Which Accelerates Faster – A Falling Ball Or A Porsche?

James D. Rall, West Virginia University, USA
Wathiq Abdul-Razzaq, West Virginia University, USA

ABSTRACT

An introductory physics experiment has been developed to address the issues seen in conventional physics lab classes including assumption verification, technological dependencies, and real world motivation for the experiment. The experiment has little technology dependence and compares the acceleration due to gravity by using position versus time graphs and the kinematic equation. The students are then asked to compare the acceleration they found to the one of a Porsche car which they seem surprised when they learn about it. This experiment may contribute significantly to the understanding of the concept of acceleration and the appreciation for the force of gravity.

Keywords: Free fall; Physics Education; Acceleration

INTRODUCTION

Students consider physics so difficult. One reason, according to Sobel (2009), ought to be that we go too fast in the lecture and make students solve problems in the exam that are not simple plug-ins and may not necessarily be problems they have practiced for homework. Thus, students think that sitting in the classroom and absorbing everything the professor says will not get them very far.

To give the students the opportunity to concentrate on the physics principles and not just solving problems, we use interesting home developed lab experiments such as the one present in this work. Pre-physics and pre-engineering students at West Virginia University (WVU) spend nearly the same amount of time in the lab classroom as they do in lecture, and virtually every student attends the labs since it accounts for 15% of the course grade. Thus we catch in the lab the excellent, as well as the weak, students in addition to the students who usually do not attend lectures. This proportion of the amount of time in lab and the full spectrum of the introductory physics students creates a unique opportunity to directly impact the student's physics education by the content of the experiments.

Three main issues students deal with in introductory laboratory class at WVU are: 1) lack of differentiating between definitions and derived equations based on assumptions, 2) disconnect of physical quantities when using computer controlled equipment, and 3) excitement and real life applications of the lab. The laboratory experiment in this work was developed to address these three issues.

MATERIALS

Many of the materials needed for this experiment can be found locally and constructed with little effort. The materials are board with position indicators, a video camera (preferably with 60 fps), two golf balls, one 2″ PVC pipe with a hole drilled along the diameter 2.54 cm from the end, three 2″ PVC pipe sections, three 2″ PVC Tee, and one photogate (preferably independent of the computer). The lengths of the PVC are arbitrary since the students should be measuring the distances separately. Figures 1(a) and (b) show the setups of the experiment.

