Cub Lecture 3 - More about Mass, Weight, and Time

Introduction

Hi Cub Scout or other youngster. In **Cub Lecture 2** we learned a lot about friction. In the process, we had to measure distances. We also had to deal with mass, like 1 oz_M. In this lecture, we also will have mass, but we will look at time as well. Our objective in this lecture will be to find out how important the mass of a pinewood derby car is to its travel time down a ramp. After some examples of the Scientific Method from the history of physics, we will have 4 questions, then there will be some experiments for you to do with 2 questions.

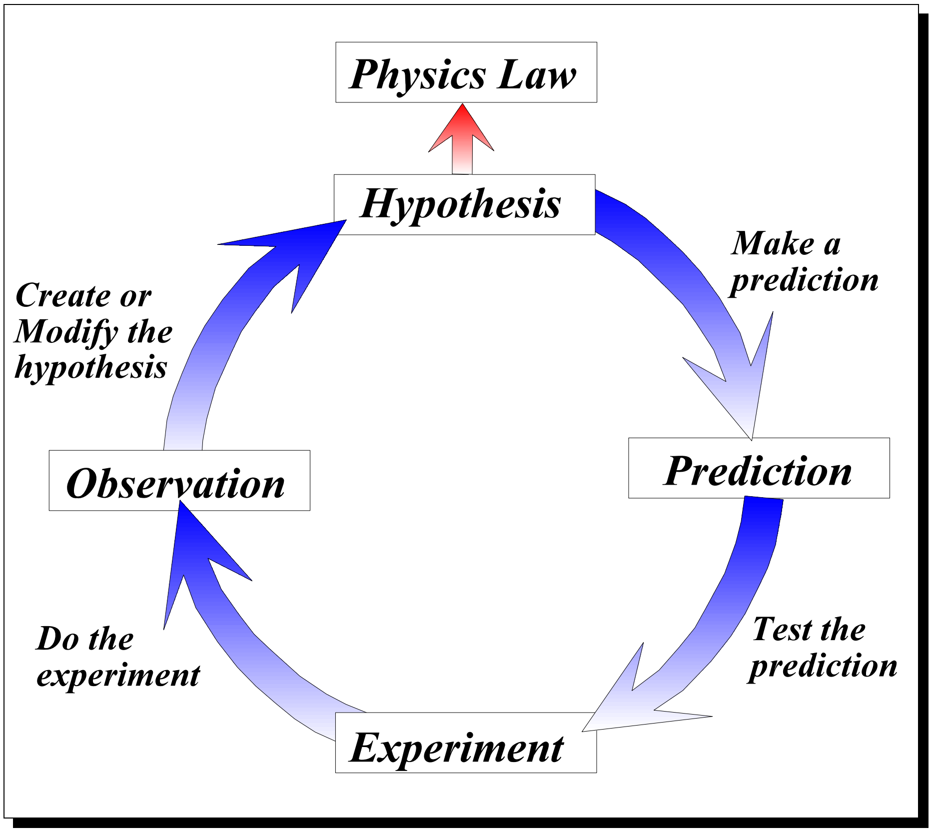

Figure 1 *- The Scientific Method consists of modifying a hypothesis until its predictions fit the observations of actual experiments. Then we have a physics law.*

The Scientific Method

In Cub Lecture 2, we used the Scientific Method to get a physics law for sliding friction. We learned some surprising things in the process. We will use the Scientific Method further in this Lecture. **Figure 1** will help fill in the details of the Scientific Method. In this method, there is sort of a loop formed when we test a hypothesis by doing an actual experiment. You can enter the loop at any point. Say you saw (*observed*) something while driving around and wondered (*hypothesized*) if it always behaved like that. So when you got home you assumed (*predicted*) that behavior might happen again if you did so-and-so (*experiment*). Based on your new *observation*, you might modify the *hypothesis*, etc. If your *hypothesis* always *predicted* the future correctly, then you have a *physics law*. Or, you could be doing an *experiment* randomly, like mixing baking soda with water, or with oil, or perhaps with vinegar – whoooosh! Such an *observation* surely would get you to thinking of some sort of reason why this would happen (*hypothesis*), and allow you to *predict* this type behavior again.

