Appendix E: Sample Lab Report

STATEMENT OF THE PROBLEM

The experimental problem was to determine if the mass of an object affects the time it takes for the object to fall. We want to know this because we are part of a team building a single machine versatile enough to launch tennis balls, baseballs and softballs for sports practice. To properly design the machine, we need to know if the different balls will fall at different rates since the user must be able to aim the balls accurately.

PREDICTION

To predict the answer to this question, we relied on our experience of the behavior of everyday objects. We know that when you let go of something, it will fall because it is pulled down by the gravitational force. That force, also known as the object's weight, increases as the mass of the object increases. F=mg. Since the object starts out at rest, its velocity changes. That means it accelerates. Thus the force causes the object to accelerate. Since the force increases with the object's mass, the acceleration also increases with the object's mass.

To determine how that force affects the time for the object to fall, we used relationships among the object's acceleration, velocity, distance, and time. From experience, we know that if one object has a larger acceleration than another one and starts off with the same velocity, then the object with the larger acceleration will take a shorter time to fall the same distance. This can be shown from the definition of average acceleration. In this case, since the gravitational force on the object does not change during the fall, the acceleration is constant. For constant acceleration, the average acceleration equals the instantaneous acceleration.

The definition of average acceleration is: $a = (v_f - v_i)/\Delta t$.

Just dropping the ball means that the initial velocity, v_i, is 0, so $a = v_f/\Delta t$. Solving for time gives:

$$\Delta t = v_f/a.$$

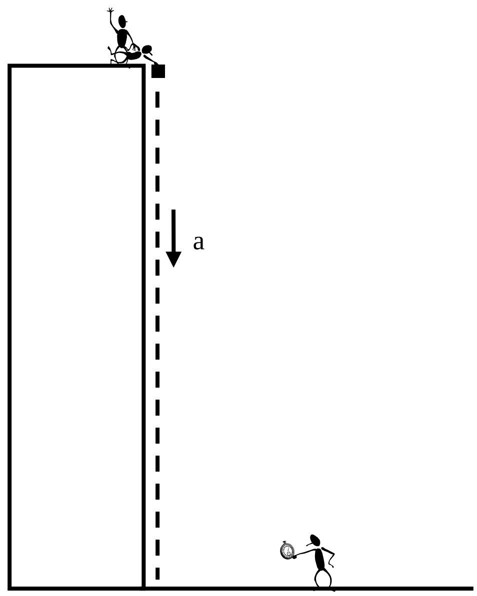
This equation says that a large acceleration gives a small time since 1/a would be small if a is large.

Thus we expect that balls with more mass, will have a larger acceleration and take less time to fall a given distance. This corresponds with our experience that a coin will hit the floor before a piece of paper when both are dropped from the same height.

EXPERIMENT AND RESULTS

We started by finding an open space on the roof of the physics building where we could safely drop the objects and see when and where they hit the ground. We used the southwest corner of the physics building. The person who timed the fall of the object was on the ground so they could observe when the object landed. The objects we used were laboratory masses of 10, 20, 50, and 100 grams. We also decided to drop the dime and quarter sideways to try to minimize the air resistance to compare with the laboratory masses.

A person on the roof dropped the objects while another person standing next to her signaled the drop to the person on the ground by lowering their hand. To ensure all objects were dropped from the same height, the person dropping the objects lay on the roof and released each object from the same height as the roof. The person on the ground started his stopwatch when he saw the hand drop and stopped it when the object hit the ground. A picture of the experiment is shown below. Because of the uncertainty of starting and stopping the stopwatch as well as dropping to object from exactly the same place, we repeated the measurement six times for each object to get an average.



We estimated that each object was dropped from the same height, with an uncertainty of a centimeter. We determined the uncertainty in the time by using the average deviation of six drop times for each object. It should be noted that the value of the average time for each drop is higher than the actual time due to the reaction time of the person using the stopwatch. We tried to increase our accuracy by having the person with the best reaction time do the timing. This reaction time was determined by how fast each of us could start and stop the stopwatch. The person with the best average time (around 0.09 seconds) was appointed to use the stopwatch. The time we recorded was the stopwatch time minus that average reaction time. The results are listed in Table 1 and graphed in Graph 1.

CONCLUSIONS

By looking at Graph 1, we saw no pattern between the mass of the object and the time it took to fall. Comparing the uncertainties of the times on Graph 1 we see that they overlap between 1.71 seconds and 1.73 seconds. Hence we must conclude that all of our objects took the same amount of time to fall. This disagreed with our initial prediction of heavier objects falling faster.

