AMDG

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3* AP Physics C
October 29, 2006

Lab #2: Conservation Laws

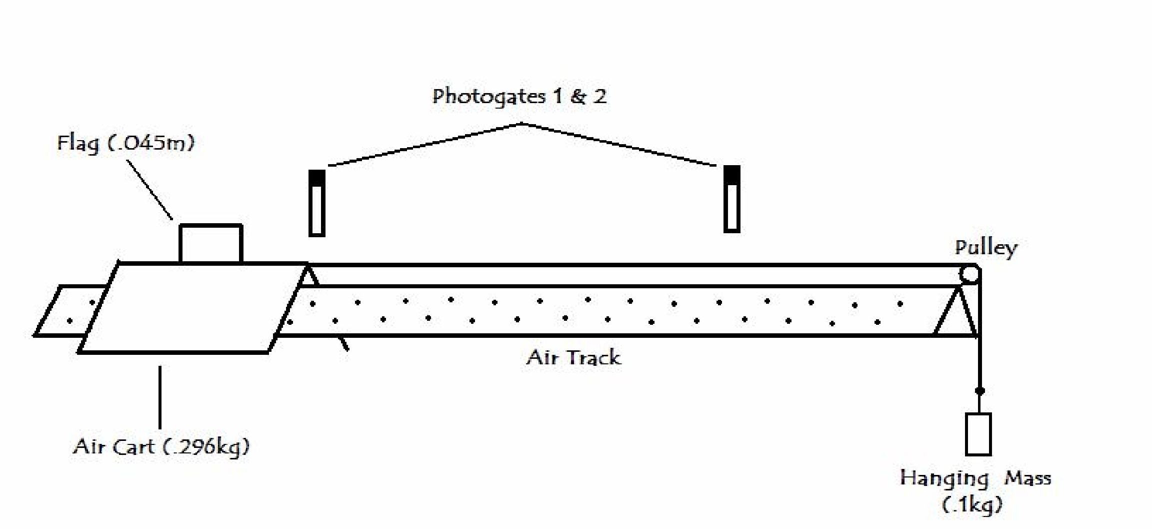
|| Abstract

In this lab, we are attempting to validate some of the conservation laws that govern our universe. In Station 1, we will check Newton's second law F=ma. We will also, in terms of energy conservation, check that the loss of potential energy of the falling mass is equal to the kinetic energy gained. In Station 2 we will measure the coefficients of static and kinetic friction between different objects. In Station 3, we will verify that the area under a curve of a Force(time) graph is indeed impulse, the change in momentum by dropping a book and taking the integral of its graph. At Station 4 we will prove that energy is conserved in a pendulum by measuring its KE at the bottom of its swing and it's PE at the top of its swing. In Station 5 we will be using Newton's laws and free body diagrams to accurately calculate the tension force on unknown scales. In Station 6 we will verify that $F_c = mv^2 / r$.

By testing these laws ourselves we will have more reason to believe their accuracy and usefulness in not only solving physics problems but also in their application to our lives.

|| Station 1

Set Up:



Collected Data:

Mass of Weight: 0.1 kg
Force due to gravity on cart: 2.9 N
Length of flag: .045 m
Distance between Photogates = .40m

Table of Velocities:

Time (s)	State 1	GT 1 (s)	Velocity 1 (m/s)	State 2	GT 2 (s)	Velocity 2 (m/s)
2.786118	1					
2.845022	0	0.058904	0.764			
3.204950				1		
3.232817				0	0.027867	1.615

Calculations:

Mass of Cart = .296kg

Theoretical Acceleration

F=ma

$$\frac{\text{Net Force acting on System}}{\text{Combined Mass of Weight/Cart System}} = \text{Acceleration}$$

.98N / (.1kg + .296kg) = $\mathbf{2.47m/s^2}$

Actual Acceleration

$\Delta V / \Delta T$ = Acceleration

$V_{final} – V_{initial} / T_{final} – T_{initial}$ = Acceleration

1.615m/s – .764m/s / 3.218s – 2.815s = $\mathbf{2.114m/s^2}$

Potential Energy Lost by Falling Weight

$mg\Delta y$ = PE

.1kg(9.8m/s^2)(.40m) = **.392J**

Change in Kinetic Energy

Kinetic Energy at First Photogate
$1/2mv^2 = KE$

$.5(.395kg)(.764\ m/s)^2 = .115J$

Kinetic Energy at Second Photogate

$.5(.395kg)(1.615\ m/s)^2 = .515J$

ΔKE = **.399J**

<u>Analysis:</u>

Percent Error of Acceleration

$\mathbf{2.47m/s^2 – 2.114m/s^2 / 2.47m/s^2 \times 100\% = 14.4\%}$

Percent Error of Energy Conservation

.399J – .392J / J x 100% = .4%

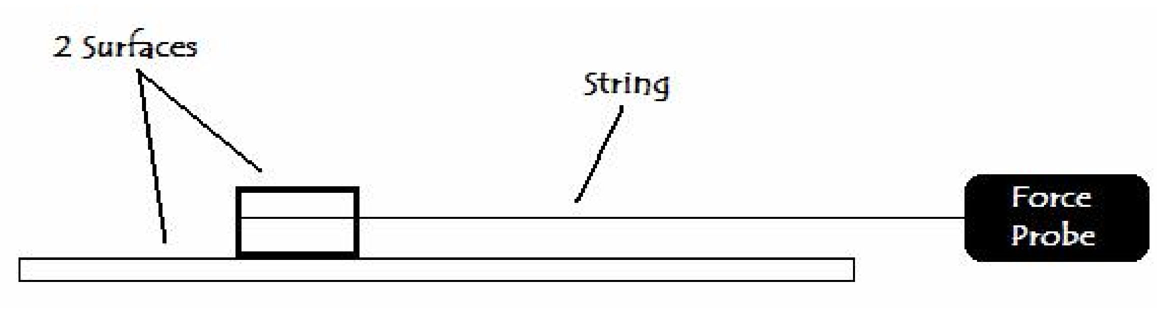
Error Analysis:

