

Physics Department
College of Science
Taibah University



First Semester
1442 Hj/2020

Booklet for

Mechanics Virtual Lab

Based on PHET interactive simulation

(<https://phet.colorado.edu>)



Courses: PHYS 1 & PHYS 103

(for the students of College of Engineering & College of
Computer Science and Engineering)

Prepared by:

Staff members of Department of Physics

القياسات العلمية ومهارات المعمل

Scientific Measurements and Lab Skills

التصثيل البياني للبيانات وتحليل البيانات Graphical Representation of Data & Data Analysis

تتمثل الاهداف في تعلم:

1. The aims are to learn how to:

a. represent the experimental data graphically.

b. calculate the physical parameters from graphs.

ا- تمثيل بيانات التجربه بيانياً

ب- حساب المعلمات الفيزيائية من الرسوم البيانية

2. Introduction:

تجرى التجارب العلمية في العادة لاكتشاف العلاقات بين معلمتين.

يتم تصميم التجربه بحيث يكونه المتغير في معلمه واحدة (معلمه مستقلة) تنتج تغير قابل للقياس في معلمه اخرى (معلمه تابعه).

• **Scientific experiments** are often carried out to discover the relationship between two parameters. The experiment is designed so that the change in one parameter (**independent parameter**) produces a measurable change in the other parameter (**dependent parameter**).

المعلمه المستقلة هي معلمه تتغير عن قصد المعلمه التابعه هي التي يتم ملاحظتها وقياسها

The **independent parameter** is the parameter that is changed intentionally. The **dependent parameter** is the observed/measured parameter.

غالباً يتم تنظيم البيانات في جدول

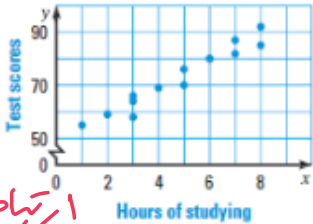
• The data collected in any experiment is often organized into a table.

Data may be **correlated** [Mrs. Grieser's math site*].

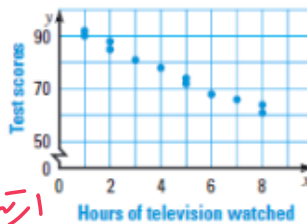
- **positive correlation:** increasing
- **negative correlation:** decreasing
- **relatively no correlation:** no apparent relationship between the data

ارتباط ايجابي: متزايد
ارتباط سلبي: تناقص

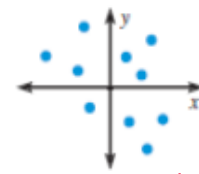
لا يوجد ارتباط نسبياً: لا توجد علاقة واضحة بين البيانات



ارتباط ايجابي
Positive correlation



ارتباط سلبي
Negative correlation



لا يوجد ارتباط
Relatively no correlation

*<https://sites.google.com/site/mrsgriesermath/>

غالباً ما تستخدم الرسوم البيانية لحساب المعلمات المحصوله لنظام التجربه اذا كانت صيغته التجربه معلومه

• **Graphs** of the collected data are often used to calculate unknown parameters of the experimental system if the system's formula is known.

تظهر المعلمه المستقلة على محور x والمعلمه التابعه على محور y

The **independent parameter** is shown on the x-axis and the **dependent parameter** is shown on the y-axis.

يجب ان يكون لهجا ور الرسم بقياس مناسب: يجب ان يوضع المقياس لجميع النقاط بوضوح. يجب ان تكون مقاييس المحاور مختلفه حسب القيم المعطاة. يجب عرض الوصلات المستقيمة

Axes of the graph should have an appropriate scale. The scale should show all the points clearly without having them too close or too far apart. The scales for the two axes can be different depending on the given values. The used units, if there are, should be displayed on each axis.

هناك عدة انواع من العلاقات الرياضيه التي يتم رسمها في الرسوم البيانيه، واكثرها شيوعا هو الرسم البياني (الخط المستقيم)

• There are several types of mathematical relation are plotted in graphs, two-dimensional straight-line (or curved-line) graph is most common.

حيث x هو المتغير المستقل و y هي متغير تابع

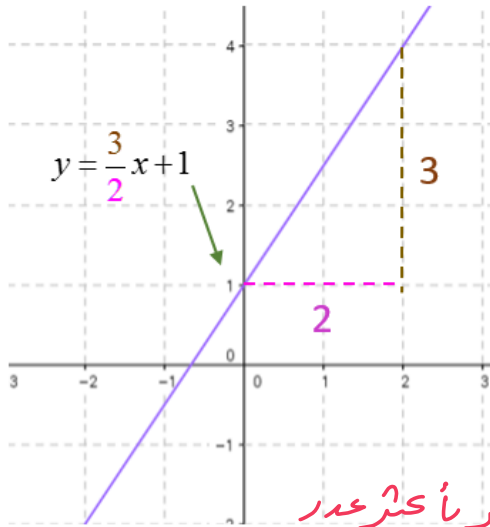
The general equation for a straight line is

m هو ميل الخط المستقيم و b هو الجزء المقطوع من محور y يعني قيمه عند $x=0$ صفر

$$y = mx + b$$

في هذه المعادله m و b ثابت

where x is the independent variable, y is the dependent variable, m is the slope of the straight line and b is the y -intercept, that is, the value of y when x equals zero. In this equation both m and b are constants. See figure 1.



• الخط الانسب هو الخط الذي يمر بأكثر عدد من النقاط مع مراعاة ان بقيه النقاط فوقه وتحت الخط وتنتشر على طول الخط بدلاً من التركيز في نهايه واحدة

Figure 1. slope and intercept in the linear relation.

الخط الانسب

3. The Line of Best Fit

• The line of best fit is the line that passes through as many points as possible, with the remaining points grouped equally above and below the line, and spread out along the line rather than concentrated at one end.

• The line of best fit is used to estimate the value of a physical parameter that is not actually recorded and plotted.

يتم استخدام الخط الانسب لتقدير قيمه المعلمه الفيزيائيه. كيف تصنف خط علائم

How to add a line fit?

1- رتب بياناتك في جدول (متغير مستقل مقابل متغير تابع)

1. Arrange your data in a table (independent variable versus the dependent variable)

2. Making a scatter plot: Describe any correlation seen. Decide whether the data can be modeled (does it show correlation?).

2. جعل نقطه مشتتة: صف أي ارتباط مرئي قرر ما اذا كانت البيانات تظهر الارتباط؟

اضافه خط مناسب: (العين) خط يبدو أنه يلائم البيانات بشكل وثيق. يجب أنه يكون هناك نقاط أعلى وأسفل الخط.

3. Adding a line fit: "Eyeball" a line that appears to fit the data closely. There should be about the same number of points above or below the line drawn as shown in figure 2.

ملاحظة: إذا كانت الصيغة المرسومة في الرسم البياني في $y = mx$ فيجب أن يكون الخط الأنسب

NOTE: If the formula plotted in the graph is in the form of $y = mx$, the fitting line should pass through the point $(0,0)$

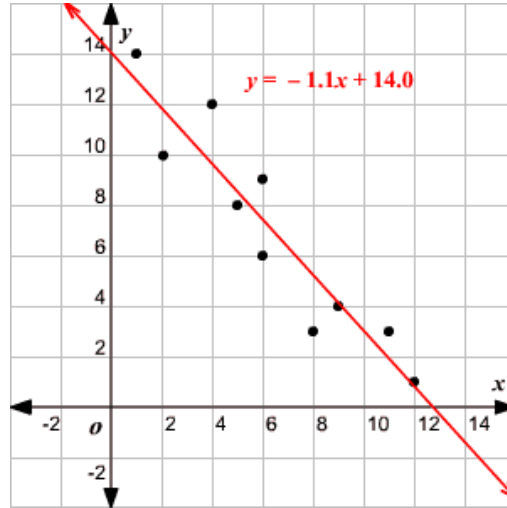


Figure 2. The line of best fit for scattered data.

لايجاد الميل للخط

To find the slope of the fitting line:

- Choose any two points on the line of best fit (i.e., (x_1, y_1) and (x_2, y_2)), not necessarily two data points. Next, draw a right triangle using these two points as shown in figure 3.
- Subtract the two y-coordinates from one another and subtract the two x-coordinates from one another. Divide the y-coordinate's result with the x-coordinate's result. Reduce the number if at all possible. The slope is

$$m = \frac{\Delta y}{\Delta x} = \frac{(y_2 - y_1)}{(x_2 - x_1)}$$

اختر نقطتين على الخط (x_1, y_1) و (x_2, y_2) . ليس بالضرورة نقطتين بيانات. بعد ذلك ارسم مثلث قائم الزاوية باستخدام النقطتين كما هو موضح. اطرح الاحداثيين y من بعضهما البعض واطرح الاحداثيين x من بعضهما البعض. اقسم نتيجة y على x .

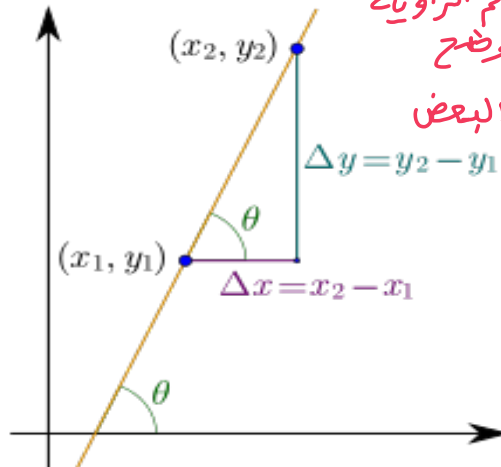


Figure 3. Calculation of the slope of a fitting line.

الخطأ المطلق (E): الفرق بين القيمة التجريبية (المقاسة) والقيمة الحقيقية. E له اتجاهات (+/-) ووحدته فيزيائية

انواع الاخطاء Errors Types

Absolute Error (E): The difference between the experimental (measured) value and the true value. Then, E has sign (+/-) and physical units:

$$E = \text{Exp. value} - \text{True value} = X_e - X_t$$

Relative Error (E_r): The absolute error corrected for the size of the measurement or expressed as the fraction, %, or parts-per-hundred (pph) of the true value. E_r has a sign,

but with no units: الخطأ النسبي: الخطأ المطلقة يصحح لحجم القياس (أو يعبر عنها بالكسر أو النسبة المئوية أو الأجزاء لكل مئة (PPH) من القيمة الحقيقية، رغم أنها حارة وليس لها وحدة

$$E_r = [(X_e - X_t) / X_t] * 100\%$$

HomeWorks:

1. Calculation of an unknown parameter when the system's formula is known

According to the laws of motion, the velocity of an object moving in the x-direction with a constant acceleration a_x at time t is given by

$$v_x = v_{x0} + a_x t$$

If the experimental data of the object velocity and the time is tabulated as

Time (s)	The object velocity (m/s)
10	48
20	73
30	108
40	133
50	165
60	193
70	228
80	253
90	285

Draw a line that appears to fit the points. Then, calculate the initial velocity of the object v_{x0} and the acceleration of the motion a_x .

Answer: $v_{x0} \sim 15 \text{ m/s}$ & $a_x \sim 3 \text{ m/s}^2$.

2. Derivation of formula from data

The table below shows the number of woodpecker clusters in a forest. Write an equation that models the number of active clusters as a function of the number of years since 1990. [Mrs. Grieser's math site *]

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000
Active clusters	22	24	27	27	34	40	42	45	51

- 1) Make a scatter plot.
- 2) Does the plot show a correlation? If so, we can fit a line to the data.

- 3) Draw a line that appears to fit the points (use a straight tool such as a thin pencil or dry spaghetti strand to help fit the line).
- 4) Write an equation for the line – find 2 points on the line.
 - two points _____
 - slope _____
 - equation _____

* <https://sites.google.com/site/mrsgriesermath/>

تجريبه ا:

Experiment 1:

تجريبه السقوط الحر

Free Falling Experiment

الهدف

1. Aims:

1- حساب تسارع الاجسام الساقطة سقوط حر بافتراض انه القوة الوحيدة المؤثرة هي قوة الجاذبية

1- Measure the acceleration of a falling object assuming that the only force acting on the object is the gravitational force.

2. اثبات انه التسارع المقاس هو تسارع الجاذبية

2- Prove that the measured acceleration is the acceleration due to gravity.

النظرية

2. Theory:

يقال انه الجسم الذي يتحرك فقط بتأثير الجاذبية يكون حر السقوط و سرعته موصوفة في قانون نيوتن الثاني للحركة

السقوط الحر للجسم حا
Free falling of an object:

An object that is moving only because of the action of gravity is said to be free

falling and its motion is described by Newton's second law of motion.

عندما يسقط الجسم في الفراغ يخضع لقوة خارجيه واحدة فقط وهي قوة الجاذبية ما يعبر عنها بوزن الجسم

When an object falls through a vacuum is subjected to only one external force, the gravitational force, expressed as the weight of the object.

تسارع الجاذبية g = تسارع الجسم

So, the acceleration of such object a = the acceleration due to gravity g .

حركه الجسم في السقوط الحر يتم وصفها بالمعادله التاليه

Then the motion of a free-falling object could be described as in the following

equation:

$$d = y - y_0 = v_{0y}t + \frac{1}{2}gt^2,$$

حيث d هي المسافه بين الموقع الابتدائي والنهائي العامودي و v_{0y} هي السرعه الابتدائيه

Where d is the distance between the initial and final vertical positions and v_{0y} is

the initial velocity of the free-falling object.

