□PHYS115 ✓PHYS121 □PHYS123
□PHYS116 □PHYS122 □PHYS124

Lab Cover Letter

Author (*You*) Trevor N. Signature: Trevor N.

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Lab Partner(s) Katherine Chen

Date Performed 21/02/2024 Date Submitted 28/02/2024

Lab (*such as #1: UNC*) #3: CME

TA: Philip

GRADE (*to be filled in by your TA*) See your TA for detailed feedback.
An '*x*' next to a subcategory means you need to improve this aspect of your work.

***Paper Subtotals* (points)**

( ) ***General* (6)**
____ Sig. figs.
____ Units
____ Clarity of Presentation
____ Format

( ) ***Abstract* (4)**
____ Quantity or principle
____ How measurement was made
____ Numerical Results
____ Conclusion

( ) ***Intro & Theory* (9)**
____ Basic principle
____ Main equations to be used
____ Apparatus
____ What will be plotted
____ Fitting parameters related

( ) ***Exp. Procedures* (15)**
____ Description
____ Stating and justifying uncertainties
____ Data Record
____ Quality of Lab Work

( ) ***Analysis & Error Analysis* (20)**
____ Discussion
____ Equations & Calculations
____ Presentation inc. Graphs, Tables
____ Results Reported & Reasonable
____ Underlined items addressed

( ) ***Discussion & Conclusions* (6)**
____ Numerical comparison of results
____ Logical conclusions
____ Discussion of pos. errors
____ Suggestions to reduce errors

( ) **Paper Total (60 points)**
(30 points for CME or EPF)

( ) **Notebook (10 points)**
____ Format (*proper style, following directions*)
____ Apparatus (*brief description of equipment, including sketches*)
____ Data (*including computer file names and manually recorded data*)
____ Experimental Technique (*describing your procedures; stating & justifying uncerts.*)
____ Analysis (*results and errors*)

( ) **Worksheet(s)/Fill-in-the-Blank-Report (30 points)** *if applicable*

( ) **Adjustments** – late submissions, improper procedures, etc. – or bonus points for exceptional work.

( ) Total Grade

Graded by ___________ *(TA's initial)*

Abstract

The purpose for this lab is to establish whether energy is truly conserved when stored and transferred between springs, gravity (height), and motion.

$$\begin{aligned}\text{Expected energy loss in GPE:} \quad & \frac{\Delta E}{\Delta y} = -0.033 \pm 0.003 \ \frac{J}{m} \\ \text{Actual enegy loss in GPE:} \quad & \frac{\Delta E}{\Delta y} = -0.056 \pm 0.002 \ \frac{J}{m}\end{aligned}$$

$$\begin{aligned}\text{Expected friction loss in spring movement:} \quad & \Delta E = -0.017 \pm 0.002 \ J \\ \text{Actual friction loss in spring movement:} \quad & \Delta E = -0.029 \pm 0.001 \ J \\ \text{Total energy lost:} \quad & \Delta E = -0.081 \pm 0.01 \ J \\ \text{Total energy lost:} \quad & \epsilon = -16 \pm 2\%\end{aligned}$$

Our expected values for energy loss and actual values slightly differed, with the system losing more energy than we expected. We ultimately attributed this to additional unmeasured friction and spring dampening, thus not disproving the theory of energy conservation.

Gravitational Potential Energy

Finding Friction

Method

- Ensure Plane is level
- Gradually add weight until the cart has constant velocity
- Measure the mass needed to offset the friction

Data

Trial	$m_c\ (g)$	$m_p\ (g)$
1	988.0	3.4
2	987.4	3.4
3	987.3	3.3
4	987.6	3.4
5	987.8	3.3
6	988.0	3.4
7	987.6	3.4
8	987.6	3.3
9	987.7	3.4
10	987.9	3.4

