 5 oscillations and finds $T = 1.6$ s.

a) Which student made the more accurate measurement? Explain.

The measurement made by ***Student B*** *is closer to the known value and is therefore more accurate.*

b) Which measurement is more precise? Explain.

The measurement made by ***Student A*** *is reported with more digits and is therefore more precise.*

c) What is the most likely source of error that could account for the difference in the results?

Although the difference in period measurements is only 0.3 s, the original timing measurements must have differed by 5 times this amount since we are told that the average period was calculated from the total time for 5 oscillations. So even though reaction time (typically ~0.2 s) is a likely source of error, this would not explain the discrepancy of approximately 1.5 s, or about one period. Therefore, the most likely source of error is that Student A mistakenly measured only 4 oscillations instead of 5.
This example shows that a more precise measurement is not always more accurate.

2. The number of significant figures reported for a measured value suggests a certain degree of precision. What is the relative uncertainty implied by the following numbers?

a) 0.30 implies an uncertainty of ± <u>*3*</u> % *(possibly 2% from rounding error)*

b) 9.8 implies an uncertainty of ± <u>*1*</u> % *(possibly 0.5% from rounding error)*

c) 52 implies an uncertainty of ± <u>*2*</u> % *(possibly 1% from rounding error)*

d) 0.503 implies an uncertainty of ± <u>*0.2*</u> % *(possibly 0.1% from rounding error)*

(Note: The relative uncertainty can be different for the same number of significant figures.)

3. A student uses a protractor to measure an angle to be $\theta = 85° \pm 1°$. What should she report for $\sin\theta$?

<u>*sin(θ) = 0.996 ± 0.002*</u>
(The uncertainty can be determined from either the max/min method or propagation of error.)

4. Use any available equipment to find the radius of a tennis ball as accurately as possible. Explain the procedure you used.

R = (3.2 ± 0.1) cm *Half the diameter measured with a Vernier caliper: D = (6.4 ± 0.2) cm*

(Note that the uncertainty of this measurement is determined not by the instrument resolution of the caliper, but by the imprecise definition of the ball's diameter since it is fuzzy.)

5. Use any available equipment to measure the acceleration of a glider on an inclined air track as accurately as possible. Clearly identify the measurements you make and the procedure you use.

A number of different procedures could be used to find the acceleration. The simplest is to release the glider from rest and use a stopwatch or photogate to measure the average time ***t*** *for it to travel a distance* ***x*** *and use the constant acceleration equation:* $x = 0.5at^2$

$x = 1.500 \pm 0.005$ m, t(s) = 1.12, 1.06, 1.19, 1.15, 1.08 so, $\langle t \rangle = 1.12$ s with SE = 0.02 s

Therefore, $a = (2.4 \pm 0.1)\ \mathrm{m/s^2}$

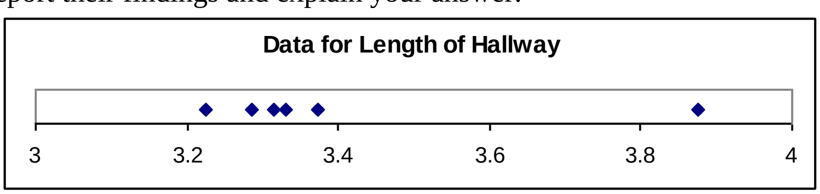
6. Use a Vernier caliper and a mass balance to find the density of a nickel coin. Is this measured density value consistent with the density of pure nickel? ($\rho_{nickel} = 8.912\ \mathrm{g/cm^3}$). From your measured density, can you determine whether nickel coins are made of pure nickel? Which of your measurements contributes the most uncertainty to your measured density value? (Equipment provided: 10 nickel coins, Vernier caliper, balance with 0.1 g resolution)

Mass = 4.99 ± 0.01 g (± 0.2%)
Diameter = 2.12 ± 0.01 cm (± 0.5%)
Thickness = 0.16 ± 0.02 cm (± 12.5%)
Volume = 0.56 ± 0.07 cm^3
Density = 8.85 ± 1.11 g/cm^3 *(± 12.5%)*

Even though the density of the nickel coin (8.9 ± 1.1 g/cm^3*) matches the density of pure nickel, we can not conclude that the coin is made of pure nickel because any number of metal alloys could yield an equivalent density. In fact, nickel coins are 25% nickel and 75% copper (according to the U.S. Mint).*

The uncertainty of the thickness of the coin (due to its uneven profile) is by far the most significant factor in the overall uncertainty of the density.