اذا السرعه الابتدائيه = صفر

If the initial velocity is $v_{0y} = 0$ so

$$d = +\frac{1}{2}gt^2$$

يمكن اعادة كتابه المعادله:

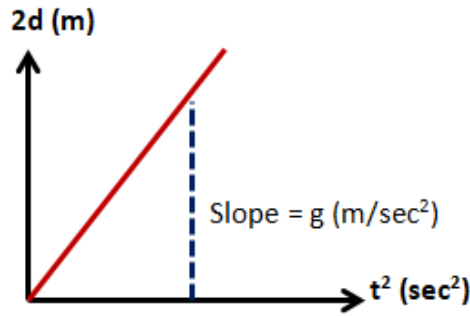
We can rewrite the equation as:

$$2d = gt^2$$

عند رسم t^2 (محور x) و $2d$ (محور y) بالنتيجه تكونه خط مستقيم يعبر بنقطه الاصل والميل g

When drawing t^2 (x - axis) and $2d$ (y - axis) . the result will be a straight

line passing through the origin and its slope = g



3. الخطوات Procedures

نستخدم هذا الرابط للحياة

We will use the following link of the PHET simulation:

https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion_en.html

1. Use the PHET simulator by clicking on the above link. Then, choose "lab" icon



استخدم محاكي PHET بالضغط على الرابط اعلاه ثم اضغط رمز (مختبر)

2. Adjust the cannon to be in the vertical position ($\theta = 90^\circ$) assuming the air resistance is 0.

ضع قيمة ابتدائية للسرعة

3. Adjust the initial velocity to 5 m/s.

اطلق الكرة بالضغط على هذا الزر



4. Launch the ball by pressing this button

احسب اعلى ارتفاع (d_{max}) والزمن (t_{max}) باستخدام هذه الايقونة

5. Measure the maximum height (d_{max}) and time (t_{max}) using this icon



, place the cross on the object at its maximum height.

كرر الخطوات 3 و 5 باستخدام سرعات ابتدائية مختلفة

6. Repeat steps 3 to 5 for different initial velocity of (10, 15, 20, 25 and 30 m/s)

احسب قيمة d_{max} و t_{max}

7. Calculate the value of $2(d_{max})$ and $(t_{max})^2$ for each measurement.

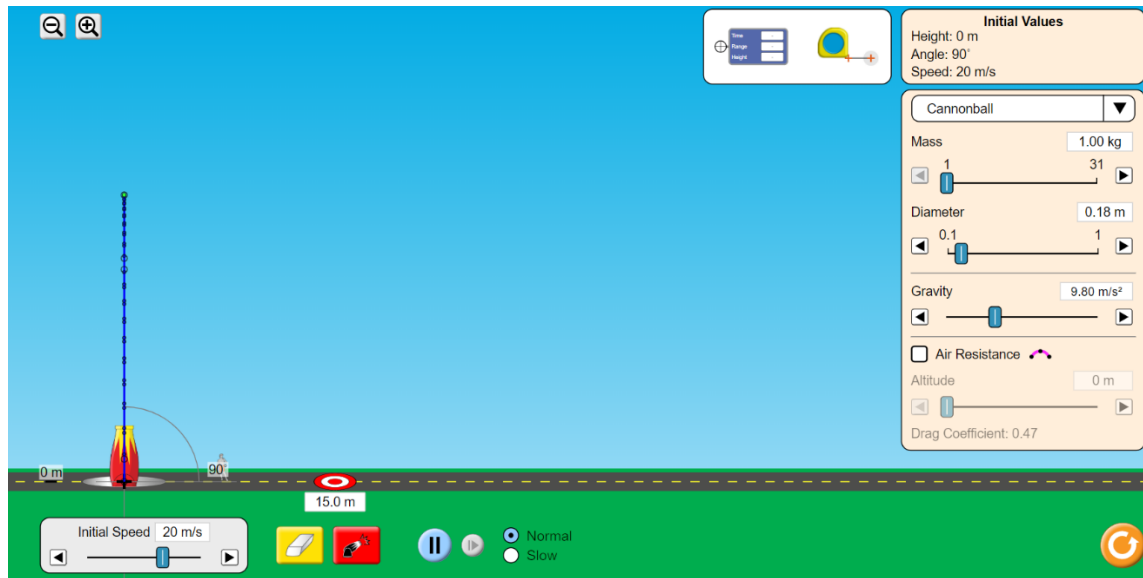


Figure 1. Simulation setup and its initial setting parameters

4. النتائج Results

1. You may record your results in the following table:

<i>free fall experiment</i>				
Inputs			Calculated values	
Initial velocity (m/s)	Maximum height d_{\max} (m)	Maximum time t_{\max} (sec)	$2d_{\max}$ (m)	$(t_{\max})^2$ (sec ²)
10				
12				
14				
16				
18				
20				
22				
24				
26				
30				

Table 1. Measured data

استخدم العلاقة

2. Using the relation:

$$d = y - y_0 = \frac{1}{2}gt^2$$

ارسم العلاقة بين $2d_{max}$ على محور y و $(t_{max})^2$ على محور x لرسم خط مستقيم يعبر نقطة الاصل. يحيل يساوي

3. Draw the relation between $(2d_{max})$ on the y-axis and $(t_{max})^2$ on the x-axis to get a straight line passing through the origin with slope = the acceleration due to gravity.

Acceleration due to the gravity (g) = Slope = m/s²

4. Compare your result with the theoretical value of the acceleration due to gravity

(9.8 m/s²)

قارنه نتائجك بالقيمه النظرية لتسارع الجاذبيه 9.8

Experiment 2:

Vectors

1. Aims

1. Learn how to represent a vector in space and determine its components.
2. Determine the resultant of adding two vectors.

2. Theory

Any vector quantity can be represented as a line segment where its length represents the magnitude of the vector, and the angle θ represent the direction of the vector as shown in figure 1. A vector can be resolved into two components; x – component (a_x) and y – components (a_y), their magnitudes can be determined using the equations:

$$a_x = a \cos \theta \quad (1)$$

$$a_y = a \sin \theta \quad (2)$$

where a is the magnitude of vector \vec{a} and θ is the angle the vector \vec{a} makes with the positive x – axis counterclockwise. We can use the following two methods to determine the resultant vector \vec{c} for two or three vectors:

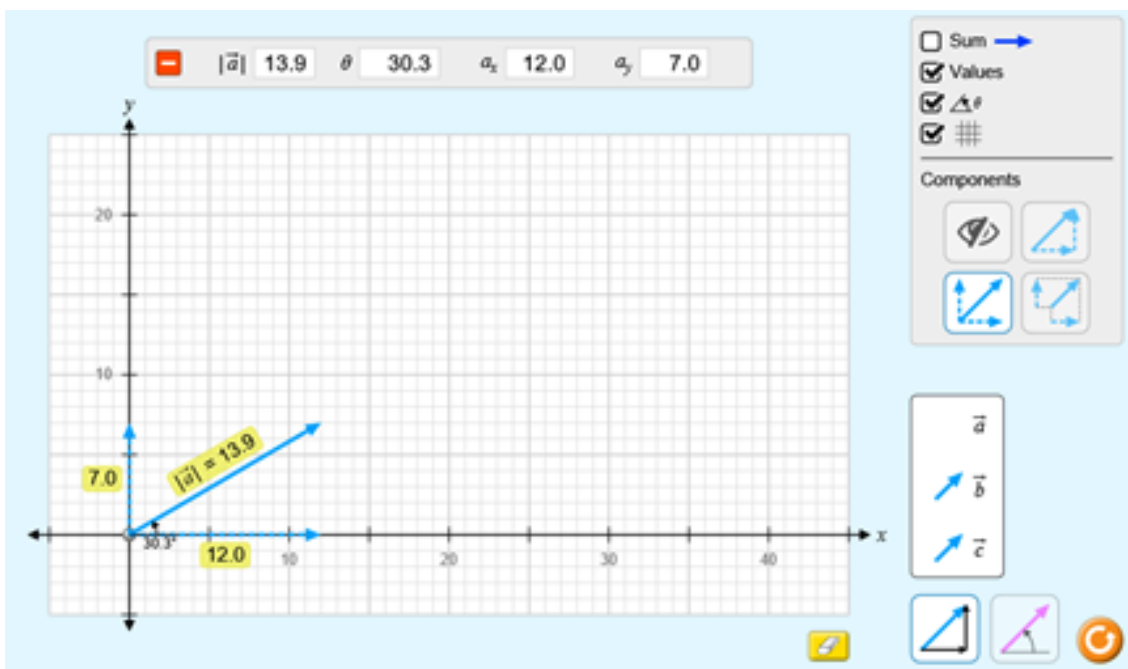


Figure 1. Vector representation

Analytical method

To determine the resultant vector, each added vector should be resolved into x and y components. Then, solving for the components of the resultant vector.

$$C_x = A_x + B_x \quad (3)$$

$$C_y = A_y + B_y \quad (4)$$

where C_x is the x-component of the resultant vector, C_y is the y-component of the resultant vector. The magnitude and direction of the resultant vector can be calculated using the following equations:

$$|\vec{R}| = \sqrt{(R_x)^2 + (R_y)^2}, \quad (5)$$

$$\theta_R = \tan^{-1} \left(\frac{R_y}{R_x} \right). \quad (6)$$

1- Graphical method

The resultant vector is calculated using head to tail method. Starting with drawing the first added vector. Then, draw the second added vector so that its tail is at the head of the first one. The resultant vector is that drawn from the tail of the first to the head of the last vector. The magnitude of the resultant vector is represented by the length of the line segment, while the direction is the angle it makes with the positive x-axis counter clockwise.

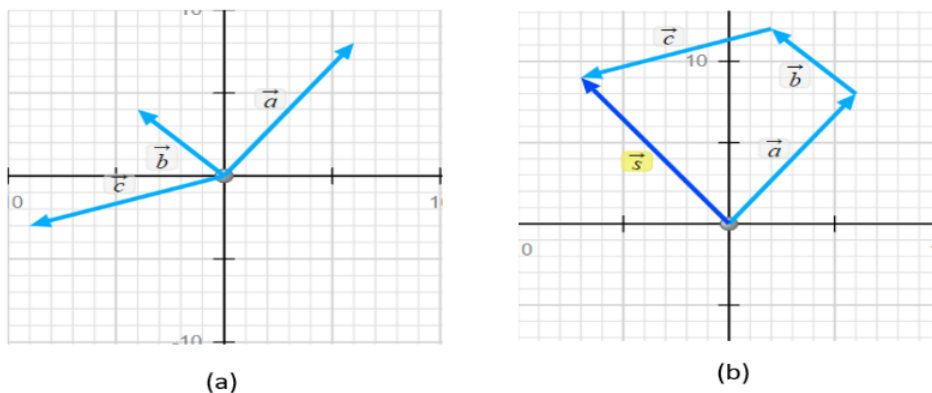


Figure 2a shows three vectors using PHET simulation, while figure 2b shows the method of adding such vectors using head to tail method.

3. Procedure and Results:

Part I: Finding the components of a vector

We will use the following link of the PHET simulation:

https://phet.colorado.edu/sims/html/vector-addition/latest/vector-addition_en.html

1. Open the vector addition PHET simulation. Select Explore 2D screen. The screen can be divided into sections as shown in figure 3.
2. Click on the P-panel and mark Values and θ .
3. Drag a vector d from vector panel (2) to graph paper (1) and move the tail of the vector to the origin and make the angle to be zero. Choose a certain length of the vector by moving its head to the length you like to have (figure 4 is an example).

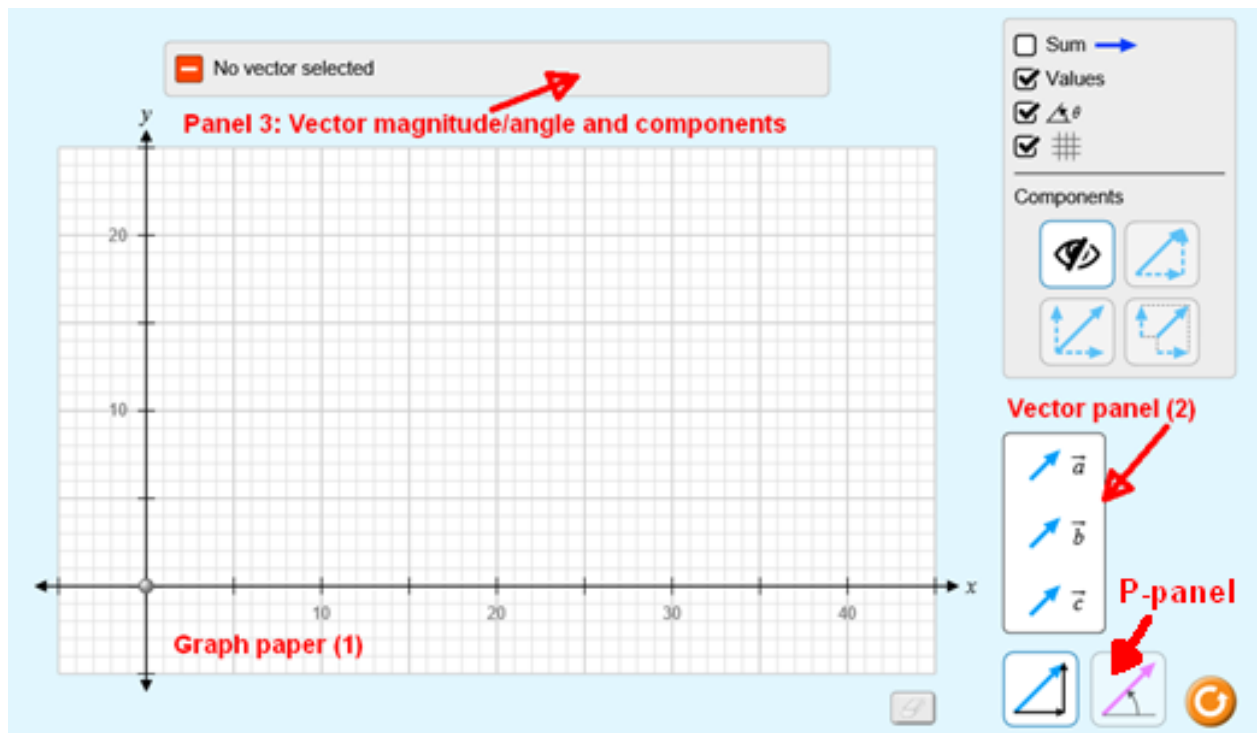


Figure 3. Simulation setup (Part I)