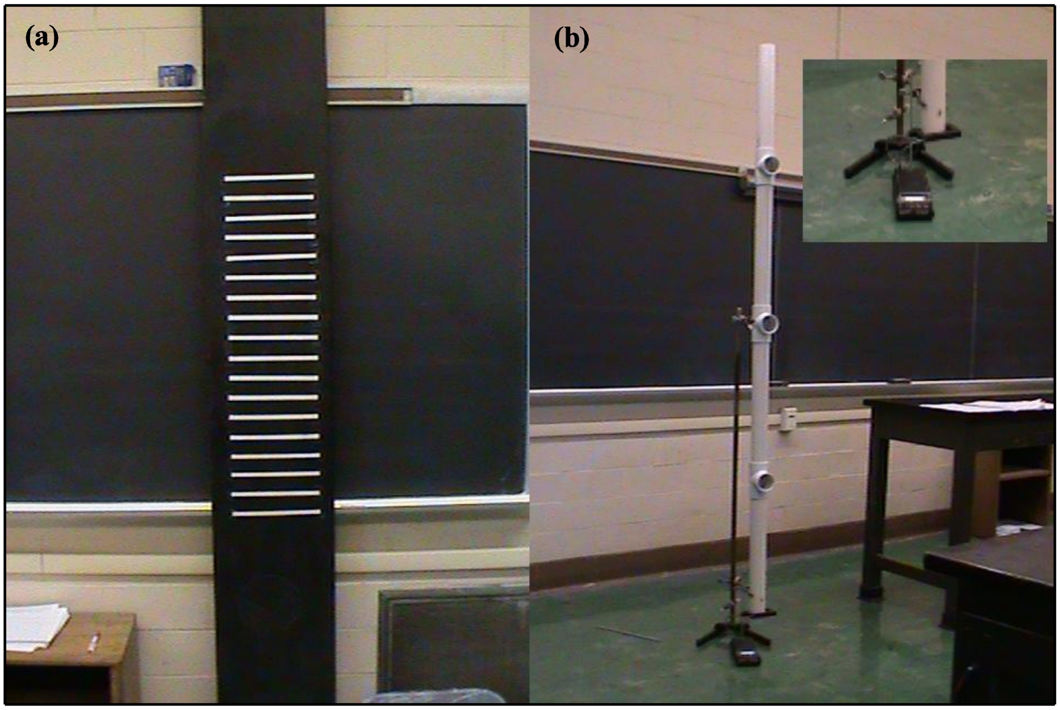

Figure 1: Experimental Setup
(a) Part I
(b) Part II with the Inset Showing the Photogate Placement on the PVC Pipe

THE EXPERIMENT

The experiment is relatively simple and easily accessible, especially since it is one of the first experiments the student will do. Both Part I and Part II described below are setup for the students to avoid any preconceived notions.

The two parts of the experiment are to distinguish between using definitions (Part I) and derived equations (Part II) to find acceleration due to gravity. The majority of the equipment used in the experiment are typical products found in local hardware and convenience stores, which help the student identify the physical meaning of the quantities received. The setup for both parts does not need the use of computer, thereby eliminating any addition technical complications. The only piece of equipment which will need to be explained is the photogate to measure the final velocity. However, the student easily grasps the concept of the photogate being a modern day stopwatch. To relate this experiment to real world examples, the students are asked to find, from the Porsche website (www.porsche.com/usa/models/911/911-carrera-s/, 2011), the acceleration of the newest Porsche car, the 911 Carrera S.

Before lab class, the student is asked to not only define free fall, but to discuss the typical violation of free fall (i.e. drag). The student is also asked to define the three typical quantities which are used to define an object's motion (position, velocity, and acceleration) and to predict the graphs of these quantities for free falling objects. To prepare the student for the second part of the lab experiment, they are guided through the derivation for the kinematic equations (1) and (2):

$$v^2 = v_o^2 + 2ad \tag{1}$$

and the other kinematic equation:

$$v = v_o + at \tag{2}$$

where v_o is the initial velocity, v is the final velocity, a is the acceleration, t is the time, and d is the displacement.

At this point the lab instructor emphasizes the importance of constant acceleration for Eq. (1) and Eq. (2) to be valid. They are also asked to show a theoretical graph of velocity versus the change in position on a linear-linear and log-linear graph, as well as linearizing Eq. (1) to easily obtain the acceleration from the graph.

Part I

The setup for this part, which we call the direct method, Figure 1(a), is simply to stand the board with position indicators vertical while having the video camera face it at a reasonable distance and centered on the board to reduce any parallax (Singh, 2000). The position indicators for the board used at WVU were white strips 5 cm apart along a black board. This configuration allows the lab instructor to apply the definition concept to the real world example of the Washington DC Department of Motor Vehicle's automatic ticketing system to provide evidence of speeding (Schuetz, 2008). This part of the experiment has been done many times before with several different variations (Singh, 2000; Overcash, 1987; and Kulp, Biermann, Howard, and Klingenberg, 2008).

The student performs the experiment by recording the golf ball being dropped in front of the board. The students take the typical data of position vs. time directly from the video camera to reduce any errors which may occur during the transfer or formatting to a computer (Schuetz, 2008). After graphing the displacement d versus the time t, the student will take the numerical derivative to plot the velocity v versus t and a further derivative obtaining the acceleration versus time graph.