Reviewing our prediction we found two mistakes. First, although the gravitational force depends on the mass of an object, the acceleration caused by that force depends on both the force and the mass of the object, $F = ma$. Thus, $a=F/m$. Since the force depends on the mass of the object, the mass actually cancels out so the acceleration is independent of the mass.

$a=F/m$

$a=mg/m$

$a = g$ which does not depend on the mass in agreement with our data.

The second mistake in our prediction did not actually affect the answer but it was wrong anyway. We thought that $\Delta t = v_f/a$ meant that a large acceleration gives a small time since $1/a$ would be small if a were large. That is incorrect because the final velocity, v_f, also depends on the acceleration. A larger acceleration gives a larger v_f. Realizing this, Δt is the result of taking a number that increases and dividing by a number that also increases. Thus Δt could increase but it could also stay the same or even decrease with acceleration according to this equation.

We cannot use that equation to conclude that a larger acceleration would cause the object to fall in a smaller time. To draw such a conclusion, we need an equation in which only the acceleration and time are changing. To do this we can use:

$a = (v_f - v_i)/\Delta t$ the definition of average acceleration (with $a_{av} = a$)

$v_{av} = (v_f + v_i)/2$ if the acceleration is constant

$v_{av} = (y_f - y_i)/\Delta t$ the definition of average velocity

For a constant acceleration, an initial velocity of zero, and taking the initial position, y_i, as zero, these equations become:

$a = v_f/\Delta t$ the definition of average acceleration (with $a_{av} = a$)

$v_{av} = v_f/2$ if the acceleration is constant

$v_{av} = y_f/\Delta t$ the definition of average velocity

Now we need to find Δt, the time to fall, in terms of a, the constant acceleration of the object, and quantities that do not change if the acceleration changes. The quantity that does not change is y_f, the height of the building. We need an equation for Δt in terms of a and y_f.

		unknowns
Find Δt		Δt
$a = v_f/\Delta t$	[1]	v_f
Find v_f		
$v_{av} = v_f/2$	[2]	v_{av}
Find v_{av}		
$v_{av} = y_f/\Delta t$	[3]	

3 unknowns and 3 equations, OK to solve. The procedure is as follows:

Solve [3] for v_{av} and put into [2].

Solve [2] for v_f and put into [1].

Solve [1] for Δt.

Executing the plan:

$y_f/\Delta t = v_f/2$

$2y_f/\Delta t = v_f$ into [1]

$a = (2y_f/\Delta t) / \Delta t$

$a\,\Delta t = (2y_f/\Delta t)$

$a\,(\Delta t)^2 = 2y_f$

$(\Delta t)^2 = 2y_f / a$

$$\boxed{\Delta t = \sqrt{\frac{2y_f}{a}}}$$

Now this equation shows that if the acceleration is larger, the time to fall is smaller since the height of the building does not change when different objects are dropped.