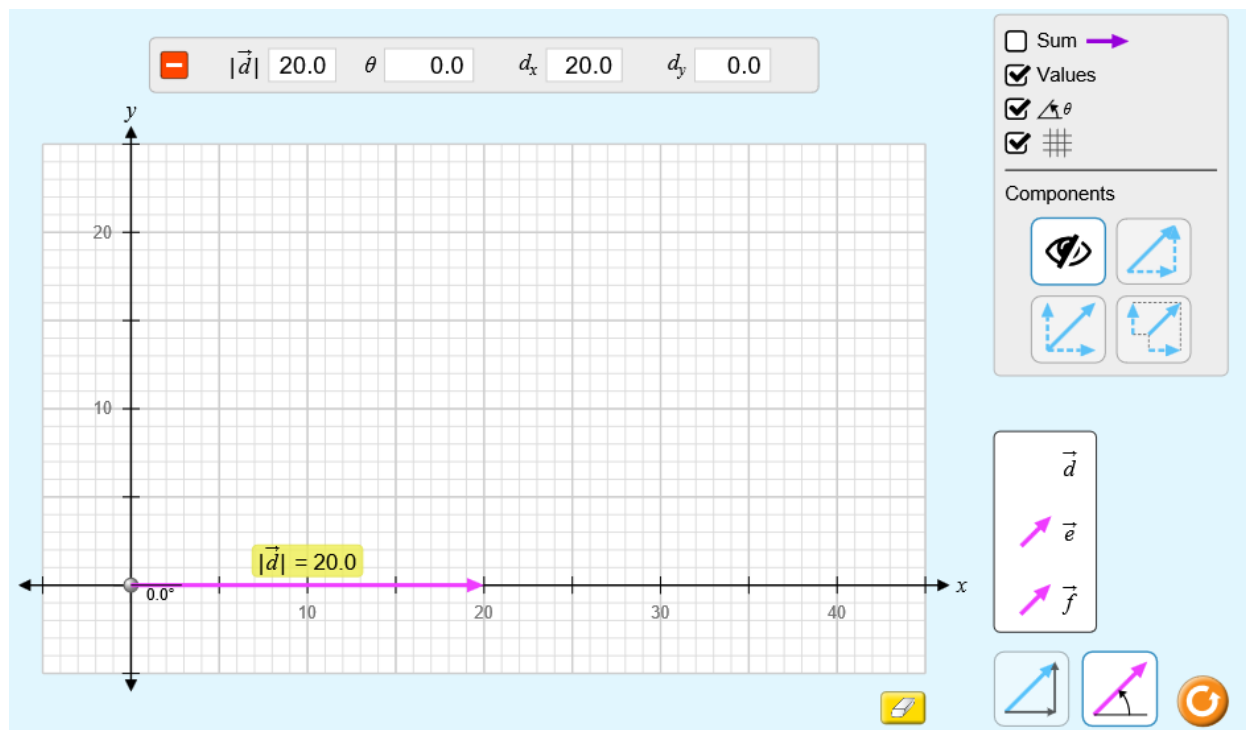


Figure 4. Example of vector creation

4. Write down the values of the vector's magnitude, angle, x-component, and y-component from panel (3) into column 2, 3, 4, 7, respectively, in Table 1 (below).
5. Find the x-component of the vector \vec{a} by using the formula $a_x = a \cos(\theta)$ and record the result in the column 5 of Table 1.
6. Find the y-component of the vector \vec{a} by using the formula $a_y = a \sin(\theta)$ and record the result in the column 8 of Table 1.
7. Increase the angle of the vector by pressing on its head and move counter-clockwise, but without changing its length. Repeat the experiment steps (4 – 6).
8. Repeat step 7 at different angles of the vector till an angle of 90° .

Table 1: Components of a Vector

No. obs.	magnitude	angle	x-component			y-component		
	a	θ	From panel 3	Calculated $a_x = a \cos \theta$	Error %	From panel 3	Calculated $a_y = a \sin \theta$	Error %
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
1		0						
2		10						
3		20						
4		30						
5		40						
6		50						
7		60						
8		70						
9		80						
10		90						

Part II: Finding the resultant of adding two vectors

1. Select EQUATIONS screen of the vector addition PhET simulation as shown in figure 5.
2. Adjust the suitable lengths and orientations of vectors \vec{a} and \vec{b} . You can control the component lengths of a vector using the base panel (5).

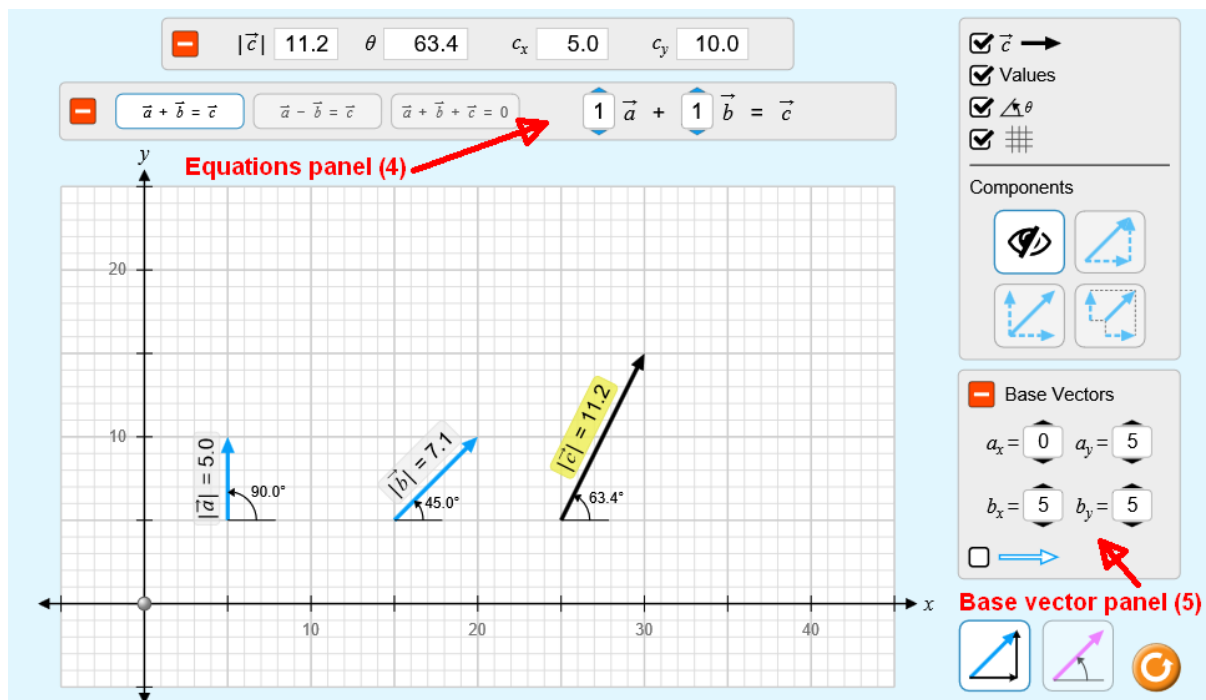


Figure 5. Simulation setup (Part II)

3. Record the length, angle, and components of vectors a , b , and the resultant vector c from panel (3), after clicking on each of them, in the respective cells in table 2 (below).
4. Calculate the x- and y-components of the vectors a and b using the formulas $a_x = a \cos(\theta)$, $b_x = b \cos(\theta)$, $a_y = a \sin(\theta)$, and $b_y = b \sin(\theta)$ and record the results in the respective cells of Table 2.
5. Calculate the x-component of the resultant vector \vec{c} by $c_x = a_x + b_x$
6. Calculate the y-component of the resultant vector \vec{c} by $c_y = a_y + b_y$
7. Calculate the magnitude of the resultant vector using the formula: $|\vec{c}| = \sqrt{(c_x)^2 + (c_y)^2}$
8. Calculate the angle of the resultant vector using the formula: $\theta_R = \tan^{-1}(c_y/c_x)$
9. Repeat steps (2-7) at different components of vectors \vec{a} and \vec{b} through Panel 5. Record the observed values in table 2. Compare between the observed and calculated values and determine the error.

*Table 2: Addition of two vectors
First trial*

First vector		Second vector		Resultant			
				calculated		observed	Error %
Magnitude	$a=10$	Magnitude	$b=10$	x- component	$c_x = a_x + b_x =$		%
Angle	$\theta =$	Angle	$\theta =$	y- component	$c_y = a_y + b_y =$		%
x- component	$a_x = a \cos \theta =$	x- component	$b_x = b \cos \theta =$	Magnitude	$ \vec{c} = \sqrt{(c_x)^2 + (c_y)^2} =$		%
y- component	$a_y = a \sin \theta =$	y- component	$b_y = b \sin \theta =$	Angle	$\theta_R = \tan^{-1}\left(\frac{c_y}{c_x}\right) =$		%

Second trial

First vector		Second vector		Resultant			
				calculated		observed	Error %
Magnitude	$a =$	Magnitude	$b =$	x- component	$c_x = a_x + b_x =$		%
Angle	$\theta =$	Angle	$\theta =$	y- component	$c_y = a_y + b_y =$		%
x- component	$a_x = a \cos \theta =$	x- component	$b_x = b \cos \theta =$	Magnitude	$ \vec{c} = \sqrt{(c_x)^2 + (c_y)^2} =$		%
y- component	$a_y = a \sin \theta =$	y- component	$b_y = b \sin \theta =$	Angle	$\theta_R = \tan^{-1}\left(\frac{c_y}{c_x}\right) =$		%

Third trial

<i>First vector</i>		<i>Second vector</i>		<i>Resultant</i>			
				<i>calculated</i>		<i>observed</i>	<i>Error %</i>
<i>Magnitude</i>	$a=$	<i>Magnitude</i>	$b=$	<i>x-component</i>	$c_x=a_x+b_x=$		%
<i>Angle</i>	$\theta=$	<i>Angle</i>	$\theta=$	<i>y-component</i>	$c_y=a_y+b_y=$		%
<i>x-component</i>	$a_x=a \cos \theta=$	<i>x-component</i>	$b_x=b \cos \theta=$	<i>Magnitude</i>	$ \vec{c} = \sqrt{(c_x)^2 + (c_y)^2} =$		%
<i>y-component</i>	$a_y=a \sin \theta=$	<i>y-component</i>	$b_y=b \sin \theta=$	<i>Angle</i>	$\theta_R = \tan^{-1}\left(\frac{c_y}{c_x}\right) =$		%

Experiment 3:

Newton's Laws of Motion

1. Aim

Verification of Newton's laws of motion, first and second laws.

PART I: Newton's First Law of Motion

2.1. Theory

Newton's first law of motion states that an object at rest remains at rest and an object in motion remains in motion with the same velocity unless acted upon by what we call an unbalanced force. Let's break this law down by defining some key terms; velocity and unbalanced force. Velocity is the speed of an object in a specified direction. An unbalanced force is an external force that changes the motion of an object. When an object is at rest or moving at a constant velocity, all the forces acting on it are balanced.

3.1. Procedure # A

We will use the following link of the PHET simulation:
https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_en.html

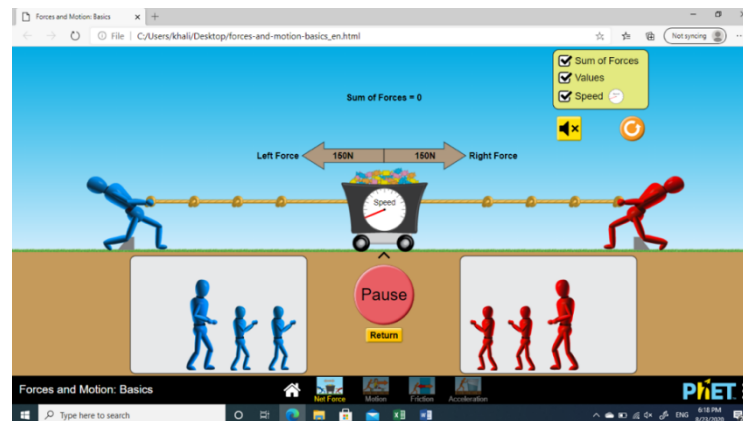


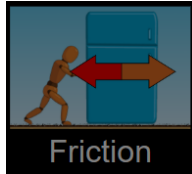
Figure 1. The setup of the “Net Force” window of the PHET simulator

For the first part of Newton's law, open the simulator. Then, press on “Net Force”

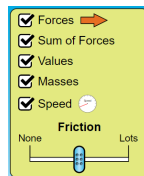


and choose two equal objects and pick them up as shown in figure 1. If two equal forces (balanced forces) acted on the object it will remain at rest (first part of Newton law).

For the second part of Newton's law, open the PHET simulator using the above link. Then



choose the “Friction” icon. The window shown in figure 2 will be presented.



1. Click on yellow panel and mark on “Sum of force”, “Values”, “Masses”, “speed”.
2. Pick up any box and places on the 50 kg box, see figure 2
3. Adjust the applied force at 90 N (you can choose any value).
4. Adjust the opposing friction force at 60 N (you can choose any value), then the resultant force will be 30 N.
5. Start the simulation.
6. The box will start moving with a certain speed.
7. Decrease the applied force or increase the friction force until the difference between them is zero (balanced forces).

At that point, you will notice that the box continues moving with a constant speed (zero acceleration), which demonstrates the second part of Newton's first law.