Friction and drag forces – one of the most obvious, yet minimal source or error was that fact that there was still drag forces and friction forces interacting in between the pulley and the surrounding air molecules. This would cause the acceleration to become lower than what we would expect.

Mass of String – another possible source of error comes from the wrong assumption that the string connecting the two masses is massless. However, this is not true, and will give us a lower acceleration than what we predicted.

|| Station 2

Set Up:



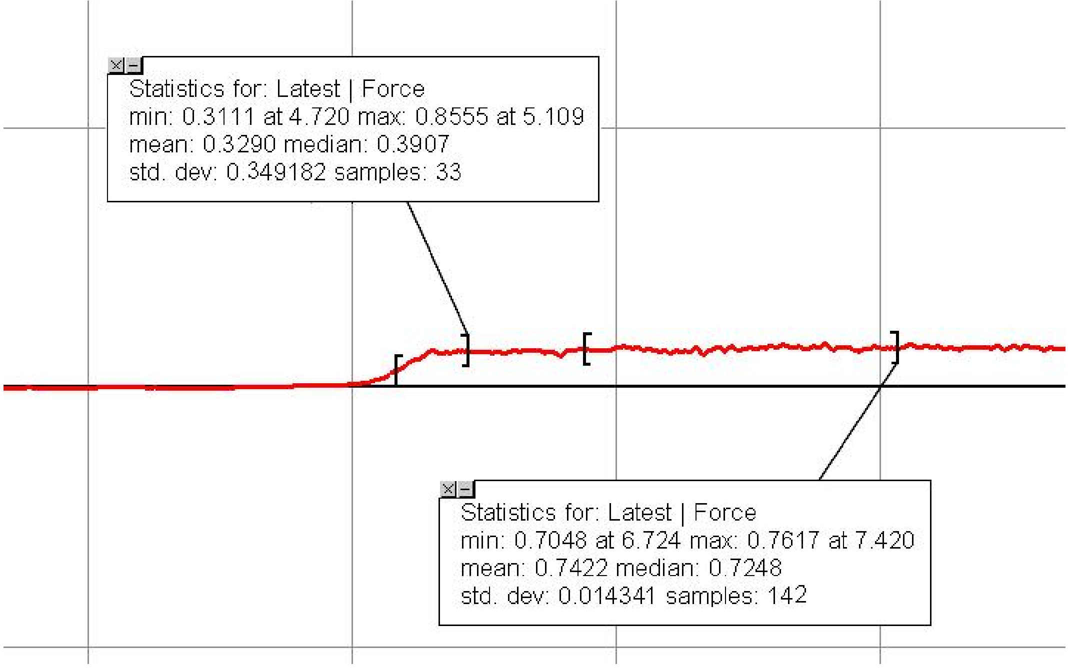
Collected Data:

Mass of glass: 0.459kg
Mass of wood: 1.7kg

Individual Data

Type of friction	Glass on glass	Wood on glass	Wood on wood
T_{max}	0.8555 N	1.782 N	.5025N
T_{avg}	0.7422 N	1.382 N	.4607 N

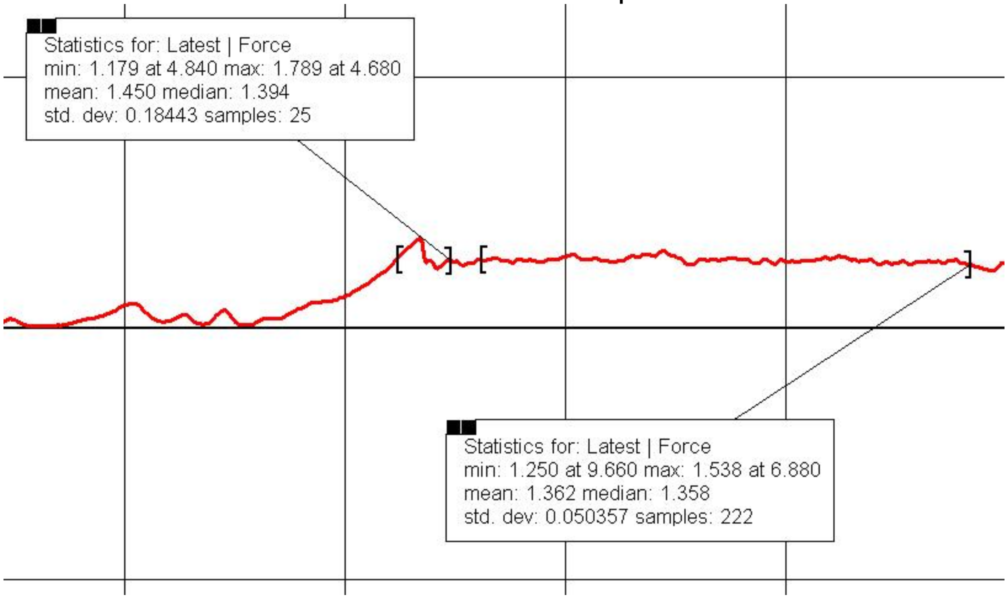
Glass – Glass Graph



```
Statistics for: Latest | Force
min: 0.3111 at 4.720 max: 0.8555 at 5.109
mean: 0.3290 median: 0.3907
std. dev: 0.349182 samples: 33
```

```
Statistics for: Latest | Force
min: 0.7048 at 6.724 max: 0.7617 at 7.420
mean: 0.7422 median: 0.7248
std. dev: 0.014341 samples: 142
```