Trial	$m_c\ (g)$	$m_p\ (g)$
Mean	987.74	3.37
STD.	10.1	0.3

Analysis

Finding W

$$F_f \approx m_p g$$
$$W \approx W_f = F_f \cdot d$$
$$= -m_p g d$$
$$W = -0.0330597d$$

$$\delta_W = \delta_{W m_p} = \delta_{m_p} g d = 0.002943d$$

$$W = d(-0.0330597 \pm 0.002943)$$

Analytical Conclusion

We estimate the energy lost to friction will be equal to $\frac{\Delta E}{\Delta y} = -0.033 \pm 0.003\ \frac{J}{m}$

Where Δy is the distance traveled

Checking energy loss

Method

- Add 50g of weight to a system that is already in balance
- Record position, velocity, acceleration
- Calculate energies and energy loss

Data

Time	Distance	Velocity	Acceleration	Kinetic Energy	Potential Energy	Total Energy
0.1517	0					
0.23995	0.015	0.19139	0.48532	0.01907	-0.00785	0.01121
0.31179	0.03	0.22557	0.46638	0.02649	-0.01571	0.01078
0.37425	0.045	0.25461	0.46362	0.03375	-0.02356	0.01019
0.4303	0.06	0.28013	0.44698	0.04085	-0.03141	0.00944
0.48174	0.075	0.30293	0.43929	0.04777	-0.03927	0.0085
0.52959	0.09	0.32366	0.42702	0.05453	-0.04712	0.00741

Time	Distance	Velocity	Acceleration	Kinetic Energy	Potential Energy	Total Energy
0.5746	0.105	0.34269	0.41856	0.06113	-0.05497	0.00616
0.61726	0.12	0.36069	0.42563	0.06772	-0.06283	0.0049
0.65788	0.135	0.37853	0.45298	0.07459	-0.07068	0.00391
0.69661	0.15	0.39723	0.5125	0.08214	-0.07853	0.00361
0.73349	0.165	0.41593	0.5012	0.09005	-0.08639	0.00367
0.7688	0.18	0.43341	0.4893	0.09779	-0.09424	0.00354
0.80276	0.195	0.45011	0.49413	0.10546	-0.10209	0.00337
0.8355	0.21	0.46477	0.40156	0.11245	-0.10995	0.0025
0.86733	0.225	0.4768	0.35424	0.11834	-0.1178	0.000543
0.89843	0.24	0.48828	0.38362	0.12411	-0.12565	-0.00155
0.92879	0.255	0.50038	0.41339	0.13033	-0.13351	-0.00317
0.95841	0.27	0.5127	0.41874	0.13683	-0.14136	-0.00453
0.98732	0.285	0.52495	0.42854	0.14345	-0.14921	-0.00577
1.01557	0.3	0.53901	0.56704	0.15124	-0.15707	-0.00583
1.043	0.315	0.55435	0.55176	0.15997	-0.16492	-0.00495
1.06971	0.33	0.56816	0.48226	0.16804	-0.17277	-0.00474
1.09582	0.345	0.58104	0.50449	0.17575	-0.18063	-0.00488