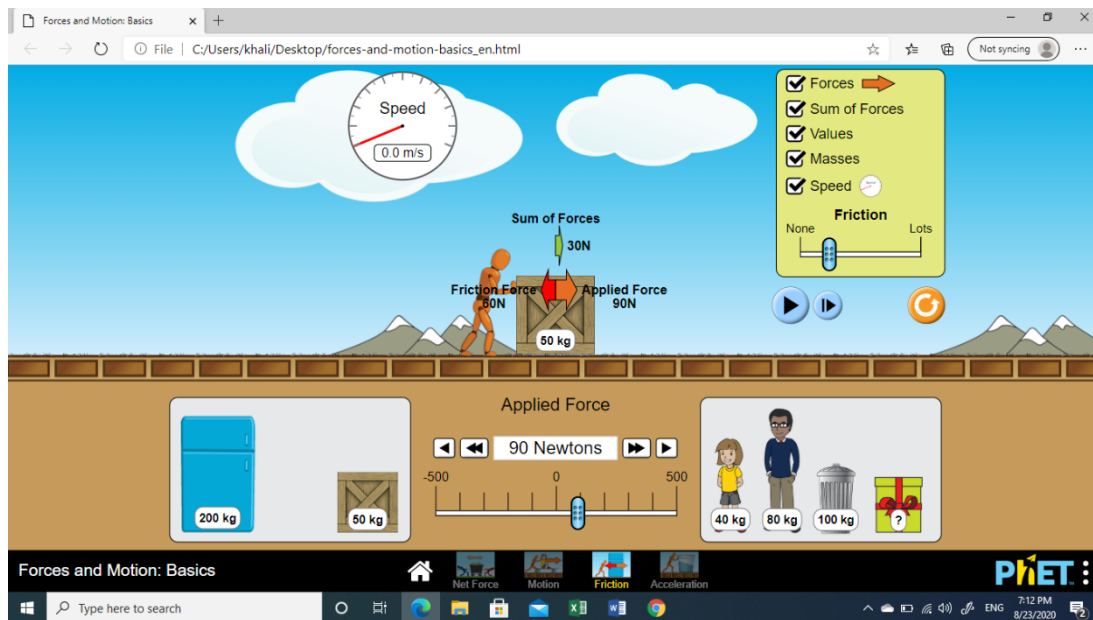




Figure 2. Simulation setup for the “Friction” window.

PART II: Newton's Second Law of Motion

2.2 Theory

Newton's second law states that the force on an object is directly proportional to its acceleration when the mass is constant. It also states that when force is constant, acceleration is inversely proportional to the mass of the object. The purpose of this simulation is to demonstrate these two relations.

3.2. Procedure # B

1. Open the PHET simulator using the above link. Then click on the “Acceleration” icon . The window shown in figure 3 will appear.
2. Setup the simulation as shown in figure 3.
3. Pick the 50 kg box from below.
4. Set the applied force at 70 N, and move the friction to "None".
5. Run the simulator by clicking on  icon.
6. Record the acceleration of the box.
7. Repeat the above steps for masses of 80, 90, 100, 130, 140, 150, 180, 200, 250 kg.
8. Record your data and tabulate them as shown in table 1 below.

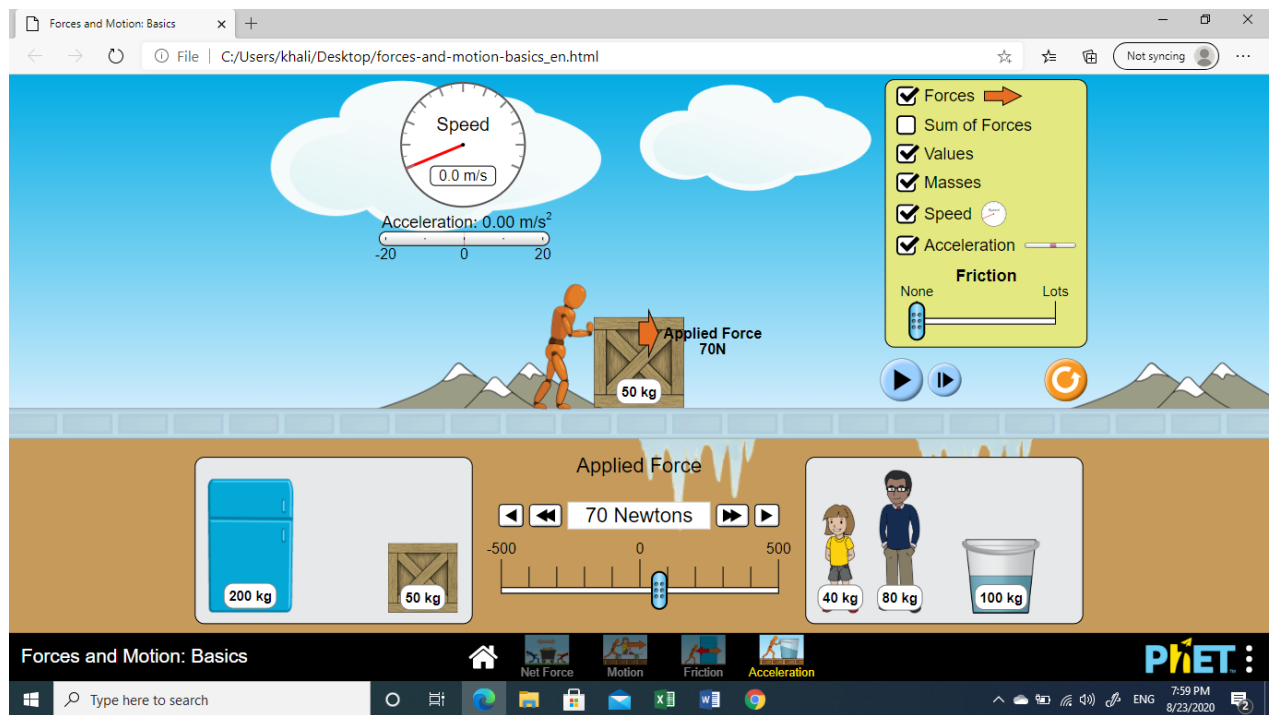


Figure 3. Simulation setup of the “acceleration” window.

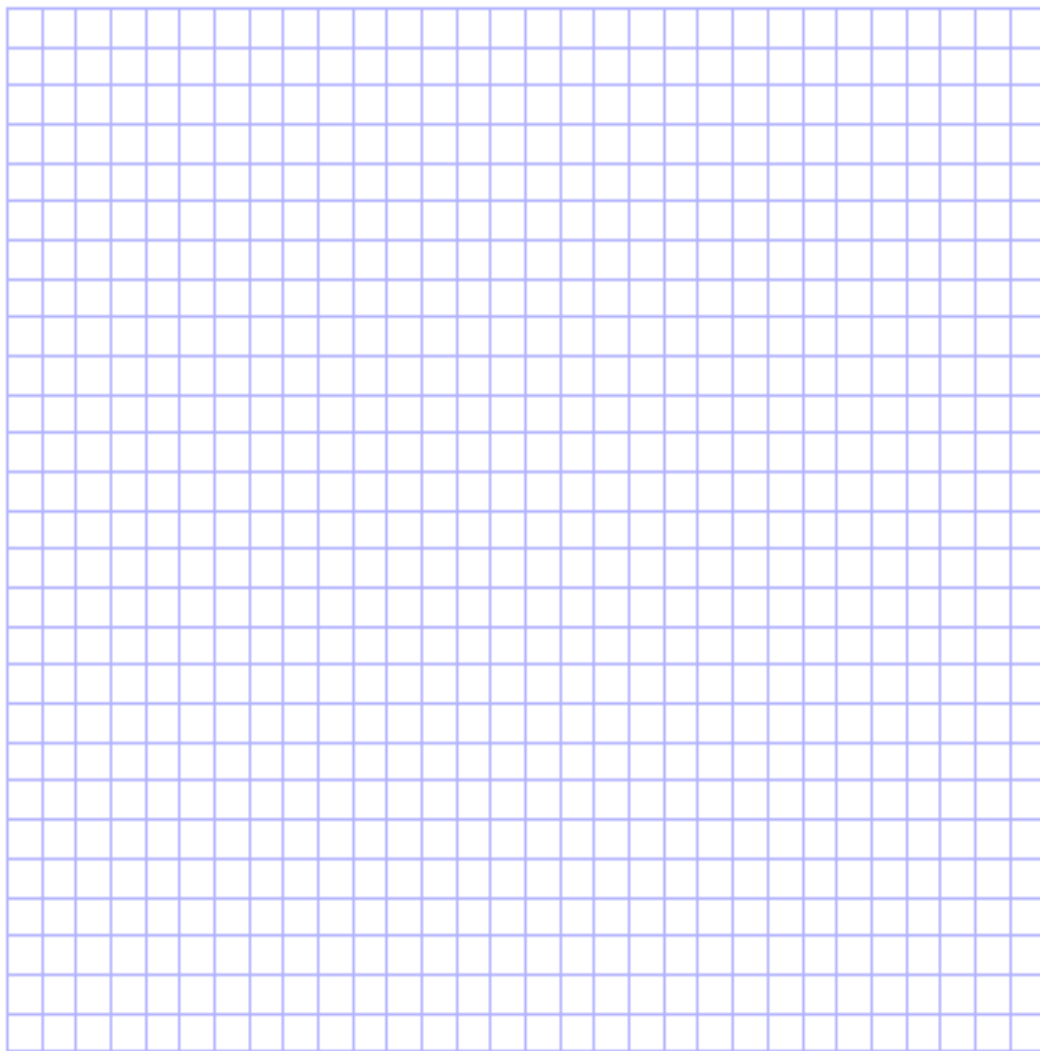
Table 1. Measured data (Method A)

Applied force= 70 N	
Mass (kg)	Acceleration. (m/s ²)
50	
80	
90	
100	
130	
140	
150	
180	
200	
250	

4.1. Results for procedure # B

1. From the table, plot mass (kg) against acceleration (m/s^2).
2. From the graph, find the acceleration when the mass of the object is changed to 120 kg and 220 kg.

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3.3. Procedure # C

1. Arrange the simulator as shown in figure 4.
2. Apply forces of values from 10 N to 100 N to a box of mass of 50 Kg.
3. Run the simulator and record acceleration.
4. Record your data as shown in table 2 below.
5. Using the data from table, plot force versus acceleration

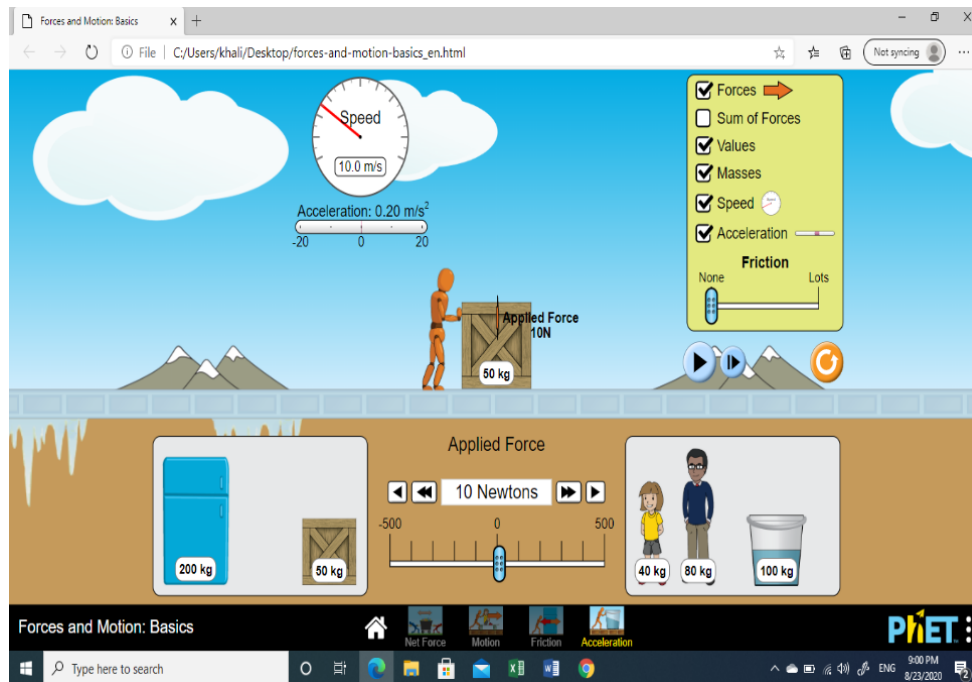


Figure. 4. Simulation setup window for procedure # C

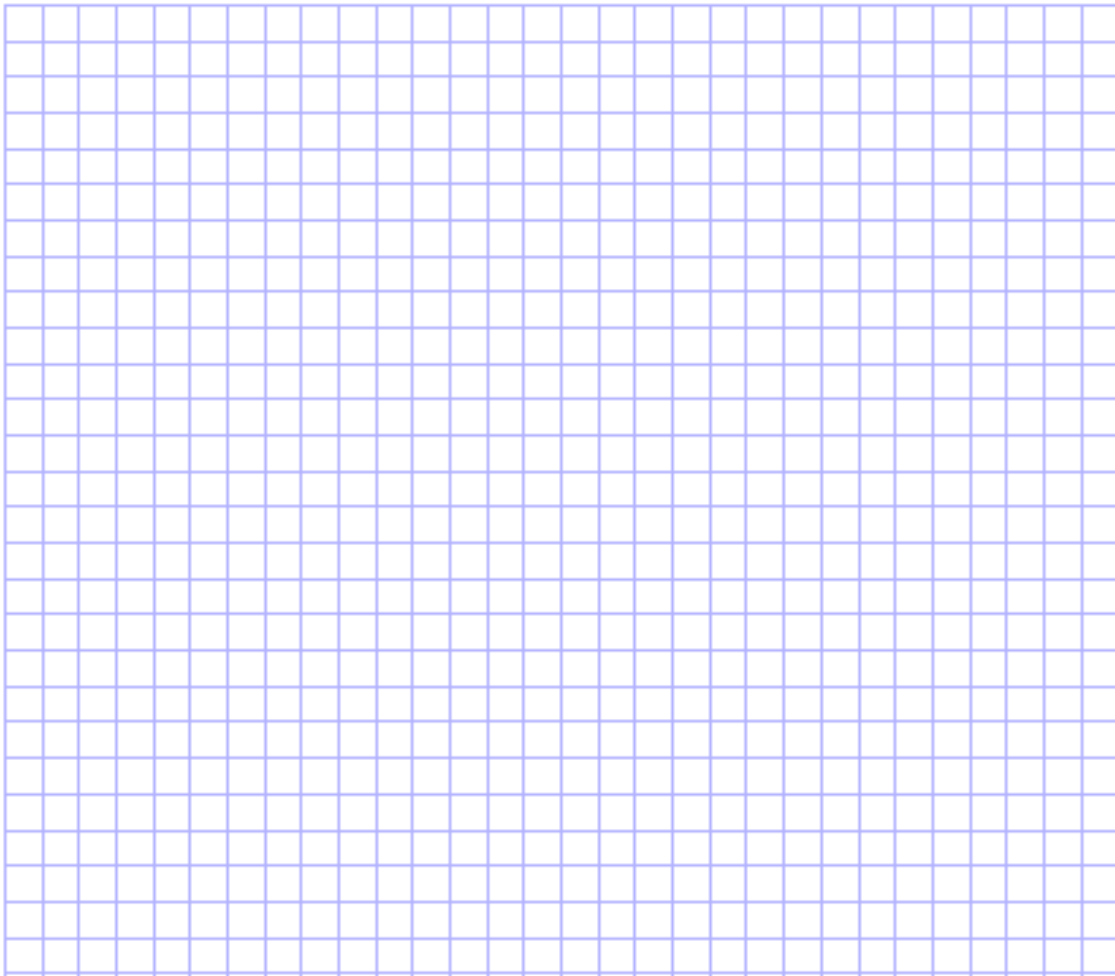
Table 1. Measured data

Mass =50 kg	
Force (N)	Acceleration. (m/s ²)
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	

4.2. Results for procedure # C

1. From the table, plot force (N) against acceleration (m/s^2).
2. From the graph, find the acceleration of the object when the applied force is changed to 55 N and 75 N.