An Old Story

A long time ago in the 1600's this Italian scientist named Galileo wondered about the difference between a heavy object and a light object, especially how fast they would fall to the ground. But, almost 2000 years earlier, a Greek gentleman named Aristotle, who was a philosopher, said it was apparent that the heavy object had more force pulling it down than did the light object. Therefore, he said, it was obvious that the heavy object would get to the ground quicker. Now philosophers are thinkers, they don't actually try things out like doing an experiment to see how nature really works. As a matter of fact, Aristotle taught that it was demeaning to actually get your "hands dirty" by trying something. He thought it was insulting to the human intellect to resort to actually trying something.

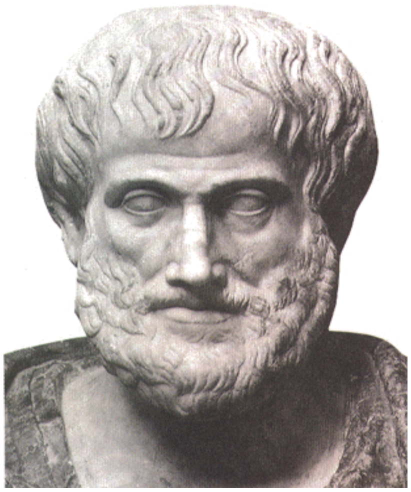

Figure 2*-Aristotle* 384-322 BC

Figure 3 *- Raindrops*

Two thousand years is a long time to wait for trying something to see if it is really true. A few people had hypothesized that Aristotle's ideas about falling objects didn't make sense. For example, if a light stone fell slower than a heavier one, what would happen if you tied them together? Shouldn't the light stone then retard the motion of the heavier stone? And then there were different sized rain drops that seemed to fall from cloud to ground at about the same time.

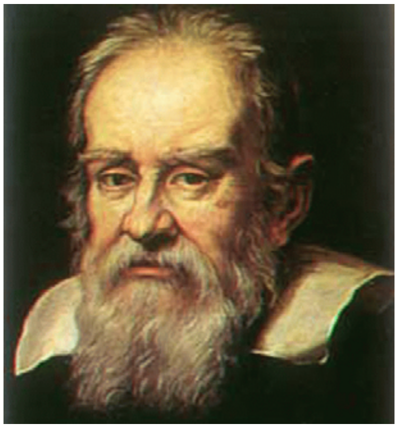

Figure 4 *- Galileo* 1564-1642

Galileo wanted to back up his thinking with actual experience and first-hand observation. He sort of started the Scientific Method way of doing things. So legend has it he dropped a large iron ball and a small iron ball from the leaning tower of Pisa. He released them at the same time and, my goodness, they both hit the ground at the same time (within a fraction of an inch). You could roll them down an inclined plane with essentially the same result. This kind of thinking, where he actually tried experiments, got him into a lot of trouble with the church authorities and they forced him to take back the things he actually saw. Well, a lot of parents are like Aristotle. They think the heavier a pinewood derby car is, the faster it will go (it may be a tiny bit faster from less air drag, but not enough to see).

Two Kinds of Forces?

Figure 5 *- Newton* 1643 -1727

The year after Galileo died, Sir Isaac Newton was born. He studied the results of Galileo and others, made various hypothesis, and confirmed them through observation. He made several far reaching physical laws, but the Law of Gravitation and his so-called Newton's Second Law are the among the most well known. His Law of Gravitation, when applied to objects near the earth's surface, states that the gravitational force F_W trying to move any mass m towards the center of the earth is:

$$F_W = m\,g \qquad (1)$$

where m is an object's mass, and g is the acceleration due to gravity. Now m itself has nothing to do with force or acceleration, but rather it is a measure of just how much "matter" there is in an object. Because we know how objects are accelerated in earth's gravity field, we know g, thus the force F_W is a measure of how much m there is. This force is called "weight", and for a given amount of material m, the weight is pretty close to constant at any point on earth. Newton's 2nd Law says there is an inertial force F_I that *resists* any attempt to accelerate a mass.