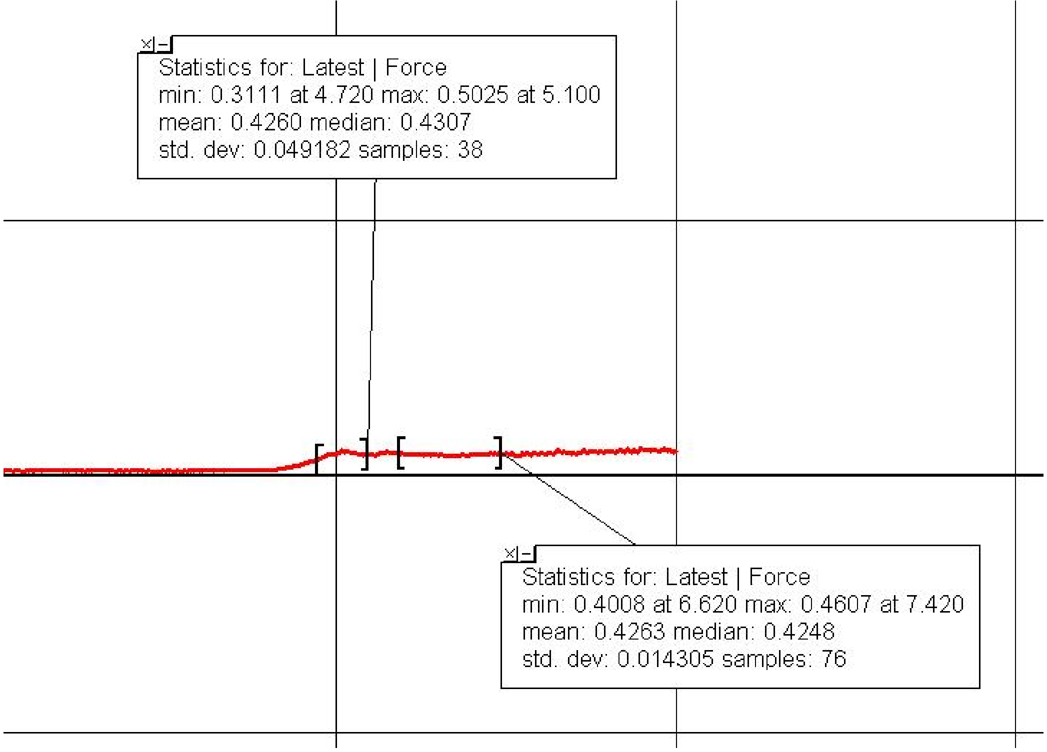
Glass – Wood Graph



Statistics for: Latest | Force
min: 1.179 at 4.840 max: 1.789 at 4.680
mean: 1.450 median: 1.394
std. dev: 0.18443 samples: 25

Statistics for: Latest | Force
min: 1.250 at 9.660 max: 1.538 at 6.880
mean: 1.362 median: 1.358
std. dev: 0.050357 samples: 222

Wood – Wood Graph



Statistics for: Latest | Force
min: 0.3111 at 4.720 max: 0.5025 at 5.100
mean: 0.4260 median: 0.4307
std. dev: 0.049182 samples: 38

Statistics for: Latest | Force
min: 0.4008 at 6.620 max: 0.4607 at 7.420
mean: 0.4263 median: 0.4248
std. dev: 0.014305 samples: 76

Calculations:

Normal Force of Wood and Glass

$mg = N$

$N_{glass} = 4.5N$

$N_{wood} = 17N$

Calculate μ_s/μ_k

Glass — Glass

$\mu_s(N) = T_{max}$
$\mu_s = .190$

$\mu_k(N) = T_{avg}$
$\mu_k = .165$

Glass — Wood

$\mu_s(N) = T_{max}$
$\mu_s = .398$

$\mu_k(N) = T_{avg}$
$\mu_k = .303$

Wood — Wood

$\mu_s(N) = T_{max}$
$\mu_s = .296$

$\mu_k(N) = T_{avg}$
$\mu_k = .271$

Analysis:

Class Data:

Class Data Table

Group		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Averages**
Glass - Glass	μ_s	0.5239	0.334	0.2773	0.224	0.238	0.248	0.19	0.290742857
	μ_k	0.5841	0.195	0.1324	0.163	0.23	0.176	0.165	0.235071429
Glass - Wood	μ_s	0.315	0.143	0.1872	0.26	0.475	0.45	0.398	0.318314286
	μ_k	0.258	0.131	0.159	0.25	0.417	0.443	0.303	0.280142857
Wood - Wood	μ_s	0.298	0.286	0.2702	0.246	0.592	0.414	0.296	0.343171429
	μ_k	0.2405	0.212	0.2281	0.161	0.315	0.265	0.271	0.2418