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Experiment 4: Projectile Motion

1. Aim

The purpose of this experiment is to study the main characteristics of a projectile motion. For a given initial velocity, the projectile range and height will be measured at various initial angles and will be also calculated by modeling the motion of an object at constant acceleration.

2. Theory

Projectile Motion

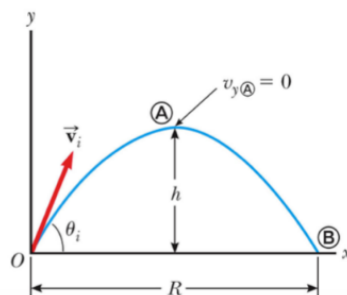
- An object may move in both the x and y directions simultaneously
- The form of two-dimensional motion we will deal with is called **projectile motion**

Assumptions of Projectile Motion

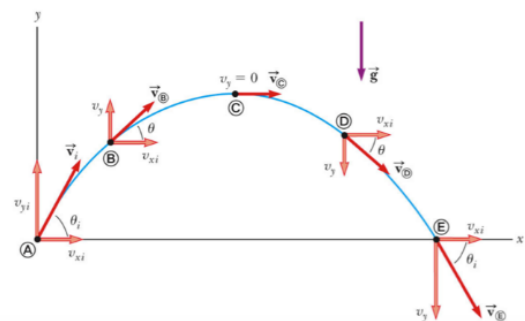
- The free-fall acceleration is constant over the range of motion
 - It is directed downward
 - It is reasonable as long as the range is small compared to the radius of the Earth
- The effect of air friction is negligible
- With these assumptions, an object in projectile motion will follow a parabolic path
 - This path is called the **trajectory**

Range and Maximum Height of a Projectile

- When analyzing projectile motion, two characteristics are of special interest
- The range, R , is the horizontal distance of the projectile
- The maximum height the projectile reaches is h



Projectile Motion Diagram



Projectile Motion – Implications

- The y-component of the velocity is zero at the maximum height of the trajectory
- The acceleration stays the same throughout the trajectory

Range of a Projectile, equation

- The range of a projectile can be expressed in terms of the initial velocity vector:

$$R = \frac{v_i^2 \sin 2\theta_i}{g}$$

- This is valid only for symmetric trajectory


The total time of motion

$$t(\text{total}) = \frac{2v_i \sin(\theta_i)}{g}$$

3. Procedure

We will use the following link of the PHET simulation:

https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion_en.html

1. Use the PHET simulator by clicking on the above link. Then, choose “lab” window by clicking on its icon . The window presented in figure 1 will show up.

2. Adjust the initial velocity at 20 m/s.

3. Adjust the gravity at 9.80 m/s².

4. Do not select the air resistance (without air resistance).

5. Make the launching from the ground (at 0 m).

6. Complete the table below at different launching angles.

7. Record your data and tabulate them as shown in table 1.

Height of a Projectile, equation

- The maximum height of the projectile can be found in terms of the initial velocity vector:

$$h = \frac{v_i^2 \sin^2 \theta_i}{2g}$$

- This equation is valid only for symmetric motion

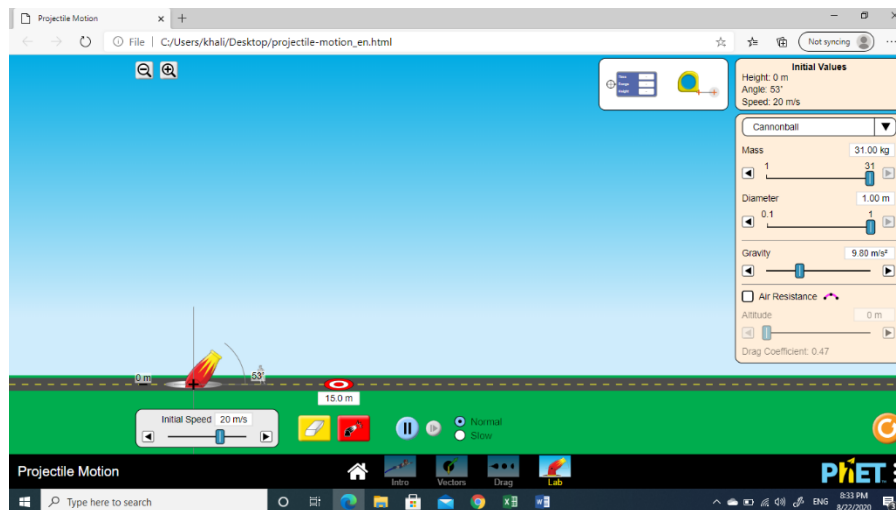


Figure 1. Simulation setup of the “lab” window

Table 1. Measured data

v _i = 20 m/s						
Inputs	Measured values			Calculated values		
θ (deg.)	R (m)	h (m)	t (total) (sec)	R (m)	h (m)	t (total) (sec)
0						
25						
35						
40						
45						
55						
65						
70						
75						
85						
90						

4. Results

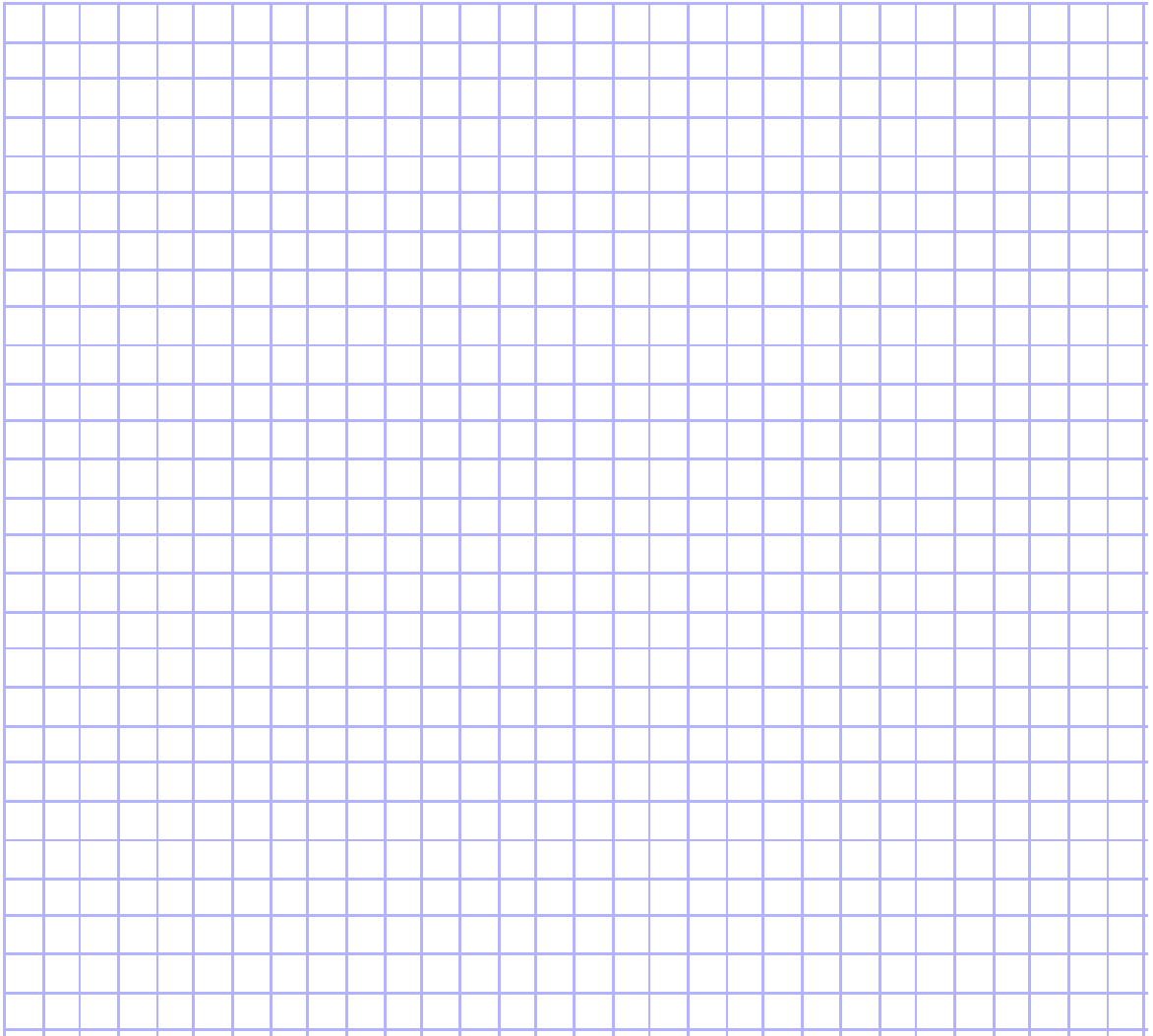
1. Calculate the range R (m), height (h) and the total time t(total) using the equation appended in section 2..
2. From the table, plot the input angle (θ_i (deg.) versus range R (m).
3. From the graph determine the angle at which the range (R) is maximum.

.....

From the graph determine the ranges for $\theta_i = 50^\circ$. and $\theta_i = 80^\circ$

.....

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Experiment 5:

Hooke's Law

1. Aims:

- 1- Verification of Hook's law.
- 2- Determination of the spring constant.

2. Theory:

When a force **F** is applied to an elastic material, it either stretches or compresses in response to the applied force.

- In mechanics, the force applied per unit area is known as **stress (i.e., stress=F/A)**, and the ratio between the material compresses or stretches extent **ΔL** to its initial length **L₀** is known as **strain (i.e., strain= ΔL/ L₀)**.

- **Hooke's law states that** within the elastic limit, the strain of a material is proportional to the stress that produces it, so that Stress/Strain=C where C is a constant known as **modulus of elasticity** whose unit is N.m⁻².

- Mathematically, Hooke's law is commonly expressed as:

$$F \propto \Delta L, \text{ then}$$

$$F = - K.\Delta L$$

where

- F is the force applied on the spring (Restoring force).
- **ΔL** is the extension length.
- K is the constant of proportionality which is known as **spring constant** in N/m. So, K could be defined as the applied force needed to produce a unit extension of the spring.
- The negative sign means that the force exerted by the spring opposes the spring's displacement.

If the applied force F is the weight of a mass m hanged on the spring (see Figure 1), we will get

$$F = mg = -K.\Delta L$$

Therefore, **in order to verify Hooke's Law**, we must verify that the applied force F (**or mg**) on a spring is proportional to the distance to which the spring is stretched where the constant of proportionality is K (see Figure 2).