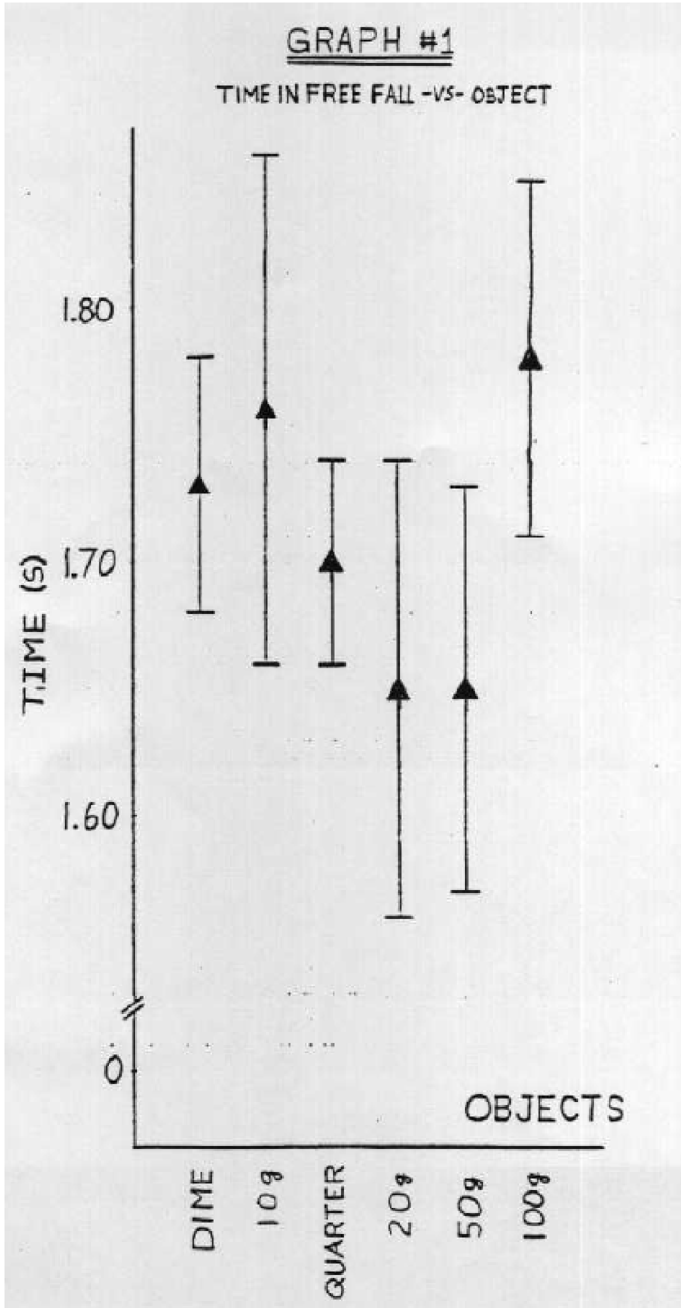
Now that we have shown that the results of our measurements are consistent with physics as we understand it, how do we explain our experience? We know that if we drop a coin and a piece of paper at the same time, the coin hits the ground first. We have shown that the reason cannot be because of their difference in weight. In this case, unlike our experiment, the air resistance is not negligible for the paper. There are two forces on it, the gravitational force that depends on its mass downward and the air resistance upwards. As we have shown, if the force depends on an object's mass then the falling time does not depend on the mass. That means that air resistance must not depend on the mass of an object. This is reasonable since if you wad a piece of paper up it has the same mass yet takes less time to fall.

Finally to check that our measurements, procedures, and calculations were correct, we computed the height of the building with 1.72 seconds as our time using $\Delta t = \sqrt{\frac{2y_f}{a}}$. We found the height of the building to be 14.5 meters or 47.6 feet. This agreed with our estimation that it was about 48 feet.

If air resistance is indeed negligible, no special alterations are necessary for constructing our tennis, baseball and softball launcher. All masses take the same amount of time to fall to the ground if they start from the same height with the same initial velocity. However, the amount of air resistance, especially for the lighter tennis ball, still needs to be checked before finalizing a design.

TABLE 1: Objects and Times in Free Fall

Object & Trial	Time (s)	Deviation From Average (s)	Object & Trial	Time (s)	Deviation From Average (s)
Dime 1	1.73	0.00	20 g 1	1.67	-0.02
2	1.71	0.02	2	1.59	0.06
3	1.80	-0.07	3	1.59	0.06
4	1.71	0.02	4	1.75	-0.10
5	1.70	0.03	5	1.57	0.07
6	1.75	-0.02	6	1.72	-0.07
Average	**1.73**	**0.05**	**Average**	**1.65**	**0.09**
Quarter 1	1.72	-0.02	50 g 1	1.72	-0.07
2	1.73	-0.03	2	1.61	0.04
3	1.70	0.00	3	1.59	0.06
4	1.66	0.04	4	1.59	0.06
5	1.67	0.03	5	1.68	-0.03
6	1.72	-0.02	6	1.74	-0.09
Average	**1.70**	**0.04**	**Average**	**1.65**	**0.08**
10 g 1	1.76	0.00	100 g 1	1.84	-0.06
2	1.68	0.08	2	1.80	-0.02
3	1.81	-0.05	3	1.80	-0.02
4	1.89	-0.13	4	1.71	0.07
5	1.73	0.03	5	1.82	-0.04
6	1.70	0.06	6	1.73	0.05
Average	**1.76**	**0.10**	**Average**	**1.78**	**0.07**


GRAPH #1
TIME IN FREE FALL -VS- OBJECT
TIME (S)
1.80
1.70
1.60
0
OBJECTS
DIME
10g
QUARTER
20g
50g
100g