Percent Difference from Class Average

Glass – Glass
μ_s .190 – .291 / .240 x 100% = 50%
μ_k .165 – .235 / .200 x 100% = 35%

Wood – Glass
μ_s .398 – .318 / .358 x 100% = 22%
μ_k .303 – .280 / .292 x 100% = 7.9%

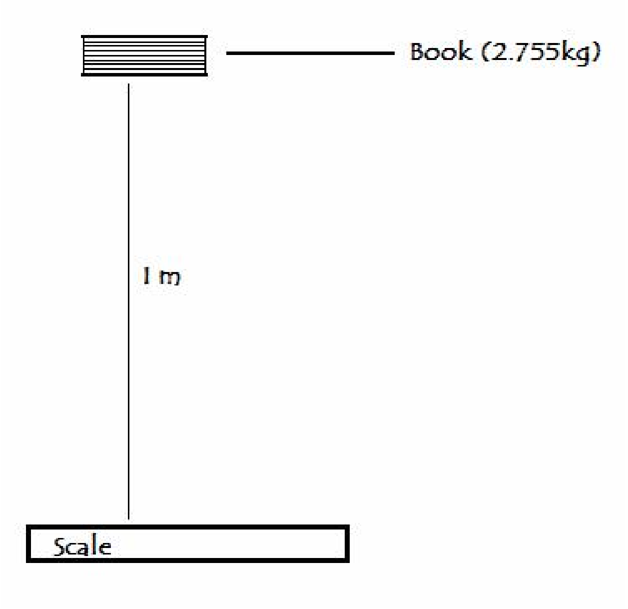
Wood – Wood
μ_s .296 – .343 / .320 x 100% = 14.7%
μ_k .271 – .242 / .392 x 100% = 7.4%

Error Analysis

Pulling the Mass at Constant Speed – in order for us to measure the kinetic coefficient of friction, we assumed that the tension force was equal to the friction force, that is, we were pulling with constant speed. This is not perfectly done so, as can be seen by the noise in the graphs. This kind of error could affect our data in either direction.

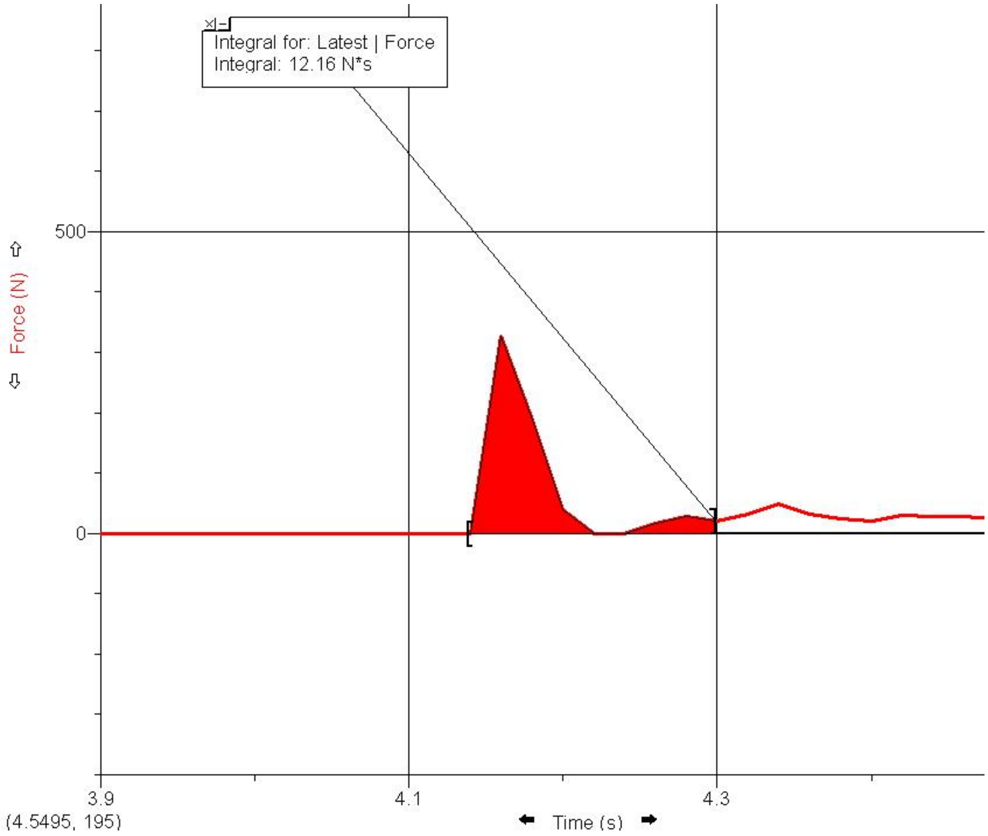
|| Station 3

Set Up:



Collected Data:

Mass of book = 2.755kg
Height = 1 m



Calculations:

Potential Energy of Falling Book

$mg\Delta y = PE$

$2.755kg(9.8m/s^2)(1m) = 27.0J$

Velocity of Falling Book at h = 0

$\frac{1}{2}mv^2 = KE$

$\frac{1}{2}(2.755kg)(v^2) = 27J$

$V = 4.427m/s$

Momentum of Falling Book

$P = mv$

$P_{initial} = 2.755kg(4.427m/s)$
$P_{initial} = 12.197kgm/s$

$P_{final} = 2.755kg(0m/s)$
$P_{final} = 0kgm/s$

$\Delta P = 12.197kgm/s$

Analysis:

Percent Error of Impulse Measurement

$12.197 – 12.16 / 12.197 = .3\%$

Error Analysis

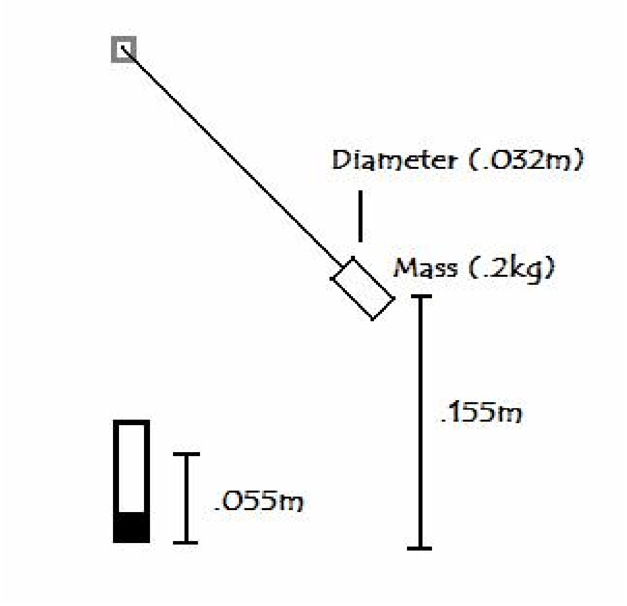
Precision – One source of error at this station was the accuracy of our equipment. For example, the scale sensor at the bottom only takes readings around 20 times per second, and considering that a falling book changes its momentum quickly, an instrument that could better graph its actual force readings would have been better suited for this station and could've given us a more accurate integral.

Assumption of an Inelastic Collision – In fact the collision is not Inelastic. For a time, there is an upward force that "bounces" the book up, giving it some momentum. The remedy? Put a sonic range finder and aim it downwards so we can catch the velocity of the book as it bounces back up.

Calibrating the Scale – one way to calibrate the scale is not really to change it, but to shift the 0 position and retake the integral, or to zero it under the sensors options in LabPro.

|| Station 4

Set Up:

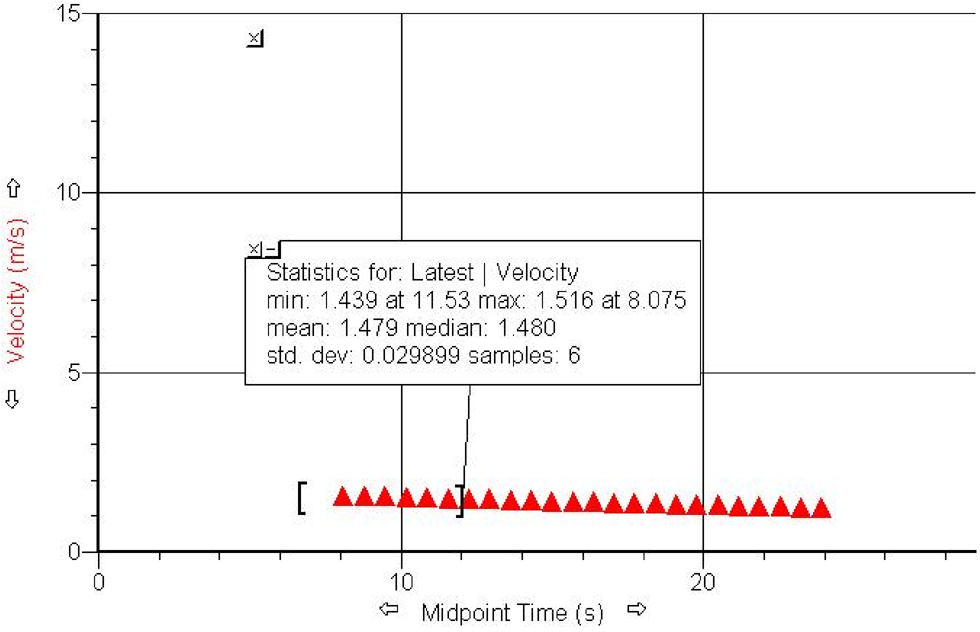


Collected Data:

Distance from table to mass at lowest point of swing = .055 m
Distance from table to mass at highest point of swing = .155 m

Diameter of Mass = .032 m
Mass of Weight = .2kg

Measured Velocity of Mass



Statistics for: Latest | Velocity
min: 1.439 at 11.53 max: 1.516 at 8.075
mean: 1.479 median: 1.480
std. dev: 0.029899 samples: 6

Calculations:

Potential Energy

$mg\Delta y = PE$

$.2kg(9.8m/s^2)(.1m) = .196J$

Kinetic Energy (At bottom of Swing)

$\frac{1}{2} mv^2 = KE$

$\frac{1}{2} (.2kg)(v^2) = .196$

V = 1.4m/s

Analysis:

Percent Error of Measured Velocity

1.479 – 1.4 / 1.4 x 100% = 5.6%

Error Analysis

Friction in between String and Pole and Drag Forces – Where the string of the pendulum meets the pole that holds it up, there is some friction that normally opposes motion. However, if not held, the pole may freely swing back and forth, which may actually catapult the mass further along and thus increase its velocity until the drag forces slows it down again.

Questions

Is energy being dissipated at the pivot point of the pendulum? If so, how much?

Yes, energy is being dissipated at the top, however, this is not the cause of a higher velocity which was unexpected. Is we did have a lower velocity one would go about calculating the dissipated energy by finding the difference in PE to KE in the system.