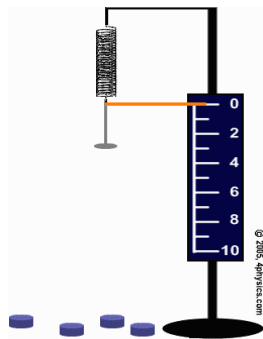


Figure 1

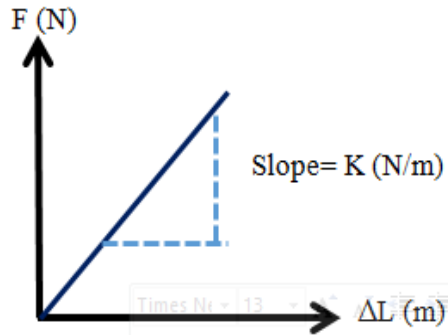



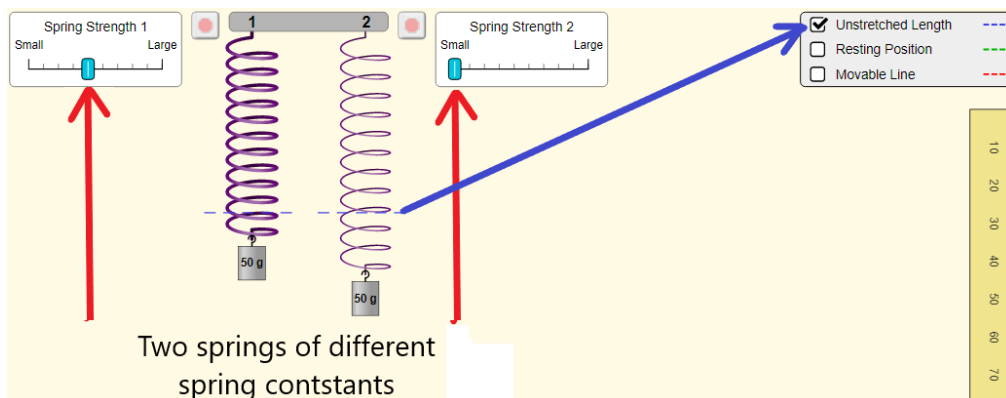
Figure 2

3. Procedure

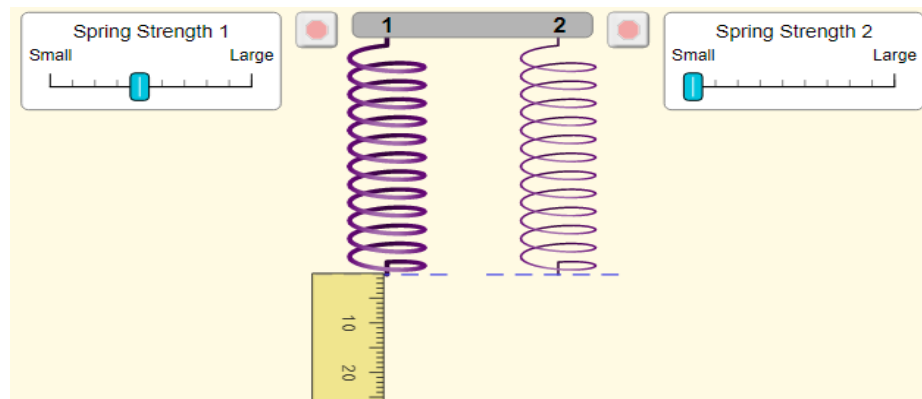
We will use the following link of the **PHET** simulation:

https://phet.colorado.edu/sims/html/masses-and-springs-basics/latest/masses-and-springs-basics_en.html

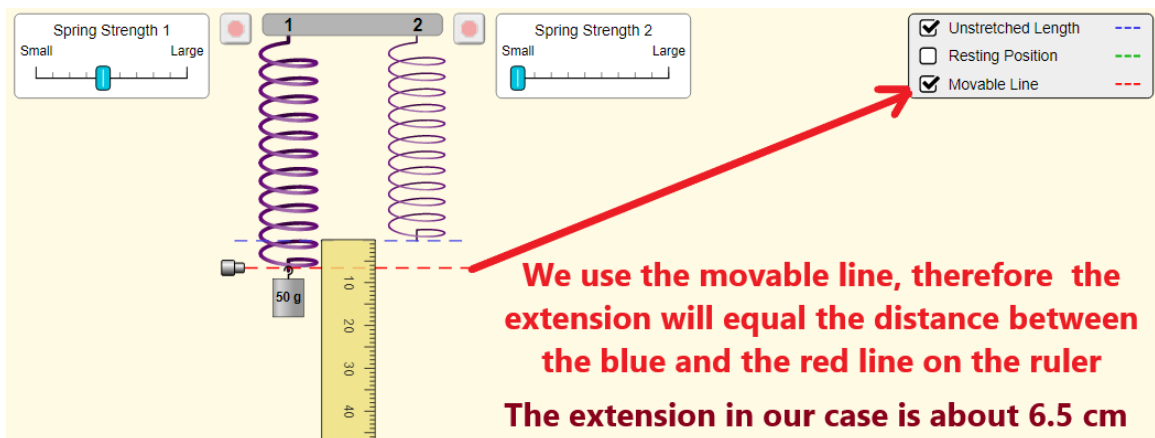
1. Use the PHET simulator by clicking on the above link. Then, choose “Stretch” icon by clicking on . Then a new window will appear.
2. Set the two springs at two different spring constants (K_1 and K_2) as shown by the red arrows in the below picture. Then, Click on the “Unstretched Length” button



3. Drag the unstretched Length dash line (blue line) to the end of the mass-load-free springs to measure their original lengths as shown in the picture below.



4. Hang one of the masses to the spring and measure the final position of the spring's edge (which is equal to the change in the spring's length ΔL).



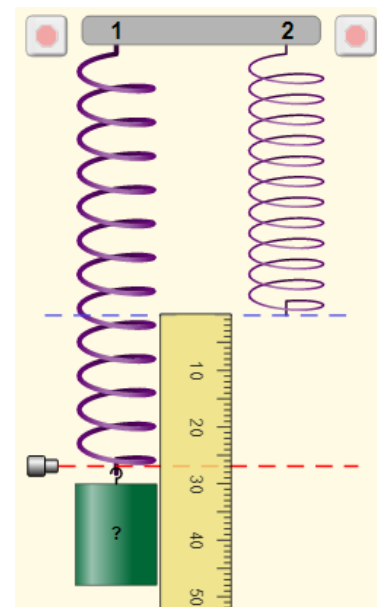
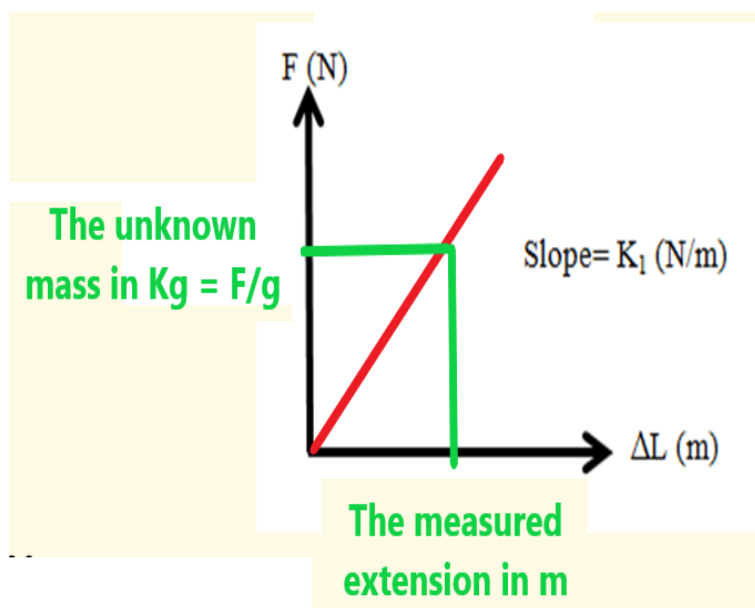
5. Repeat the above steps with different masses.
6. Plot a graph using your readings, the applied force (mg) vs. the increase in the spring length ΔL .
7. You should convert the unit of the mass from gram (g) to kilogram (Kg) and the unit of the length from cm to m. So that K will take the units of N/m.

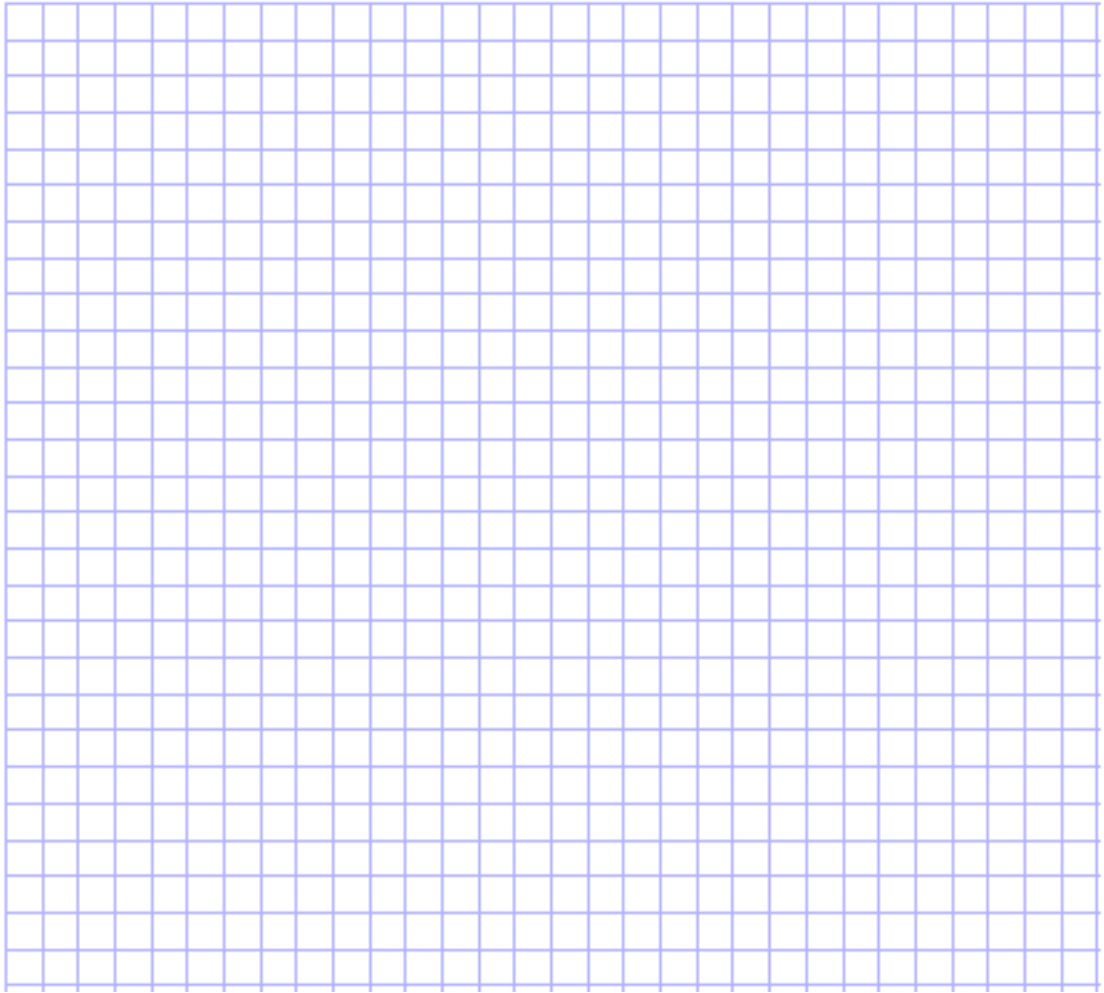
4. Results

1. You may record your results in the following table:

Mass (g)	Mass (kg)	Weight $F = mg$	Extension ΔL (cm)	Extension ΔL (m)	Spring constant $K = F/\Delta L$ (N/m)
50					
100					
250					

2. Draw the relation between F on the Y-axis and ΔL on the X-axis, we get a straight line passing through the origin where its slope is equal to K_1 , as shown in Figure 2.
3. Repeat the above steps to determine the spring constant K_2 of the right spring.
4. Determine the green unknown mass by hanging it to the spring and measure the corresponding extension.





Experiment 6:

The simple pendulum

1. Aims:

1. Study the simple harmonic motion of a simple pendulum.
2. Measure the acceleration due to gravity (g) on different planets.

2. Theory:

The simple pendulum consists of a small sphere (bob) suspended by a string whose mass is negligible in comparison with that of the sphere. The string length is very much larger than the radius of the sphere. Under these conditions, the sphere has a transitional motion along a circular arc (see Fig. 1).

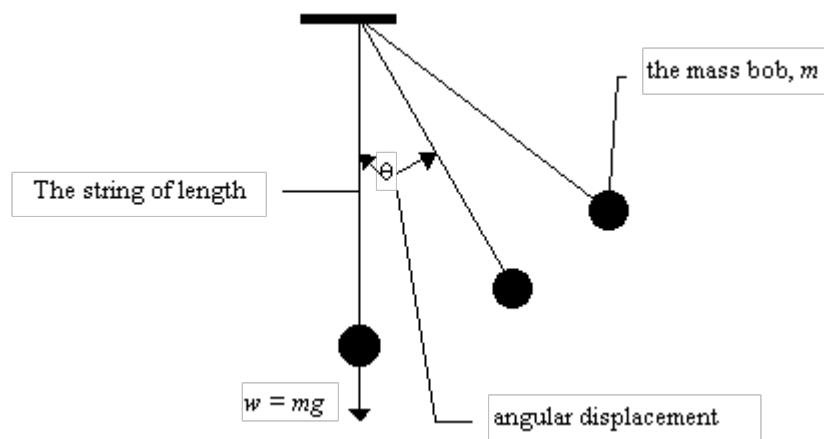


Fig. 1. Diagram Analysis of the Simple Pendulum.

For a small angle (θ) between the string and the vertical direction, the period of oscillation (T) is given by:

$$T = 2\pi \sqrt{\frac{L}{g}}$$

where (L) is the length of the pendulum measured from the top of the string (at the fixed point) to the center of the bob.

The time period (T) of a simple pendulum does not depend on the mass or the initial angular displacement, but depends only on the length (L) of the string and the value of the gravitational field strength (g).