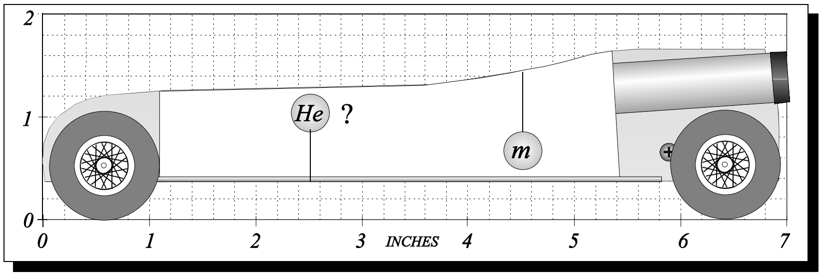

Figure 6 *- A rocket powered PWD car, with a mass* ***m*** *hanging from the roof and a balloon tied to the floor.*

$$F_I = m\,a \qquad (2)$$

In **Figure 6** we show a pinewood derby (PWD) car with a small rocket engine in the rear. A mass m hangs inside from the car top. **Figure 7 a** shows a close up of the mass m when stationary. Also, suppose the car's rocket causes an acceleration ***a*** that increases the car velocity from 0 meters per second to 9.8 meters per second, and suppose this velocity increase occurs in 1 second. This is equivalent to going from stationary to 22 mph in 1 second, or to 60 mph in 2.73 seconds.

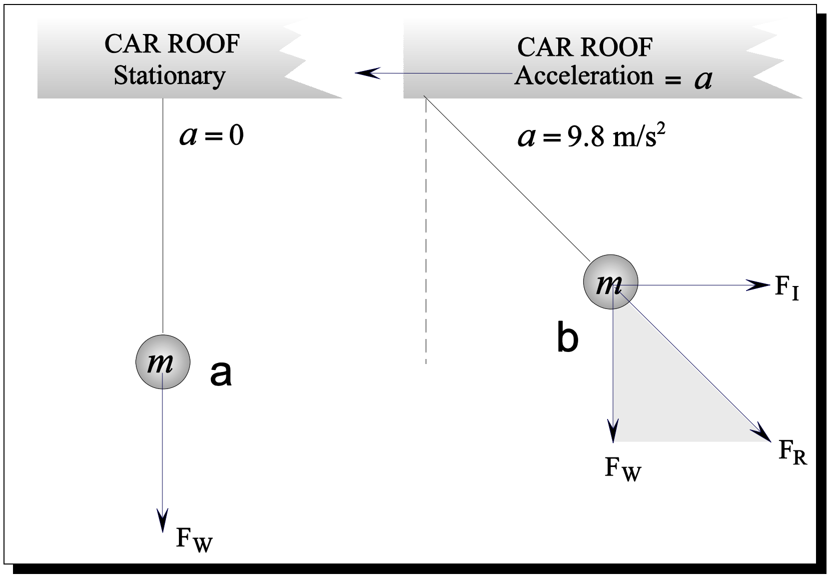

Figure 7 *- A mass* ***m*** *hanging from the PWD car top.*

That's a pretty good acceleration, but drag racers routinely obtain such a velocity change. In **Figure 7 b**, we see the effects on the mass *m* from the Newton's 2nd Law force F_I . The support point on the car's roof takes off at *9.8 m s^{-2} but the inertia of mass *m*, which is its resistance to being accelerated, causes it to swing towards the rear of the car as moved by the inertial force F_I. We picked the car's forward acceleration to be 9.8 m s^{-2} because that's precisely the acceleration due to gravity, namely *g* (in **Lecture 2**, we had in English units that $g = 32$ ft s^{-2} which is 9.8 m s^{-2}). See the force triangle again, like we saw in the last Lecture 2? Here, the forces F_I and F_W are equal, meaning rise over run = 1, and the resultant force F_R has swung back to a 45 degree angle. F_R is an equal combination of the gravity weight force and the inertial motion resistance force.