Where in the hanging mass should we measure its height from? does it matter?

We should measure the hanging mass from its center of gravity, midway of the solid cylinder. It matters because an object acts as if all its mass was it its center of gravity.

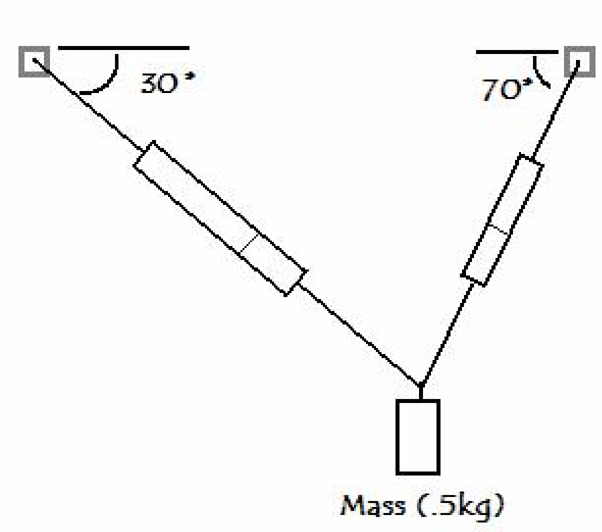
How can we determine its initial height from a measurement of angle?

By using trig, we find the (Length of string)cos(θ) and then subtracting that value from the length of the string to find Δy.

|| Station 5

Part 1

Set Up:



Collected Data:

Mass Weight = .5kg
Angle on T_1 = 30°
Angle on T_2 = 70°

Calculations:

First Equation

Horizontal Forces Balance Out

$T_1\cos(30°) = T_2\cos(70°)$

$T_1 = T_2\cos(70°)/ \cos(30°)$

Second Equation

Vertical Forces Balance

$T_1\sin(30°) + T_2\sin(70°) = 4.9N$

Substitute

$[T_2\cos(70°)/ \cos(30°)]\sin(30°) + T_2\sin(70°) = 4.9N$

$.197T_2 + .940T_2 = 4.9N$

$T_2 = 4.310N$

$T_1 = 1.702N$

Analysis:

Percent Error in Measurement

T_1 4.310N – 4.15N / 4.310N x 100% = 3.7%

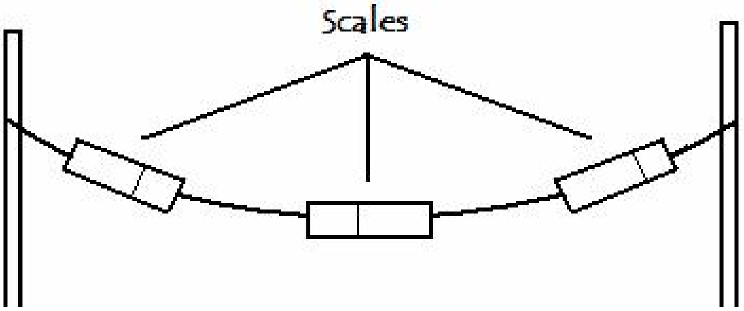
T_2 1.702N – 1.50N / 1.702N x 100% = 11.9%

Error Analysis

Precision of Instruments – without disturbing the set, we had to measure the angle of the tensions acting on the scale. I can honestly say that we simply superimposed the protractor, and may be off by ±2°. This could definitely affect the outcome either way. A good way to combat this would be to use the knowledge of the scales to calculate the angle at which they are depressed, or by getting a more accurate protractor.

Part 2

Set Up:



Collected Data:

Tension on Leftmost Spring = 3.7N
Tension on Rightmost Spring = 3.9N

Calculations:

Since tension along a string can be considered constant (same throughout)
Tension in Center = Avg. other 2 springs

3.7N + 3.9N / 2 = 3.8N

Analysis:

Percent Error of Tension in Center Scale

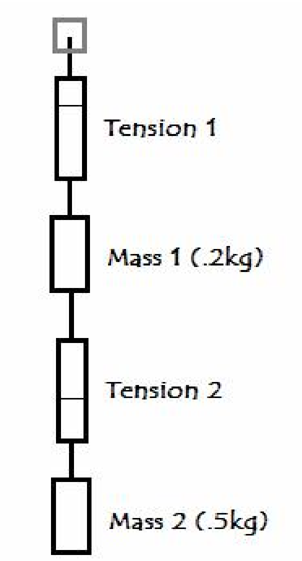
3.8N – 3.8N / 3.8N x 100% = 0%

Error Anaylsis

Angle of the Scales – because the scales have mass, they sag. This creates instead causes the scales to become slightly tiled and thus causes there actually to be more force on the lowermost scale.