3. Procedure

We will use the following link of the **PHET** simulation

https://phet.colorado.edu/sims/html/pendulum-lab/latest/pendulum-lab_en.html

1. Open the Pendulum Lab PhET simulator by clicking on the above link. Select LAB.

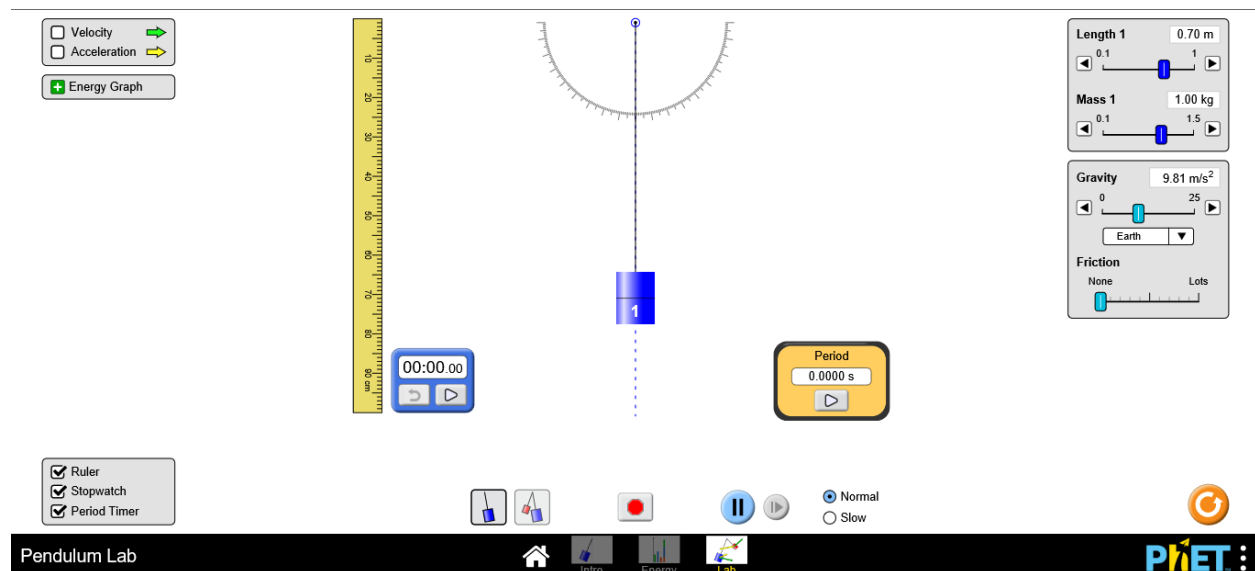


Fig. 2: Panel of PhET for simple pendulum.

2. Click on lab screen and use the length controller to control the length of the pendulum (L), set $L = 1$ m.
3. Set mass = 0.5 kg, gravity = Earth, Friction = None, Stopwatch = ON, and Speed = Normal.
4. Drag the pendulum bob to an angular displacement (amplitude) of a small angle (<10 degrees). Let the mass to swing and the bob oscillates periodically.

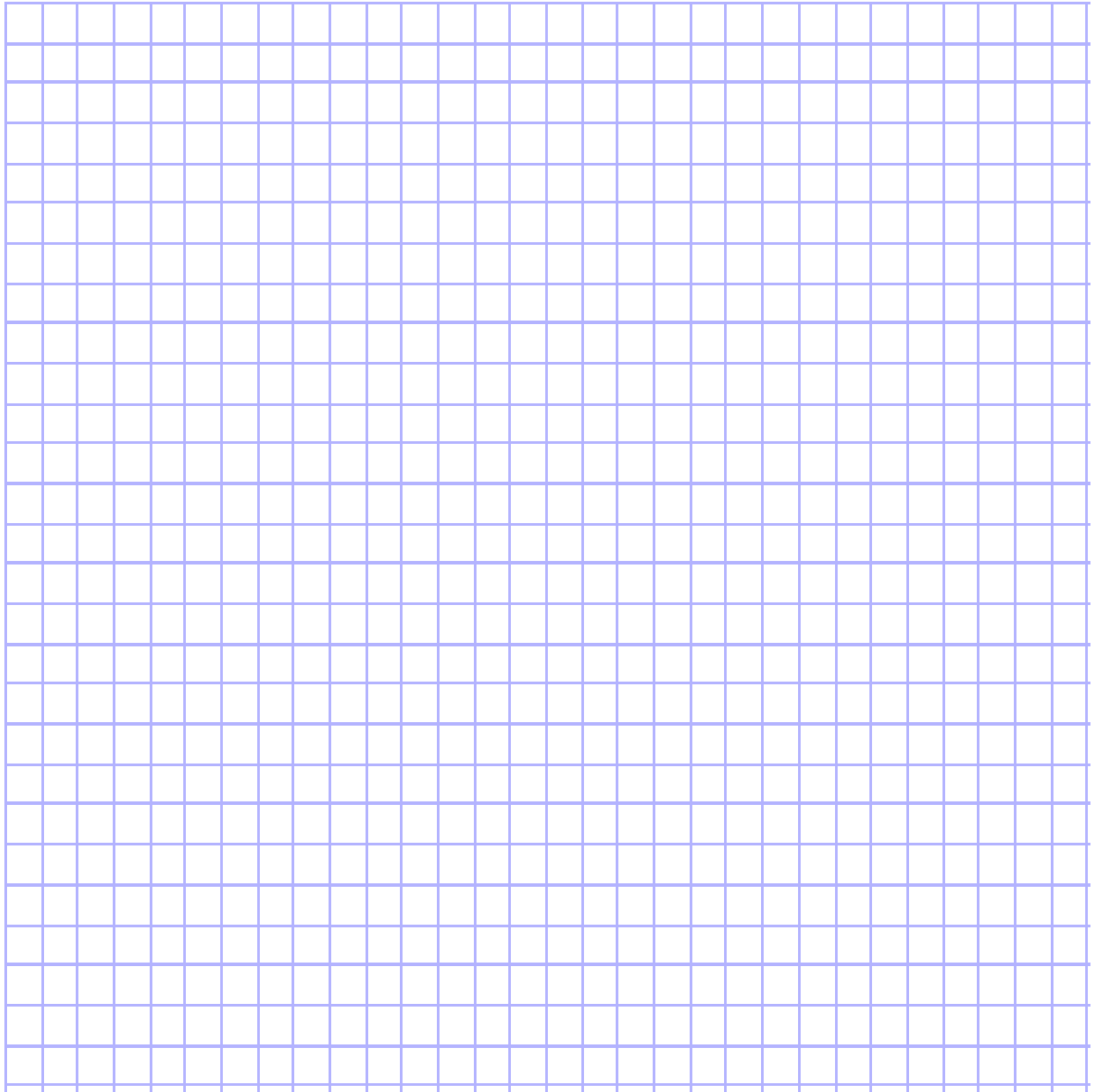
5. Start the stopwatch and count the time of 10 oscillations of the bob. Then, record the periodic time (T) in the given table 1 below.
6. Repeat the previous steps for different lengths of (L) for the same mass of the bob assuming the same angle.
7. Record the length also in the table 1.
8. Repeat steps 4 to 8 for moon instead of earth, but it is enough to click on period timer (on the lower left corner of the lab screen) to measure the periodic time of one full oscillation (T).
9. Plot a graph of T^2 versus L.

Table 1. Experimental data

Planet	Earth			Moon	
L (m)	T for 10 oscillations (s)	T (s)	T^2 (s ²)	T (s)	T^2 (s ²)
1.0					
0.9					
0.8					
0.7					
0.6					
0.5					
0.4					
0.3					
0.2					

4. Results

1. Calculate the experimental value of g on earth and moon from the slope of the graphs using the following equation: $g = \frac{4\pi^2}{slope}$. (refer to Experiment 1 to calculate the slope)
2. Compare your calculated g value to the theoretical values of g for earth and moon that are known to be 9.8 m/s^2 and 1.62 m/s^2 , respectively.
3. Determine the acceleration of the bob due to gravity on "Planet x"



Experiment 7:

Determination of the acceleration due to gravity using a spring

1. Aims:

- 1- Demonstration of the simple harmonic motion of a mass hanged on a spring.
- 2- Determination of the acceleration due to gravity using a loaded spring.

2. Theory:

The simple harmonic motion is a special type of periodic motion where the restoring force on the moving object is directly proportional to the object's displacement magnitude and acts towards the object's equilibrium position. See Fig. 1.

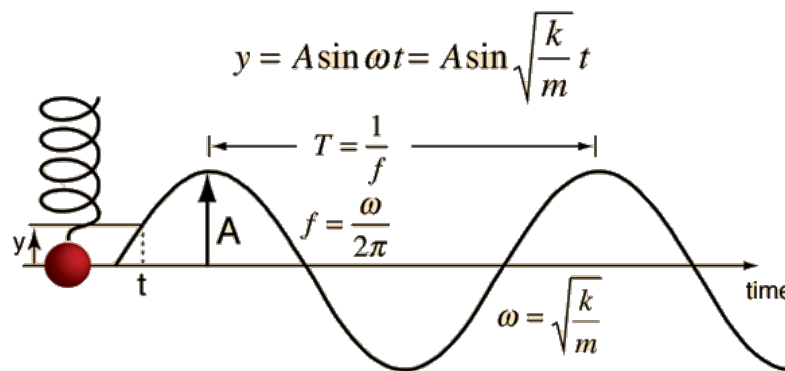


Figure 1. A representation of the simple harmonic motion of a spring.

The period of the oscillation T of a mass m at the end of the spiral spring depends on the mass m attached to the spring and the spring's constant K . The periodic time can be given by

$$T = 2\pi \sqrt{\frac{m}{K}} \Rightarrow T^2 = 4\pi^2 \frac{m}{K}, \quad (1)$$

According to Hook's law, if the applied force \mathbf{F} is the weight of the mass m hanged **on** the spring (see Figure 1), we will have

$$|F| = mg = K\Delta L, \quad (2)$$

and then,

$$K = \frac{mg}{\Delta L}, \quad (3)$$

By substituting Eq. (3) into (2), we get

$$T^2 = \frac{4\pi^2}{g} \Delta L, \quad (4)$$

Therefore, by plotting the relation between T^2 on the Y-axis and the extension ΔL on the X-axis, we obtain a straight line passing through the origin where its slope = $4\pi^2/g$. From the slope, one can determine the acceleration due to gravity where $g = 4\pi^2/\text{slope}$, see Fig. 2.

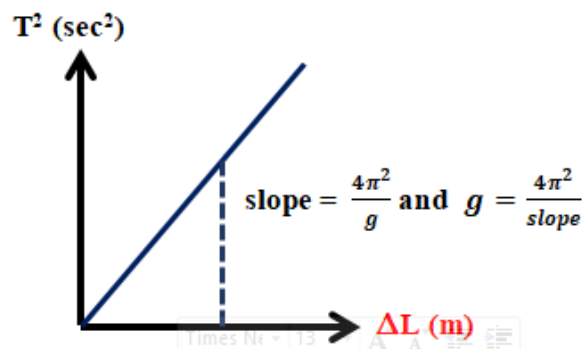


Figure 2.

- Note that we can use Eq. (4) to determine the spring constant by plotting the relation between T^2 on the Y- axis and the loaded mass m on the X-axis, so we get a straight line whose slope = = $4\pi^2/K$, as shown in Fig. 3.

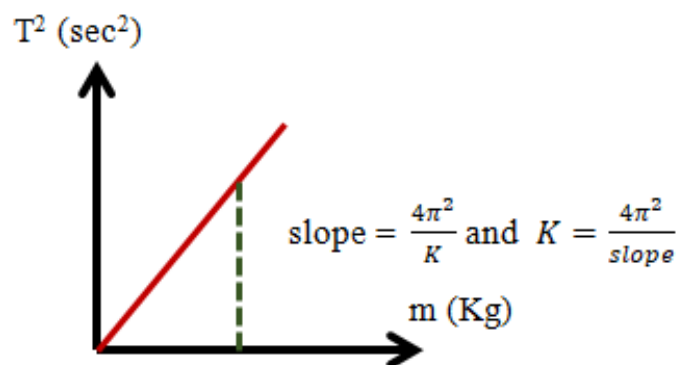



Figure 3.

3. Procedures

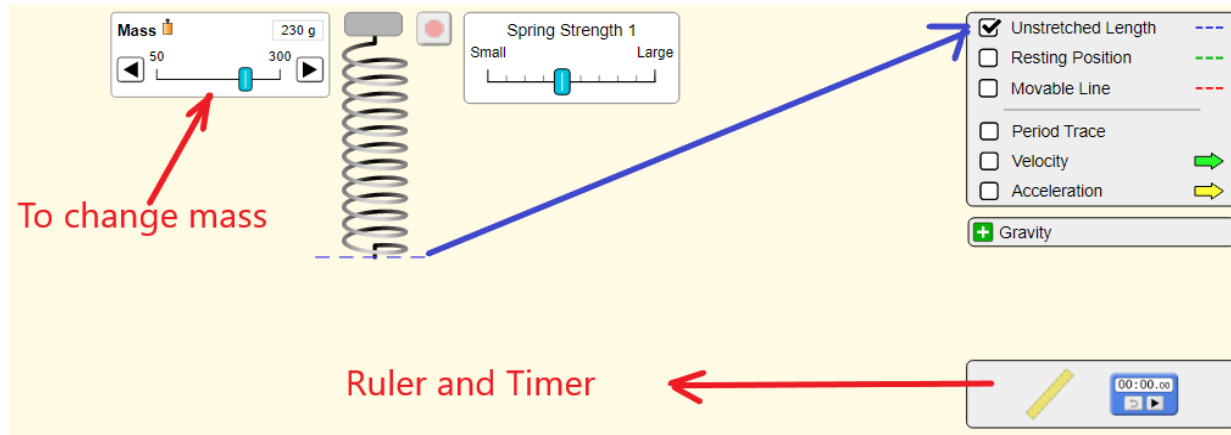
We will use the following link of the PHET simulation:

https://phet.colorado.edu/sims/html/masses-and-springs-basics/latest/masses-and-springs-basics_en.html

1. Use the PHET simulator by clicking on the above link. Then, choose “Lab” icon by

clicking on . Then a new window will appear.

2. First, determine the original length of the spring L_0 . Here, let us consider the unstretched length line (blue line) as a reference line (or benchmark line) at the edge of the spring.

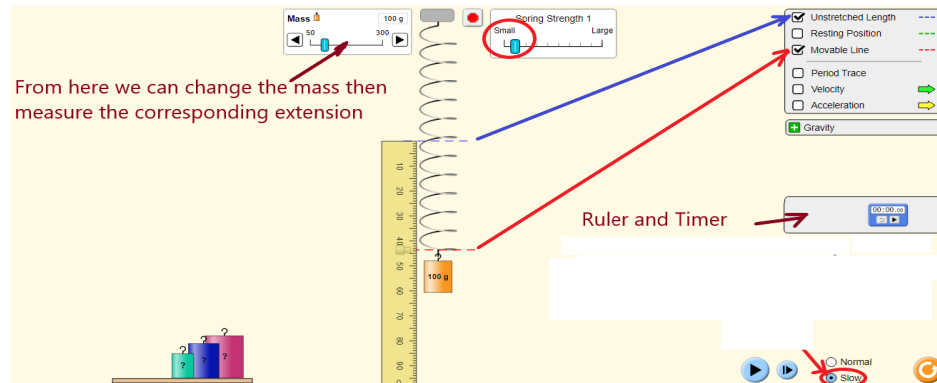


3. Attach the smallest mass (100 g) to the spiral spring. Then, measure the corresponding extension ΔL using the “resulting position” line (green) and the ruler. As well as the movable line (red) can be used in this measurement.