Part II

For the use of the kinematic equation, Eq. (1), the final velocity of the golf ball must be measured while adjusting the height at which its dropped. As such, the PVC pipes act as a guide to accurately determine the final velocity through the photogate placed at the bottom. The setup, Figure 1(b), is rather simple by adjoining the PVC Tees while insuring the PVC with the holes is at the bottom for the photogate to detect the ball. The students proceed to gently drop the golf ball from the measured heights and record the time of the photogate for the ball to pass through it at the bottom. The student then gets final velocity from dividing the diameter of the ball by the recorded time. The final velocity vs. displacement graph is then plotted. Since many students are new to science and graphing, this is the perfect time to reiterate the usefulness of log-log graphs and linearization techniques to easily obtain the acceleration. The students then compare acceleration from each part and are asked if the assumption in Part II is valid.

Although these two parts are done independently, there may be some usefulness in combing them. This may be done by cutting a slit into one side of the PVC pipe to show the golf ball being dropped. The video camera can then record the position of the ball at the exact same time the final velocity and height are done. This may solidify to the students the data represents the same effect, but through different means. The assumption of the object of freefall can also be challenged by incorporating different surface areas and dropping them from much higher distance so the drag effect will be observed (Singh, 2000).

COMPARISON TO PORSCHE

The student is asked to visit the Porsche website to figure out the acceleration of the newest Porsche car, the 911 Carrera (www.porsche.com/usa/models/911/911-carrera-s/). It is stated in the website that the car manages to accelerate from zero to 60 mph in 4.3 seconds. The student is asked to use Eq. (2) to calculate the acceleration of the car, which will be 6.2 m/s. The student realizes that the Porsche's newest car accelerates at nearly 2/3 of that of gravity. The student is prompted to think: What does that mean? Applying Eq. (1) using v_o= 0, v = 60 mph, a = 9.8 m/s^2 for gravity, we will get d = 36.6 m. Thus a ball that falls from d = 36.6 m high building (about 11 stories) will reach the ground at the same speed listed in the Porsche web site of 60 mph but with a higher acceleration, i.e. higher pace of changing speed. The student also calculates the time it would take gravity to accelerate an object from zero to 60 mph, t = 2.7 seconds which is less than the Porsche 4.3 seconds.

CONCLUSION

The excited student has to answer the question, "Which accelerates faster – a falling ball or the expensive Porsche car?" The answer, of course, is a falling ball. The hope is that the student will understand the concept of acceleration and the not-so-weak gravitational force. What a thrilled driver gets from driving a Porsche is the high acceleration of the car relative to the other much cheaper cars; thus, the student will realize that free falling is even more thrilling than driving a Porsche if free falling is not harmful when hitting the ground. We feel this experiment gives the student a rich understanding of acceleration, the appreciation for the force of gravity, and the connection between real life and physics.

AUTHOR INFORMATION

Dr. Abdul-Razzaq received his PhD in 1986 from the University of Illinois at Chicago. He completed his post-doctorate work at Michigan State University. Currently he is Professor of Physics and Director of Introductory Physics Curriculum at West Virginia University. He has had research activities in diverse areas including studies of magnetic and transport properties of thin films and multilayers, studies of magnetic nanoparticles, applied studies related to health and environment, and research in education. E-mail: wabdulra@wvu.edu. Corresponding author.

Dr. James Rall just received his PhD in 2011 from West Virginia University. He was a Teaching assistant at West Virginia University when this work was performed. His research specialty is in magnetism of nanoparticles. E-mail: jrall@mix.wvu.edu.

REFERENCES

1. Sobel M 2009, Physics for the Non-Scientist: A Middle Way *The Physics Teacher* 47, 346.
2. Porsche website 2011 http://www.porsche.com/usa/models/911/911-carrera-s/
3. Schuetz A 2008, Photo Enforcement *The Physics Teacher* 46 248.
4. Singh K 2000 Flight of the bagel *The Physics Teacher* 38, 432.
5. Overcash D R 1987 Video analysis of motion *The Physics Teacher* 25, 503.
6. Kulp C W, Biermann M L, Howard T, Klingenberg K, and R, 2008 When Two Balls Are Just One *The Physics Teacher* 46, 168.