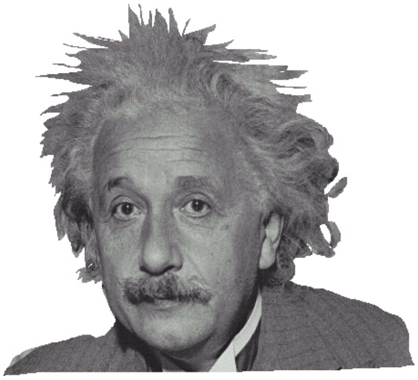

Figure 8 *- Einstein* 1879 - 1955

Here is where Einstein comes in. He showed, about 100 years ago, that: *in an accelerating frame of reference there is no way to tell the difference between a gravitational force* F_W *and an inertial force* F_I*.*

So, from equations (1) and (2) when we set these 2 forces equal, we have

$$ma = mg \qquad (3)$$

Consider that *m* hasn't changed, its just how much material is there, so we must have

$$g = a \qquad (4)$$

Thus, there is no difference when a mass, of any size, is subjected to a non-gravitational acceleration or to a gravitational acceleration. In other words, inertial resistance to motion is a consequence of gravitational acceleration just as it is a consequence of any acceleration. A lot of experiments were done by astronomers and astronauts to confirm Einstein's theory.

From the force triangle in **Figure 7** Pythagorus says that the resultant force F_R is $\sqrt{2}$ or 1.414 times larger than either F_W or F_I. So accelerating mass *m* thinks it has gained 41% more weight and that straight "up" is actually up and towards the car front by 45 degrees.

OK, now its time for some questions on the first part of this Cub Lecture 3, good luck! These new questions have numbers that start where the Lecture 2 questions stopped.

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*In the last lecture, we used the English system. However, in this Lecture we will use the metric system. Only 3 countries, the USA, Myanmar, and Liberia, use the English system. Refer to **Appendix 1** for a quick review of metric vs English units.

question 25: Who thought that "common sense" or just thinking was good enough to figure out how things worked?

a Einstein
b Aristotle
c Newton
d Galileo
e None of the above

question 26: Who showed that a mass resists accelerated motion when falling exactly as it resists accelerated motion when pulled or pushed by any other external force?

a Einstein
b Aristotle
c Newton
d Galileo
e None of the above

question 27: Who was one of the first scientists to experiment and use the Scientific Method to discover a physical law of motion?

a Einstein
b Aristotle
c Newton
d Galileo
e None of the above

question 28: In **Figure 6**, what happens to the helium-filled balloon, tied to the car floor, when the car accelerates to the left (this is a little tricky and goes against common sense)?

a It swings to the rear by 45 degrees, just like mass m, because of its inertia.
b It swings to the front by 45 degrees, because it wants to move opposite to where it thinks straight down is.
c It stays floating straight up, because it wants to move opposite to gravity only.
d It tends to wave back and forth because it can't tell which force F_W or F_I is more important.
e None of the above

Pendulum motion

Figure 9 shows a pinewood derby car on a ramp R which is part of a large circle of radius L. Actually, if the circle has a radius of about 30 ft, then the height H of the car above the coast run on the floor is about 4 ft. Many tracks have such a uniformly sagging ramp with about this radius. At point P the car enters the horizontal coasting run and crosses the finish line at F.