Note that:

- we may use a small spring strength to increase the observed extension.
 - to measure the extension precisely, we may use the slow button to be able to stop the oscillation at a proper time. After recording the extension length, we can change the mode to be normal again.
4. Use a stopwatch, to record the time for 20 oscillations then divide the measured time by 20 to obtain the periodic time T for one complete period.

- Repeat the above steps for different values of mass, with an increase of 50 g, to obtain the corresponding extension.
- Convert the unit of the length from cm to m.



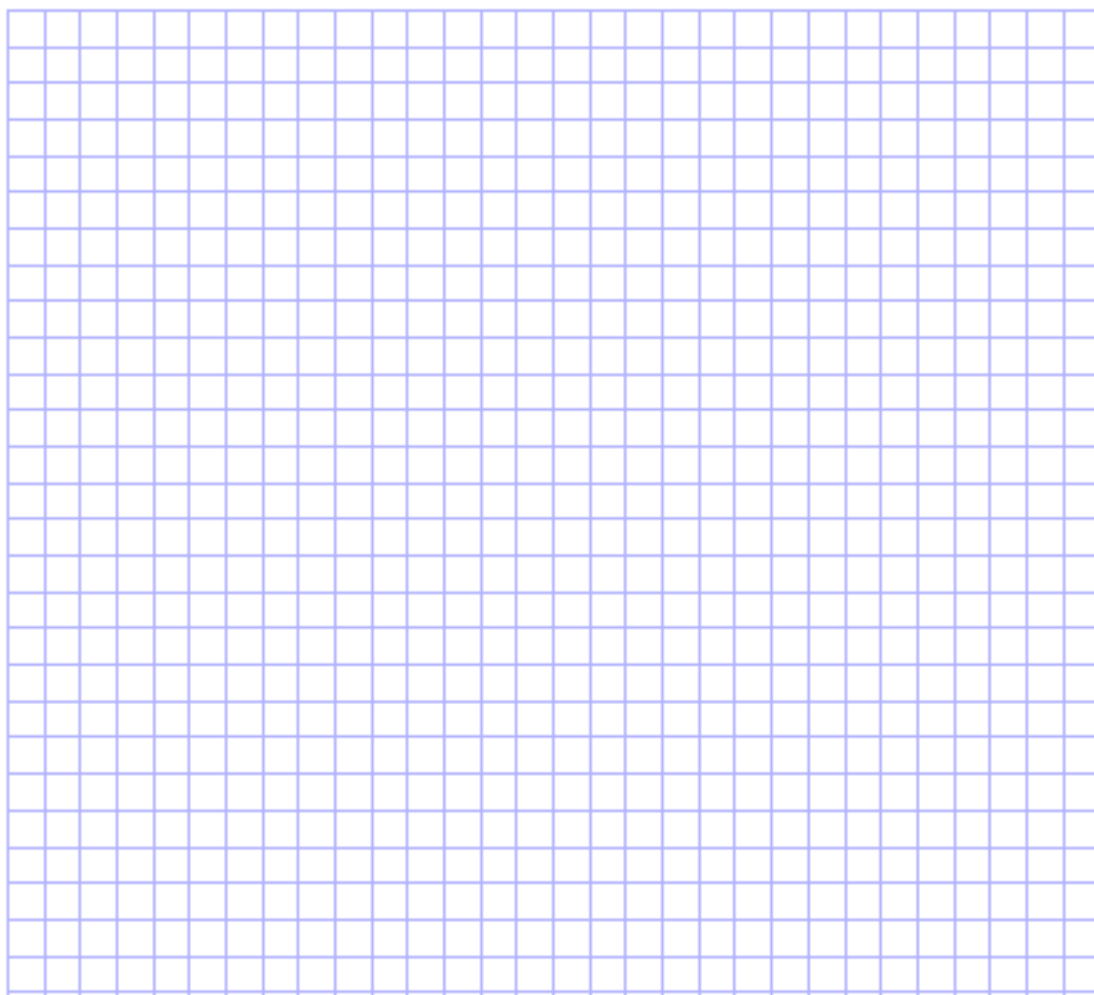
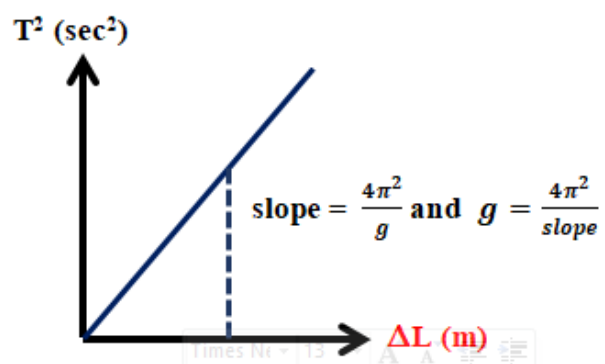
4. Results

- You may record your results in the following table:

Mass (g)	Extension ΔL (cm)	Extension ΔL (m)	T (s)	$T(s^2)$	$g (m/s^2) = \frac{4\pi^2}{T^2} \Delta L$
100					
150					
200					
250					
300					

- Plot the relation between T^2 on the Y-axis and ΔL on the X-axis, we get a straight line passing through the origin where its slope equal slope = $\frac{4\pi^2}{g}$ as in the following graph.

- Calculate the acceleration due to gravity using the relation: $g = \frac{4\pi^2}{slope}$.



Experiment 8:

Conservation of Mechanical Energy

1. Aims:

- 1- Verify the conservation law of mechanical energy.
- 2- Calculate the object velocity using the conservation law of mechanical energy.

2. Theory:

Conservation of Energy

Energy cannot be created or destroyed, but is merely changed from one form into another.

The total mechanical energy of an object (E_M) = Kinetic energy (E_K) + Potential energy (E_p).

The kinetic energy is given by ($E_k = \frac{1}{2}mv^2$), where **m** is the mass of an object and **v** its velocity.

The gravitational potential energy is given by ($E_p = mgh$), where **m** the mass of an object, **h** is the height above the surface of earth and **g** is the acceleration due to gravity.

The conservation Law of mechanical energy

The total amount of mechanical energy, in a closed system in the absence of dissipative forces (e.g. friction, air resistance), remains constant.

$$E_M = E_k + E_p = \text{constant}$$

For different heights an object from the surface of earth (h_1, h_2 and h_3), we can then write:

$$E_M = mgh_1 + \frac{1}{2}mv_1^2 = mgh_2 + \frac{1}{2}mv_2^2 = mgh_3 + \frac{1}{2}mv_3^2$$

$$\text{i. e., } mgh_i + \frac{1}{2}mv_i^2 = \text{constant}$$

When an object launched vertically by an angle $\theta=90^\circ$ and when neglecting the air resistance, so the gravitational force will be the only force acting on that object. Its motion could be described by the following equation:

$$v_y = v_{0y} - gt,$$

where v_{0y} is the launching (initial) velocity and v_y is the velocity at any time t


3. Procedures

1. We will use the following link of the **PHET** simulation:


https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion_en.html

1. Use the PHET simulator by clicking on the above link. Then, choose “lab” window


by clicking on its icon . The window presented in figure 1 will show up.

2. Adjust the cannon  to be in the vertical position ($\theta_i = 90^\circ$) and untick the air resistance icon. **Here, the motion of the projectile is the same as a free-falling object.**

3. Choose the initial velocity to be $v_{0y} = 30$ m/s and the object mass (m) to be 1 kg.

4. Launch an object by pressing this button 

5. **Position #1 (at the maximum height of the motion);**

- Measure the maximum height (h_{\max}) and time (t_{\max}) using this icon , by placing the cross mark on the object at its maximum height. Here, the final velocity = 0. Calculate the total energy (E_{M1}) = Kinetic energy ($E_{K1}=0$) + Potential energy ($E_{P1}=mgh_1$) where $h_1 = h_{\max}$

6. **Position # 2 at $t_2 = 1$ s**, repeat steps 4 and 5 to calculate the total energy (E_{M2}) = Kinetic energy ($E_{K2} = \frac{1}{2}mv_2^2$) + Potential energy ($E_{P2}= mgh_2$) where the object velocity can be calculated from $v_2 = v_y = v_{0y} + a_y t$ where $a_y = -g = -9.8$ m/s².

7. Compare the values of the total energy obtained at **positions # 1 & 2** and check the conservation law of energy.

8. Position #3 at $t_3 = 0.5$,

Measure the height of the object h_3 and calculate the velocity v_3 at $t = 0.5$ using the conservation law of mechanical energy by comparing the total energy at positions #1 and 3 according the following equation

$$mgh_1 + \frac{1}{2}mv_1^2 = mgh_3 + \frac{1}{2}mv_3^2, \text{ where } v_1 = 0$$

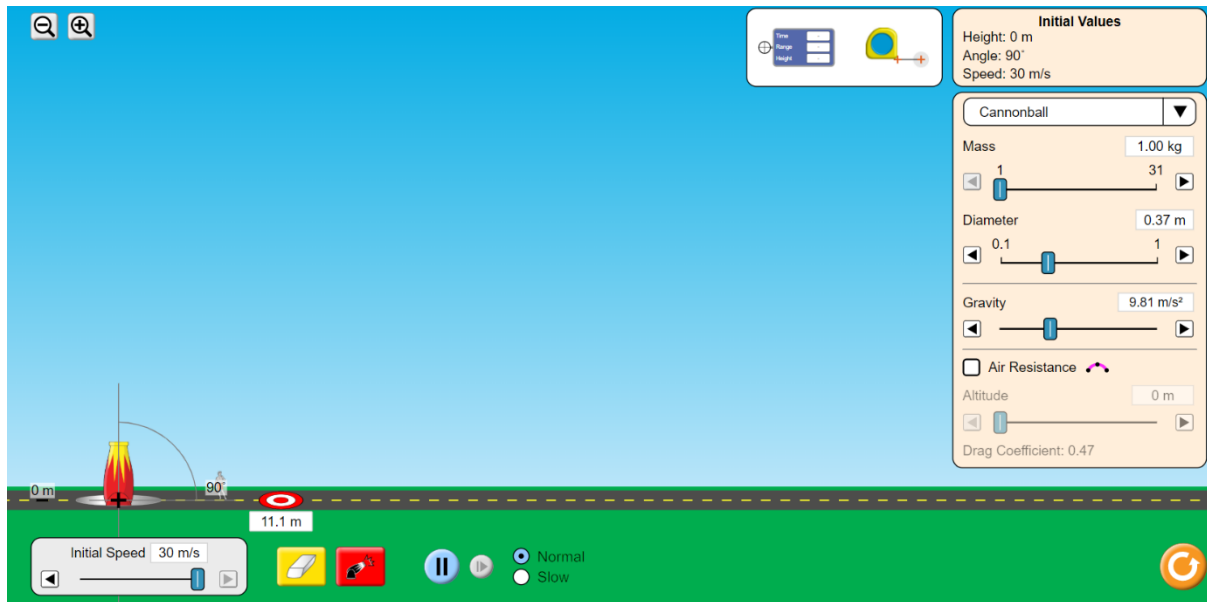


Figure 1. Simulation setup and its initial setting parameters

4. Results

Part I: verifying the law of conservation of energy

$$m=1 \text{ kg}, \quad v_{0y} = 30 \text{ m/s}, \quad g=9.8 \text{ m/s}^2$$

Position #1

$$h_1 = h_{\max} = \dots \text{ m}, \quad t_1 = t_{\max} = \dots \text{ s},$$

Potential energy $E_{p1} = mg h_{\max} = \dots \times \dots \times \dots = \dots \text{ J}$ and the kinetic energy $E_{k1} = \frac{1}{2} m v_1^2 = 0$ since $v_1 = 0$.

The total energy $E_{M1} = E_{p1} + E_{k1} = \dots + \dots = \dots \text{ J}$

Position# 2

$$h_2 = \dots \text{ m}, \quad t_2 = 1 \text{ s}, \quad v_2 = v_{0y} - gt = \dots \text{ m/s}$$

Potential energy $E_{p2} = mgh_2 = \dots \times \dots \times \dots = \dots \text{ J}$ and Kinetic energy $= E_{k2} = \frac{1}{2} m v_2^2 = \frac{1}{2} \times \dots \times (\dots)^2 = \dots \text{ J}$

The total energy $E_{M2} = E_{p2} + E_{k2} = \dots + \dots = \dots \text{ J}$

Now, compare between E_{M1} and E_{M2} to prove the law of conservation of energy.

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Part II: Calculation of the velocity of object using the conservation law of energy

Position #3

$h_3 = \dots \text{ m}, \quad t_3 = 0.5 \text{ s},$

Potential energy $E_{p3} = mgh_3 = \dots \times \dots \times \dots = \dots \text{ J}$ and Kinetic energy $= E_k = \frac{1}{2} m v_3^2 = \frac{1}{2} \times \dots \times (\dots)^2 = \dots \text{ J}$

The total energy $E_{M3} = E_{p3} + E_{k3} = \dots + \dots = \dots \text{ J}$

Velocity calculation:

Using

$$\frac{1}{2} m v_1^2 + m g h_1 = \frac{1}{2} m v_3^2 + m g h_3$$

$h_1 = h_{\text{max}}, \quad v_1 = 0 \text{ m/s}$

$h_3 = \dots, \quad v_3 = \dots \text{ m}$

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