Analysis

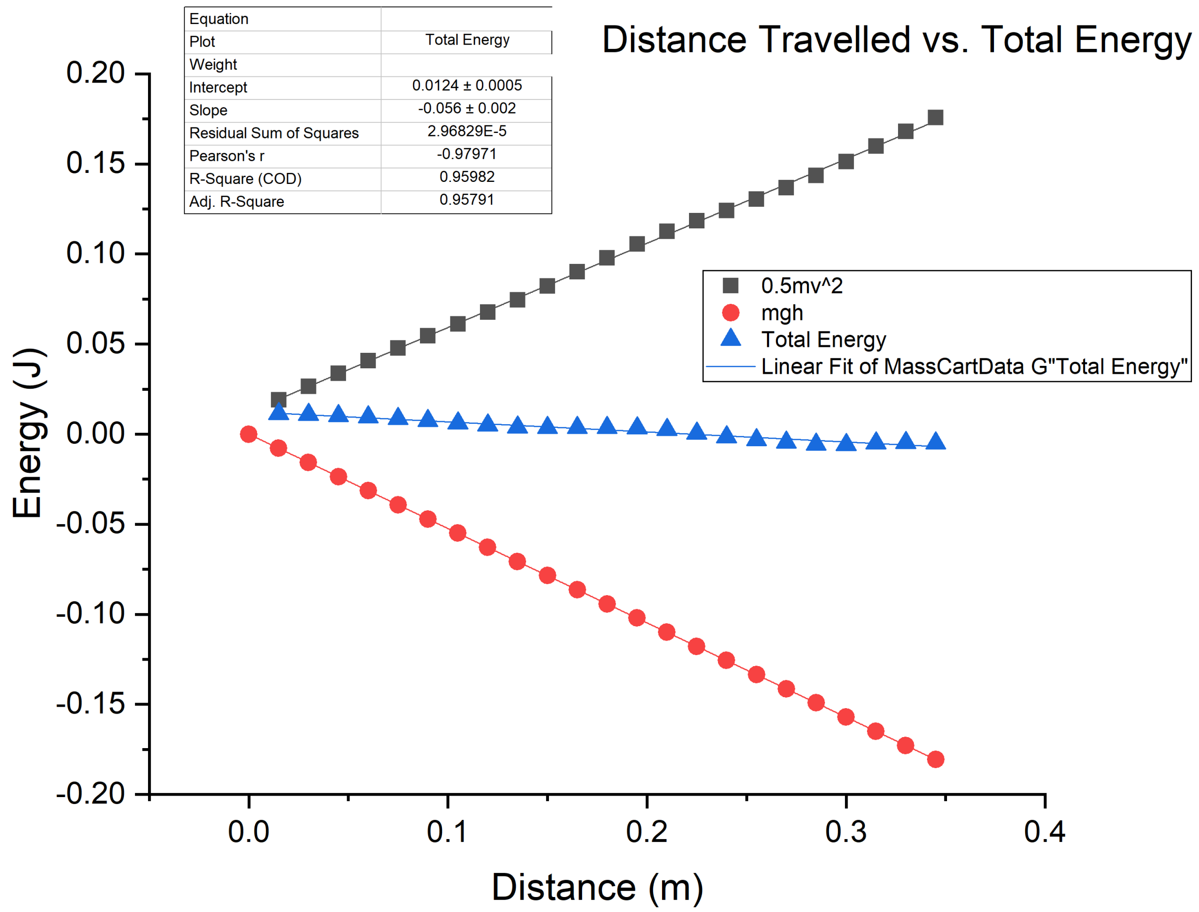

Fig 1: Kinetic, Gravitational Potential, and Total Energy vs. distance traveled

Finding W

$W = -0.0330597d$
$W = -0.0330597(0.345)$
$W = -0.0114055965\ J$

$\delta_W = 0.002943d$
$\delta_W = 0.002943(0.345)$
$\delta_W = 0.001\ J$

$W = -0.011 \pm 0.001\ J$

Estimating energy loss

From the graph, our slope is
$\frac{dE}{dy} = -0.056 \pm 0.002$

$\Delta E = \frac{d\Delta E}{dy} d$
$= -0.056(0.345)$
$= -0.01932\ J$

$\delta_{\Delta E} = \delta_{\frac{d\Delta E}{dy}} d$
$= 0.002(0.345)$
$= 0.00069\ J$

$\Delta E = -0.01932 \pm 0.0007\ J$

Analytical Conclusion

From our prior estimate of energy lost to friction, we estimate that
$\Delta E = -0.011 \pm 0.001\ J$

Experimentally, we have instead determined that we lost
$\Delta E = -0.01932 \pm 0.0007\ J$

We deduced that there is likely significantly more friction in the system due to the non-negligible increase of force on the pulley, as well as significantly more air-resistance due to the larger weight.