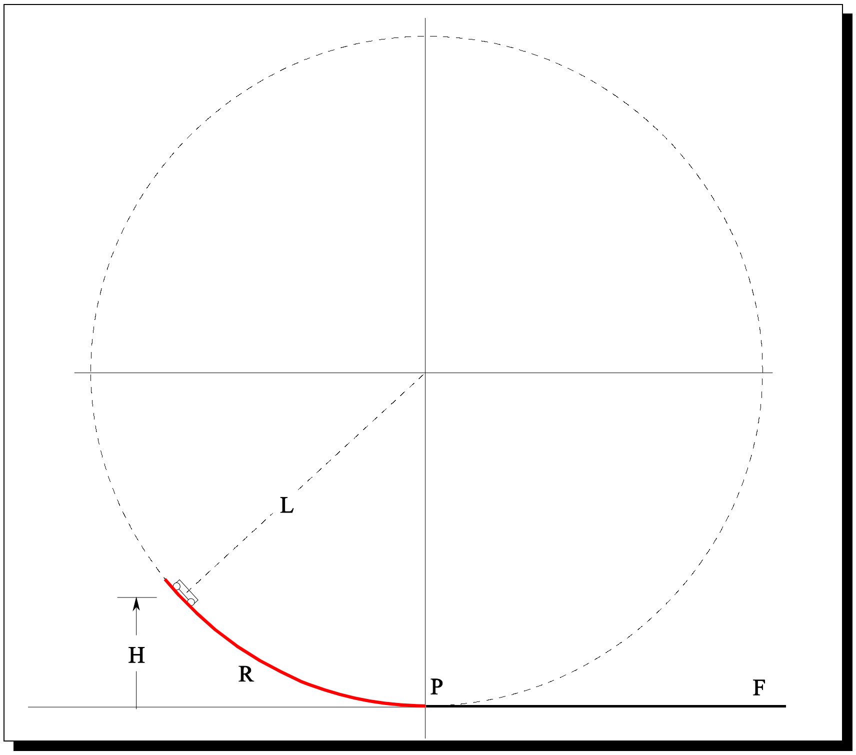

Figure 9 *- A pinewood derby track with a ramp R that is the arc of a circle of radius L = 30 ft.*

In **Figure 10** we have replaced the car with a pendulum of some mass *m*. The motion of the pendulum mass under gravity forces is exactly the same as the motion of the car mass on the curved ramp if L is the same. The only difference is that the ramp pushes on the car from the bottom to follow a circular arc whereas the pendulum mass is pulled from the top to follow the same circular arc. At point P, if the mass *m* left the pendulum string, it could also coast along the horizontal like a car.

Now, lets test this as a hypothesis, namely: **Hypothesis 1**
A pinewood derby car going down a curved circular arc ramp will have the same motion as a pendulum mass swinging through the same arc.
Next, we make a prediction, based on this hypothesis, that when we release both a PWD car and a pendulum mass, they hit point P simultaneously (provided we consider all the PWD mass located at its center of mass, called CM).

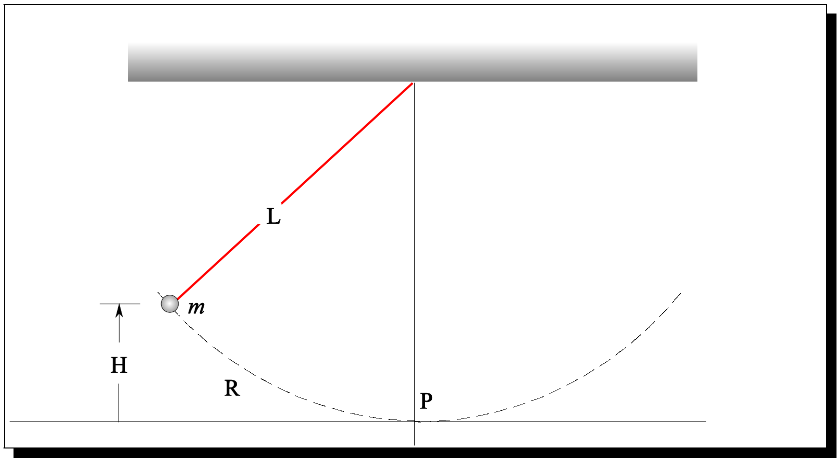

Figure 10 *- The car has been replaced by a pendulum supported by a string of length L = 30 ft.*

For an experiment to test this prediction, I will set up a pendulum and a small curved ramp. **Figure 11** shows a pendulum set up. You need to go ahead and set up a pendulum similar to the one shown as you will need it later. First, bend a paper clip like in **Figure 12.** Then use the thread from your equipment supply to tie one end to the paper clip and the other end to a support close to 36 inches above the bottom end of the paper clip. **Figure 13** shows how I have positioned a small clamp on a cabinet door from which to drop the 3 ft length of thread. However, you can attach the top of the thread to any convenient fixed item so that you will have a 3 ft length to swing. Oh yes, also as shown in **Figure 12** we have slipped a PWD wheel over the paper clip hook as a pendulum mass.

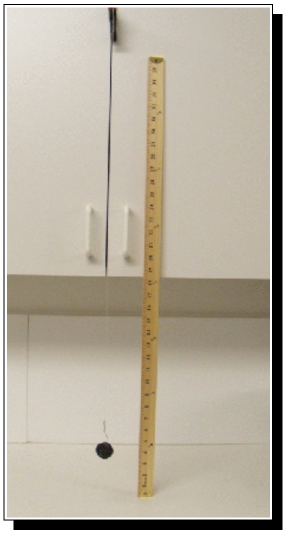

Figure 11 *- A simple pendulum*

So I have arranged to do an experiment to test the prediction of **hypothesis 1**. In **Video 1** there is shown a sequence of motion as a pinewood derby (PWD) car is released at the same time a pendulum is released. The pendulum mass (wheel) is also shown in **Figure 11**. We make a ramp of radius of curvature = 36 in. We position the pendulum bob at height H which is 4 inches directly above the center of mass of the PWD car, just in front of the rear wheels. According to **hypothesis 1**, both the car CM and the pendulum mass should travel the same arc, of radius 36 inches, in the same time. Click right then click pause close to the end of the *.wmv video to see which crosses the vertical first.