Part 3

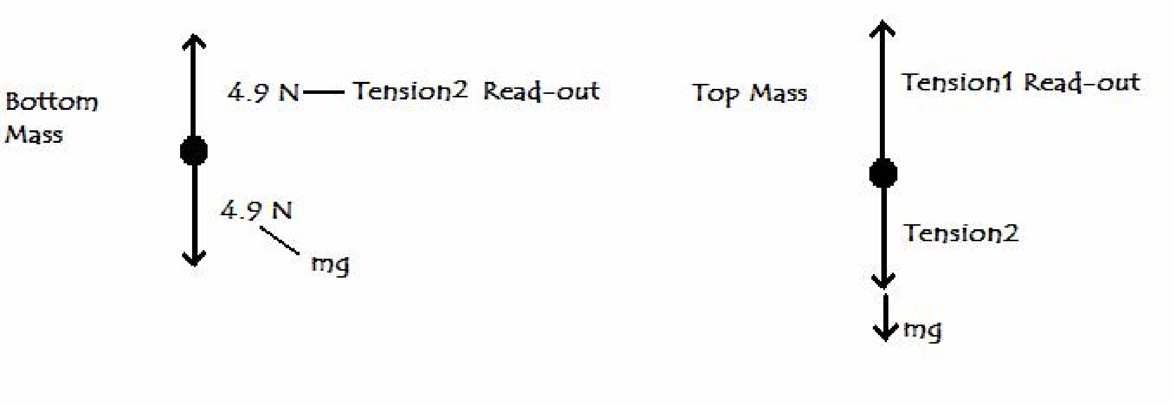
Set Up:



Collected Data:

Mass 1 = .2kg
Mass 2 = .5kg

Calculations:



Tension 2 = m_2g

Tension 2 = **4.9N**

Tension 1 = $T_2 + m_1g$

Tension 1 = 4.9N + 1.96N

Tension 1 = **6.86N**

Analysis:

Percent Error in T_2

4.9 – 5N / 4.9N x 100% = 2.0%

Percent Error in T_1

6.86N – 7.5 / 6.86N x 100% = 9.3%

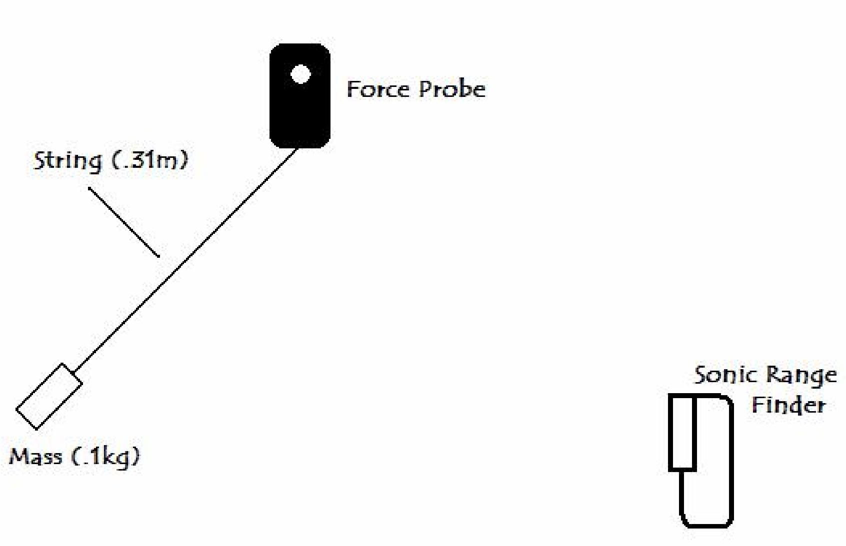
Error Analysis

The gauges and strings have masses – An incorrect assumption on our part and also on the rest of this station in this lab if the assumption that we are using massless gauges and strings. However these springs do have masses, which should heighten our calculated tensions once accounted for.

|| Station 6

Part 1

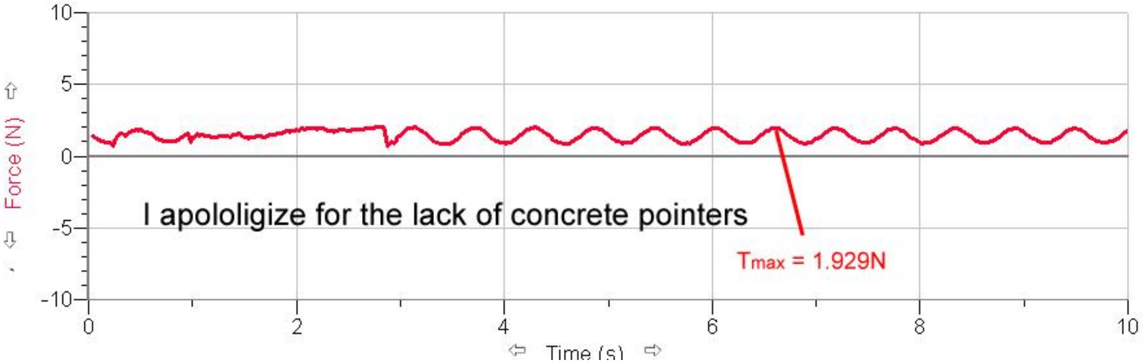
Set Up:



Collected Data:

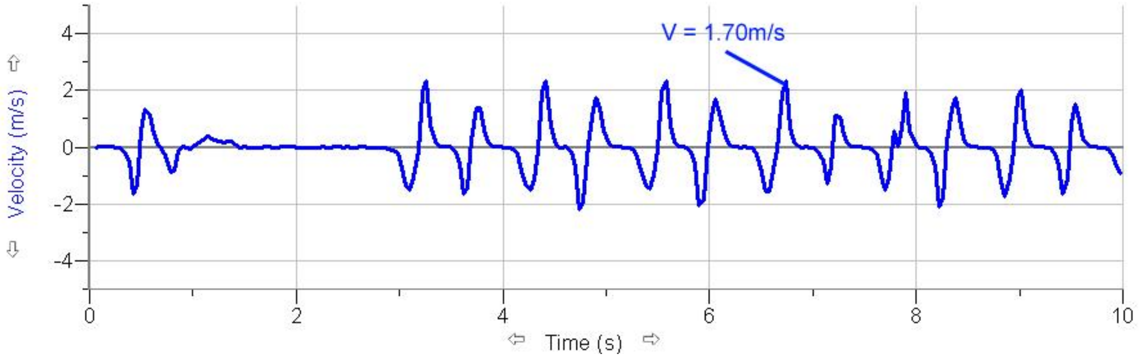
Length of String (r) = .31m
Mass of pendulum = .1 kg