Spring Potential Energy

Finding the Spring Constant

Method

- Put a meter stick next to the string, parallel, with numbering visible from the side through the string
- Measure the tip of the hook of the spring at different weights

Data

Weight (g)	Position (cm)
50.0	82.25
55.0	80.90
60.0	79.15
65.0	77.35
70.0	75.75
75.0	74.35
80.0	72.85
85.0	71.70
90.0	69.65
95.0	68.25
100.0	66.50

Analysis

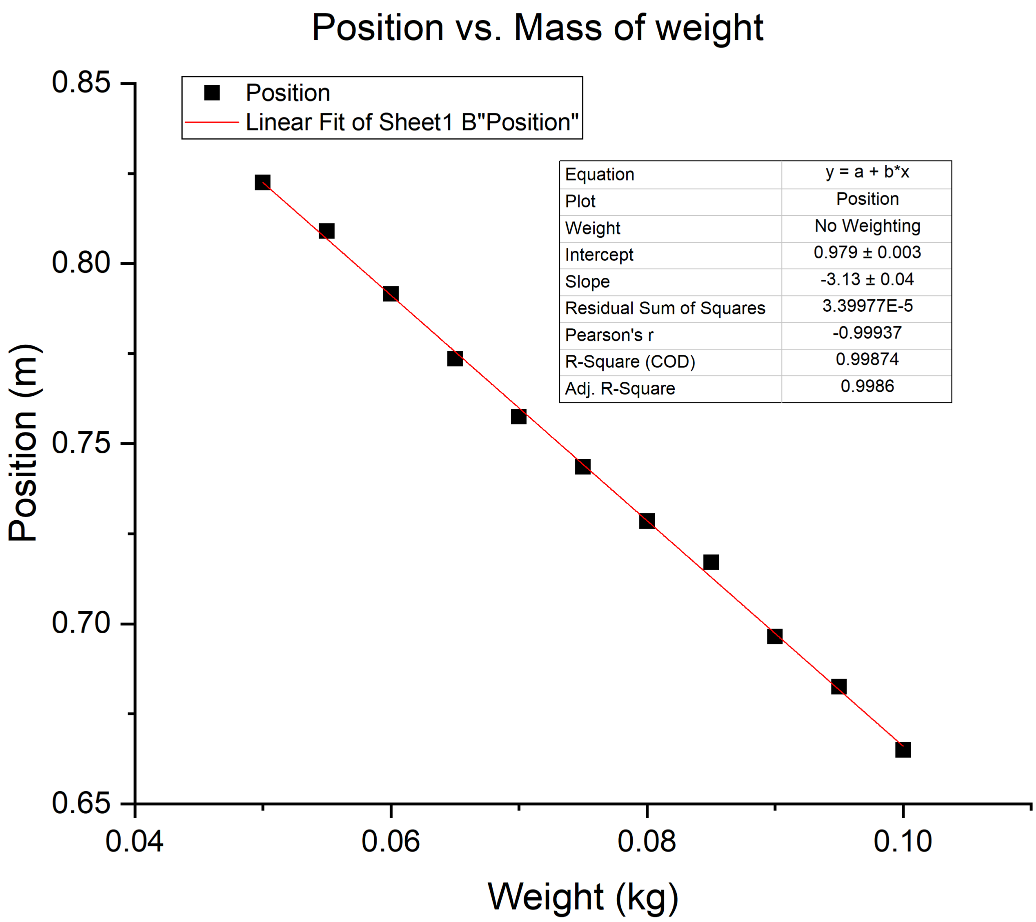

Fig 2: Position of the end of the spring vs. mass hung upon it

Finding k

The force on the spring can be calculated by the amount of mass hanging on it.

$$F_s = F_g = mg$$
$$F_s = k\Delta x$$

The slope represents: $\frac{d\Delta x}{dm}$

$$mg = k\Delta x$$
$$g = k\frac{d\Delta x}{dm}$$
$$k = \frac{g}{\frac{d\Delta x}{dm}}$$
$$k = \frac{9.81}{3.13}$$
$$k = 3.134\ \frac{N}{m}$$

$$k = \frac{g}{\frac{d\Delta x}{dm}}$$

The variance in g is negligible compared to that of $\frac{d\Delta x}{dm}$

Let $s = \frac{d\Delta x}{dm}$

$$\delta_k = \delta_{ks} = \delta_s \frac{g}{s^2}$$
$$= 0.04\left(\frac{9.81}{3.13^2}\right)$$
$$= 0.04\ \frac{N}{m}$$

$$k = 3.13 \pm 0.04\ \frac{N}{m}$$

Analytical Conclusion

Experimentally, we can deduce that the spring constant for our given spring is $k = 3.13 \pm 0.04\ \frac{N}{m}$