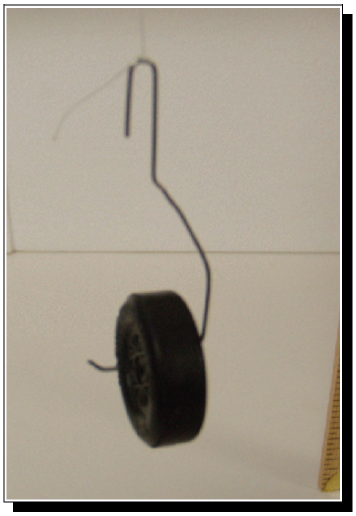

Figure 12 *- A paper clip and PWD wheel supported by a thread.*

Video 1 *- PWD car CM vs Pendulum bob race. Click left to start, then right to see pause option.*

Figure 13 *- A clamp to support the thread.*

The result is that the pendulum mass appears to cross the vertical at the same time as the CM of the PWD car. So, because of this observation, we can conclude that the **hypothesis 1** is correct and our prediction is verified. Now, lets play like we're Galileo and test Aristotle's hypothesis as our second experiment. But you will do this next experiment at home.

Hypothesis 2 (Aristotle)

A heavier object will respond to the force of gravity by falling faster than a lighter object.

As shown in **Video 2**, pull the pendulum bob back to about 8 inches above its lowest point when vertical. When your watch second hand is on a good starting mark (like at the 12 O'Clock mark) release the mass as in the video. After 10 swings exactly (at this point when catching the mass), note the time in seconds (A wrist watch with second hand stop action, or an inexpensive stop watch from, say, Radio Shack™ is easier but not really necessary).

Video2 *-Testing the timing of a pendulum swing. Click left to start.*

Do this 3 times and take the average divided by 10 as your total time per swing. In **Video 2**, I got 18.3 seconds average or 1.83 seconds per complete swing. Call this **experiment 1**. (To get a fraction of a second you have to guess some or have a sharp eye). You can practice using **Video 2**. My times were:

1. Time for 10 swings = 18.0 s
2. Time for 10 swings = 18.0 s
3. Time for 10 swings = 19.0 s

Avg Time for 3 "10 swings" = 18.3 s

In **Video 1** the time to reach the vertical was one quarter of a total swing, or 1.83/4 = 0.46 s.

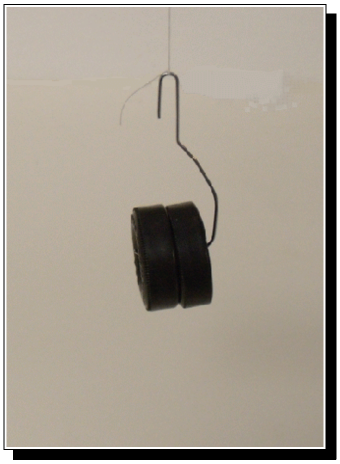

Figure 14 - *Double the mass of the pendulum.*

Notice that the amplitude of the swings gradually decrease because of air resistance. However, a detailed look at the physics, which is beyond the scope of this lecture, shows that even small swings take almost exactly the same time as the larger ones.

Next, double the mass of the pendulum by adding another wheel as in **Figure 14**. Then repeat **experiment 1** as **experiment 2** using double mass.