7. A group of students are told to use a meter stick to find the length of a hallway. They take 6 independent measurements as follows: 3.314 m, 3.225 m, 3.332 m, 3.875 m, 3.374 m, 3.285 m. Show how they should report their findings and explain your answer.



The measurement of 3.875 m is an extreme outlier (it is 10 standard deviations from the other values) and is most likely a mistake. The best estimate of the length is found from the average of the other 5 values (3.31 m), which agrees with the median value of all 6 data points (3.32 m) within the uncertainty determined as the standard error of the 5 "good" data values.

Best estimate of length of hallway = (3.31 ± 0.02) m , but (3.3 ± 0.1) m would also be reasonable.

8. In an investigation to empirically determine the value of π, a student measures the circumference and diameter of several circles of varying size and uses Excel to make a linear plot of circumference versus diameter (both in units of meters). A linear regression fit yields the result of: $y = 3.1527x - 0.0502$, with $R^2 = 0.9967$ for the 5 data points plotted. How should this student report the final result? Does the empirical ratio of C/D agree with the accepted value of π?

C/D = *3.15 ± 0.10* *(where the uncertainty is the standard error in the slope, found from* R^2*)*

Yes, this empirical value agrees with π since 3.1416 lies within the experimental uncertainty range.

9. A student performs a simple experiment to find the average acceleration of a falling object. He drops a baseball from a building and uses a string and meter stick to measure the height the ball was dropped. He uses a stopwatch to find an average time of fall for 3 trials from the same height and reports the following data: $h = 5.25 \pm 0.15$ m, $t = 1.14 \pm 0.06$ s.

a) Use the equation $a = 2h/t^2$ to determine the average acceleration and its uncertainty.

$$a = \frac{2h}{t^2} = \frac{2(5.25 \pm 0.15 \text{ m})}{(1.14 \pm 0.06 \text{ s})^2} = 8.1 \pm 0.9 \text{ m/s}^2$$

Explanation: The uncertainty in ***a*** *can be approximated using the upper/lower bound method, which yields 8 ± 1 m/s*^{2}*, but applying the propagation of uncertainty equation gives a more accurate estimate and more insight into the relative contribution of each term (see part* **c** *below). With this latter approach , we find that the relative uncertainty for the height is ± 2.9% and for the time is ± 2(5.3%), so that the combined relative uncertainty (adding in quadrature) is ± 10.9%. This yields an average acceleration of 8.08 ± 0.88 m/s*^{2}*, which when properly rounded is 8.1 ± 0.9 m/s*^{2}*.*

b) Comment on the accuracy of the acceleration result. Do you think the student made any mistakes?
While it is impossible to know if the student's result is accurate without knowing detailed information about the drag factor, it is plausible that the average acceleration of the falling ball is about 0.8 g over the fall distance of about 3 stories. Since the objective of the experiment was to find the average acceleration of a falling object (as opposed to measuring g), the systematic effect of the air resistance is not an error, and just because the average acceleration is significantly less than g does not necessarily indicate that a procedural mistake was made by the student. However, if the acceleration value was significantly greater than g, then we could claim that the student made a mistake.

c) What one suggestion would you tell this student to improve the experimental result? Please explain.
The uncertainty in the time measurement contributes the most to the overall uncertainty in the average acceleration (by a factor of about 3 times the height measurement), so improving the precision of this measurement (with more trials or an automated timing device) will most significantly reduce the uncertainty of the result, and hopefully give a more accurate value.

10. Describe a procedure you could use to determine the coefficient of friction between two objects.
The coefficient of kinetic friction between two objects (like a wooden block and a table) could be determined by using a spring scale or force probe to measure the force required to pull the object across a horizontal surface at constant speed so that the tension equals the frictional force. Then the coefficient of friction can be calculated by dividing the frictional force by the normal force, which in this case is equal to the magnitude of the object's weight. The coefficient of static friction is determined in a similar fashion from the maximum tension force that is needed to initially get the object moving.

An alternative method is to place the object on an inclined plane and increase the angle made with the horizontal until the object first starts to slide (for static friction) or the slightly lower angle at which the object slides with constant speed (for kinetic friction). The coefficient of friction can then be calculated from these two angles by the simple equation: $\mu = \tan\theta$