Finding Energy loss in the Spring

Data

At 100g of weight:

Trial	Max Excursion	Resting Position
1	42.80	66.55
2	42.25	66.55
3	40.35	66.55
4	41.10	66.55
Mean	41.8	
STD.	0.6	

$$\text{Unstretched Spring} = 93.90\ \text{cm}$$

Analysis

Finding Energy Values

In all cases, the uncertainty of the hanging mass is negligible at around $0.00001\ kg$ as the other uncertainties are multiple orders of magnitude larger

U_{ki}

$$U_{ki} = \frac{1}{2}kx^2 = 0\ J$$

$$\delta_{U_{ki}} = \delta_{U_{ki}k} = \delta_k \frac{1}{2}x^2$$
$$= 0$$

$$U_{ki} = 0 \pm 0\ J$$

U_{kf}

$U_{kf} = \frac{1}{2}kx^2$
$= \frac{1}{2}3.134(0.9390 - 0.418)^2$
$= 0.4253\ J$

$\delta_{U_{kf}} = \sqrt{\delta^2_{U_{kf}k} + \delta^2_{U_{kf}x}} = \sqrt{(\delta_k \frac{1}{2}x^2)^2 + (\delta_x kx)^2}$
$= \sqrt{(0.04(0.5)(0.9390 - 0.418)^2)^2 + (0.006(3.134)(0.9390 - 0.418))^2}$
$= 0.01\ J$

$U_{kf} = 0.43 \pm 0.01\ J$

U_{gi}

$U_{gi} = mgh = 0\ J$

$\delta_{U_{gi}} = \delta_{U_{gi}h} = \delta_h mg$
$= 0$

$U_{gi} = 0 \pm 0\ J$

U_{gf}

$U_{fg} = mgh$
$= -0.1(9.81)(0.9390 - 0.418)$
$= -0.5111\ J$

$\delta_{U_{gf}} = \delta_{U_{gf}h} = \delta_h mg$
$= 0.006(0.1)(9.81)$
$= 0.006$

$U_{gf} = -0.511 \pm 0.006\ J$

ΔE

$\Delta E = U_{gf} + U_{kf} - U_{gi} - U_{ki}$
$= 0.43 - 0.511 = -0.081\ J$

$\delta_{\Delta_E} = \sqrt{\delta^2_{U_{gf}} + \delta^2_{U_{kf}}}$
$= \sqrt{0.01^2 + 0.006^2}$
$= 0.01\ J$

$\Delta E = -0.081 \pm 0.01\ J$

W_f Estimated

$W_f = d(-0.0330597 \pm 0.002943)$
$W_f = (0.9390 - 0.418)(-0.0330597 \pm 0.002943)$

$W_f = -0.0172241037 \pm 0.001533303$
$W_f = -0.017 \pm 0.002 \ J$

$\frac{dW_f}{d\Delta E} \approx 20.99\%$

W_f Experimental

$W_f = d(-0.056 \pm 0.002)$
$W_f = (0.9390 - 0.418)(-0.056 \pm 0.002)$
$W_f = -0.029176 \pm 0.001042$
$W_f = -0.029 \pm 0.001$

$\frac{dW_f}{d\Delta E} \approx 35.80\%$

Finding ϵ

$$\epsilon = \frac{\Delta U_k + \Delta U_g}{|\Delta U_g|}$$
$$= \frac{0.43 - 0.511}{0.511}$$
$$= -0.1585$$

$$\delta_\epsilon = \sqrt{\delta^2_{\epsilon U_{kf}} + \delta^2_{\epsilon U_{gf}}} = \sqrt{\left(\frac{\delta_{U_{kf}}}{|U_{gf}|}\right)^2 + \left(-\frac{\delta_{U_{gf}} U_{kf}}{U_{gf}^2}\right)^2}$$
$$= \sqrt{\left(\frac{0.01}{0.511}\right)^2 + \left(\frac{0.006(0.43)}{0.511^2}\right)^2}$$
$$= 0.02$$