Your average time for 10 swings in **experiment 2** is:
Avg time for 10 swings = _________ s

question 29: Your difference in the average "10 swing" time between **experiment 1** and **experiment 2** is between (subtract the smaller time from the larger)?
(example = 18.3 - 18.0 = 0.3 s, which would have an answer **a** , but other answers could be OK as well)

a 0 < time difference < 0.5 s
b 0.6 < time difference < 1.0 s
c 1.1 < time difference < 1.5 s
d 1.6 < time difference < 2.0 s
e 2.1 < time difference < 2.6 s

It may have just occurred to you that the motion shown in **Video 1** could be taken as an experiment to test Aristotle's hypothesis as well. The PWD car mass is 5 oz_M = 141.75 grams and a 1999 wheel mass 3.5 grams. Therefore a mass lighter than the car by 141.75/3.5 = 40.5 times made it to the finish line (point P) very close to a mass 40 times larger.

Final exam for **Lecture 3** is this **question 30**
Is Aristotle's hypothesis 2 still false according to your observations in experiment 1, experiment 2, and a separate laboratory's (mine) experiment in **Video 1**?

a Yes
b No

The final answer to mass

We have followed through history those key figures who worked on how mass behaved, namely Aristotle, Galileo, Newton, and Einstein. And now mankind is on the verge of testing a really unique hypothesis. We know mass has this strange property that resists being put in motion or stopping already existing motion, whether you drop it on your foot or kick it with your foot. Many physicists think that there is a sub-atomic particle, called the Higgs* boson, that is responsible for making mass behave as it does when left alone, or when forces are applied to it. Nobody has seen one, but it is supposed to be about 150 times more massive than the proton. It creates a field, like the electric field that can make your hair stand on end. This Higgs field can cause ordinary matter, made of atoms, to resist moving through it like a marble resists moving through oil. The Large Hadron Collider in Europe has just recently started up and may find the Higgs in just a matter of months from now. If so, the "person" in **Figure 15** may be literally hundreds of people, as a multitude of scientists are working together as a team on this very complicated (and expensive) experiment. Also, Higgs and his team may also appear as having been the first to hypothesize this particle.

?

Figure 15 *- Whose picture goes here?*

Happy Racing from Doc Jobe and please fill out the Word answer sheet to complete your 30 questions. When you e-mail the Word answer sheet as an attachment to me I will grade it. If you did the experiments and got reasonable answers (say 75% correct), you will get the Physics Award Patch mailed to you. About 100 physics patches are now available and more will be prepared if this Cub Lecture series becomes popular.

Figure 16 *- Physics Award Patch for the Cub's uniform.*

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* Peter Higgs was one of several scientists who first hypothesized this particle's existence.

Appendix 1 - Units

Table 1 - *Some units used in physics* (Conversion from Google conversion calculator)

Basic Quantity Name	Absolute Basic Dimension Equivalent	Metric SI (MKS) Unit Name	Metric SI (MKS) Basic Dimension	English Unit Name	English Basic Dimension	Conversion English = C x Metric Where C =
Length	L	Meter	m	Foot	ft	3.28084
Mass	M	Kilogram	kg	Pound	lb	2.20462
Time	T	Second	s	Second	s	1.00000
Area	L^2		m^2		ft^2	10.76391
Volume	L^3		m^3		ft^3	35.31467
Density	$M\ L^{-3}$		$kg\ m^{-3}$		$lb\ ft^{-3}$	0.062428
Velocity	$L\ T^{-1}$		$m\ s^{-1}$		$ft\ s^{-1}$	3.28084
Acceleration	$L\ T^{-2}$		$m\ s^{-2}$		$ft\ s^{-2}$	3.28084
Force	$M\ L\ T^{-2}$	Newton (N)	$kg\ m\ s^{-2}$	Poundal(pdl)	$lb\ ft\ s^{-2}$	7.23301

The key thing about **Table 1** is that all units in classical mechanics are a combination of only 3 absolute measures, namely length, mass, and time. All the other units can be formed from these 3 and are called derived units. To get English units from metric units, multiply the metric unit by the conversion factor C listed in the rightmost column. Some derived units are given special names in honor of the key scientist that discovered a related physical law. For example, Isaac Newton's 2nd law states that Force = mass times acceleration. Therefore, force units in the metric system are given the special name "Newtons". A Newton is formed from the basic quantity, M, times the acceleration which is itself derived as a distance per second per second, or LT^{-2}. Remember that "per" means "divided by". Thus velocity in meters per second is $\frac{m}{s}$, sometimes written as $m\ s^{-1}$, where all quantities in the denominator are given a negative exponent when written as times the numerator quantities. So a negative exponent, -1 , also means "per".