Measured Tension and Velocity of Pendulum at Lowest Point



I apololigize for the lack of concrete pointers

T_{max} = 1.929N



Calculations:

Calculating F_c Using Known Velocity

$mv^2 / r = F_c$

$.1kg(1.70m/s)^2 / .31m = .932N$

Calculating F_c Using Known Tension

At bottom of swing $F_c = T - mg$

1.929N – .98N = .949N

Analysis:

Average Error of F_c

.932 – .949 / .941 x 100% = 1.8%

Error Analysis

Accuracy of Sensors – As I noticed on the graph, the time that the force probe read out greatest did not exactly correspond to the time the velocity was at its maximum. This may be caused by how fast data is read by the computer. Had I counted for the slight time shift, the velocity would have been greater and thus its calculated F_c just slightly higher.

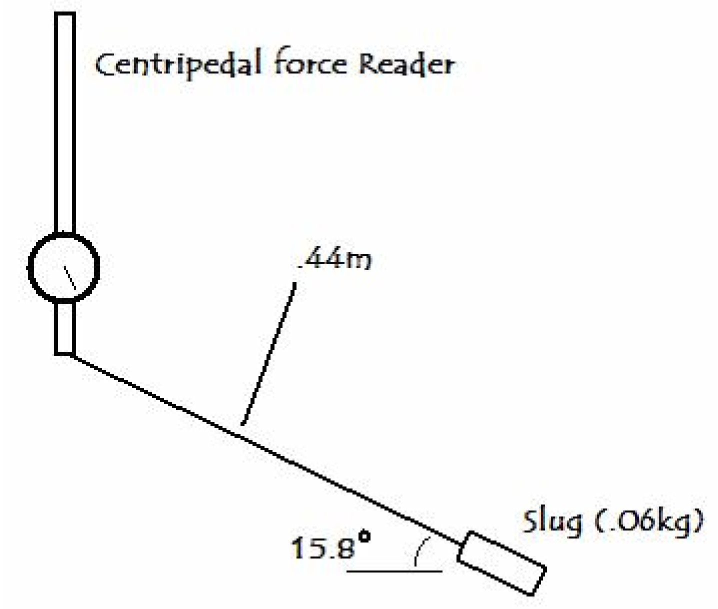
Questions

Does friction play a role in either of these experiments? If so, in what "direction"?

Interestingly enough, I don't believe that friction plays a huge role at all. When the velocity lowers in the pendulum due to friction, so does the Force probe read a lower value accordingly.

Part 2:

Set Up:



Collected Data:

Weight slug = .6N
Tension read out = 2.2N
Length at that given Force = .44m

Time for 20 revolutions: 13.10s

Calculations:

Angle of Elevation (Slug to Pole)
Vertical Forces Cancel

$$.6N = 2.2\sin(\theta)$$
$$15.8° = \theta$$

Radius of Path of Slug (Radius for 1 Revolution)

$$.44\cos(15.8°) = .423m$$

Circumference of Path

2πR = Circumfrence

2π(.423m) = 2.658m

Total Distance Traveled

Circumfrence x 20

.2.658m x 20 = 53.156m total

Velocity of Slug

Distance traveled / time = Velocity

53.156m / 13.20s = 4.058m/s

F_c of Slug

$mv^2 / R = F_c$

$.0612kg(4.058m/s)^2 / .423 = F_c$

$2.382 = F_c$

Calculating F_c due to Force Reading

2.2cos(15.8°) = 2.12N

Analysis:

Average Percent Difference

2.382N – 2.12N / 2.247N x 100% = 12.0%

Error Analysis

Imprecision of the Device – In this part of the lab, a common human error that couldn't be helped was the way Ryan handled the rotating rod. As most people would do, Ryan gave not consistent force, but instead a quick burst of force to accelerate the slug and keep it rotating around in a circle. This made it quite hard for Peter to note the exact force of the rod, however from the clue, "It was mostly around 2.2N". I deduce that he was actually reading the tension force at its lowest point where it stayed most of the time until Ryan gave it a burst of force. Had the actual tension on the string been read out it would be higher that what we had, making our calculated F_c via tension higher. A simple correction would be to consistently add force to the swinging slug so that the force read out constant.

Questions

Can you eliminate from your analysis the angle the string & slug system makes with the horizontal? (That is, can you make it really small?)

The only way to make the angle 0 would be to put infinite tension in the rod, which is impossible. Also, trying to put that much force into swinging a slug is quite dangerous.

|| Conclusion

Since it has been a long ways away since I stated my abstract, let me remind you that the purpose of this lab was to prove some essential conservation laws in a variety of ways. I believe that in all our stations we have presented beyond doubt that laws such as Newton's 2nd law and the conservation on momentum and energy do exist.

Although error, both human and experimental was quite common throughout our lab work, most of the error is accounted for. Through numerous trials we and verified the usefulness of the laws crucial to the understanding of Physics.