$\epsilon = -0.16 \pm 0.02$
$\epsilon = -16 \pm 2\%$

Analytical Conclusion

We experimentally determined that in this system, we lose about $\epsilon = -16 \pm 2\%$ of the energy when transferred from Gravitational potential to kinetic and finally to spring potential energy. We also attribute the loss in energy mainly to the dampening of the spring, as our expected friction due to the system calculated in the first part of the lab only accounts for a loss of $W_f = -0.017 \pm 0.002 \ J$ while our total energy loss is $\Delta E = -0.081 \pm 0.01 \ J$

Conclusion

We conclude that energy is conserved as our estimated values for friction and actual energy loss in the first section of this lab line up pretty closely. Although they are not within the statistical limits to be likely equal, we determined that the additional energy loss in the first lab was due to additional friction due to the substantial increase in weight, and thus normal force upon the pulley. In the second half of the lab, we determined we lose about $16 \pm 2\%$ of the energy when the energy is transferring from gravitational potential to kinetic and finally to spring potential. Although roughly 21% of the energy lost could be explained by the same frictional constant we determined in the first part of the lab, we deduce that the remaining energy loss is due to dampening in the spring and other additional frictions due to and even more substantially increased weight from the first lab and a higher tension due to the spring as well. If we use the experimental value for friction from the first lab, we can estimate energy lost to friction to be about 36% of all energy lost. This leaves us with approximately 10% of energy transferred lost due to spring dampening, which is a very rational loss for a spring.

Although we do lose more energy compared to what theoretically should be happening, we deduce that the additional energy loss is due to our imperfect system and measurement techniques, leading to marginally more energy lost overall. Since the number is not drastically inequivalent, we conclude that energy is indeed conserved.

$$\begin{aligned}
\text{Expected energy loss in GPE:} \quad & \frac{\Delta E}{\Delta y} = -0.033 \pm 0.003 \ \frac{J}{m} \\
\text{Actual enegy loss in GPE:} \quad & \frac{\Delta E}{\Delta y} = -0.056 \pm 0.002 \ \frac{J}{m} \\
\\
\text{Expected friction loss in spring movement:} \quad & \Delta E = -0.017 \pm 0.002 \ J \\
\text{Actual friction loss in spring movement:} \quad & \Delta E = -0.029 \pm 0.001 \ J \\
\text{Total energy lost:} \quad & \Delta E = -0.081 \pm 0.01 \ J \\
\text{Total energy lost:} \quad & \epsilon = -16 \pm 2\%
\end{aligned}$$

Acknowledgements and info

- Lab #3
- 21/02/2024
- Station 14 Rockefeller 404
- PHYS 121

Lab Partner: Katherine Chen
Lab Manual: Lab 3 CME PHYS 121

Spring Potential energy

Trevor & Katherine PHYS 121 LAB 3 CME Station 14

Weight (g)	Position (cm)
50.0	82.25
55.0	80.90
60.0	79.15
65.0	77.35
70.0	75.75
75.0	74.35
80.0	72.85
85.0	71.70
90.0	69.65
95.0	68.25
100.0	66.50

We put a meterstick next to the spring, parallel and looked perpendicular to both the spring & meterstick and recorded the position of the end of the spring

Unstretched Spring: 93.90cm

Max. Excursion: ~~52.00cm~~ ~~41.10cm~~

Mass: 100.0g

Rest pos: 66.55cm

M=100.0g Unstretched=93.90cm

Trial	Max (cm)	Resting position (cm)
1	42.80	66.55
2	42.95	66.55
3	40.35	66.55
4	41.10	66.55
Mean	41.8	
Std. Err.	0.6	

$$x = \frac{mg}{k} + x_0$$

$$x = \frac{g}{k} m + x_0$$

$$\frac{g}{k} = -3.13 \pm 0.04$$ From Origin

$$x_0 = 0.979 \pm 0.003$$

$$k = \frac{g}{-3.13} = -3.134185 \text{ N/m}$$

$$\delta_k = \delta_{k_s} = \delta_s \cdot \frac{-g}{s^2} =$$

$$0.003 \cdot \frac{-9.81}{3.13^2} = 0.003 \text{ N/m}$$

$$k = 3.134 \pm 0.003 \text{ N/m}$$

Max movement $= 93.90 - 41.8 = \boxed{52.1 \pm 0.6\,\text{cm}}$

Spring Potential energy

Weight (g)	Position (cm)
50.0	82.25
55.0	80.90
60.0	79.15
65.0	77.35
70.0	75.75
75.0	74.35
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100.0	66.50

We put a meterstick next to the spring, parallel and looked perpendicular to both the spring & meterstick and recorded the position of the end of the spring

Unstretched Spring: 93.90cm

Max. Excursion: ~~52.00cm~~ ~~[illegible]~~

Mass: 100.0g

Rest Position: 66.55cm

M = 100.0g Unstretched = 93.90cm

Trial	Max (cm)	~~[illegible]~~ Resting position (cm)
1	42.80	66.55
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$$x = \frac{mg}{k} + x_0$$

$$x = \frac{g}{k} m + x_0$$

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$$x_0 = 0.979 \pm 0.003$$

$$k = \frac{g}{-3.13} = -3.134185 \text{ N/m}$$

$$\delta_k = \delta_{k_s} = \delta_s \cdot \frac{-g}{s^2} =$$

$$0.003 \cdot \frac{-9.81}{3.13^2} = 0.003 \text{ N/m}$$

$$k = 3.134 \pm 0.003 \text{ N/m}$$

Max movement $= 93.90 - 41.8 = \boxed{52.1 \pm 0.6 \text{ cm}}$

$\frac{1}{2}kx^2$ mgh

Position (cm)	Spring Energy (J)	Grav. Energy (J)
0	0	0
52.1 (±0.6)	0.4253	-0.51058

$$\varepsilon = \frac{U_{kf} + U_{gf}}{|U_{gf}|} = \boxed{0.1670}$$

$$\delta_\varepsilon = \sqrt{\delta_{\varepsilon U_{kf}}^2 + \delta_{\varepsilon U_{gf}}^2}$$

$$\delta_{\varepsilon U_{kf}} = \delta_{U_{kf}} \frac{1}{|U_{gf}|}$$

$$\delta_{\varepsilon U_{gf}} = \delta_{U_{gf}} \cdot \frac{U_{kf}}{U_{gf}^2}$$

$$\delta_\varepsilon = \sqrt{\left(\delta_{U_{kf}} \frac{1}{|U_{gf}|}\right)^2 + \left(\delta_{U_{gf}} \cdot \frac{U_{kf}}{U_{gf}^2}\right)^2}$$

$x_i = 0$ $x_f = 52.1 \pm 0.6$

$U_{ki} = 0$ $U_{kf} = \frac{1}{2}kx^2 = 0.4253$

$U_{gi} = 0$ $-mgx = -0.51058$

$$\delta_{U_{gf}} = \delta_{U_{gfh}} = \delta_h mg$$ (mass & g errors are negligable)

$$\delta_{U_{kf}} = \sqrt{\delta_{U_{kfk}}^2 + \delta_{U_{kfx}}^2}$$

$$\delta_{U_{kfk}} = \delta_k \cdot \frac{1}{2}x^2$$

$$\delta_{U_{kfx}} = \delta_x \cdot kx$$

$$\delta_{U_{kf}} = \sqrt{\left(\delta_k \frac{1}{2}x^2\right)^2 + \left(\delta_x kx\right)^2} =$$

$$\delta_\varepsilon = \sqrt{\frac{\left(\delta_k \frac{1}{2}x^2\right)^2 + \left(\delta_x kx\right)^2}{U_{gf}^2} + \left(\delta_h mg \frac{U_{kf}}{U_{gf}^2}\right)^2}$$

$= 0.02$

$$\boxed{\varepsilon = 0.18 \pm 0.02}$$