Lab 02: Data Analysis II
Plotting with Excel

Objective

To learn how to use Excel to plot and analyze data associated with variables that are expected to follow linear, power, or exponential relationships.

Introduction

Plotting your data is very important because it allows you to see the trend of your data. It also enables you to discover systematic errors or mistakes in your measurements. In this lab, you will use Excel to plot and analyze data following linear, power, or exponential trends.

Perfect linear relationship

The following equation describes the position x as a function of time t of an object moving at constant speed along a straight path.

$$x = x_0 + vt. \tag{1}$$

The object is at position $x = x_0$ when time $t = 0$. This is an equation of a straight line and if you plot the position along the vertical axis and the time along the horizonal axis, you should get a straight line as shown in the following figure:

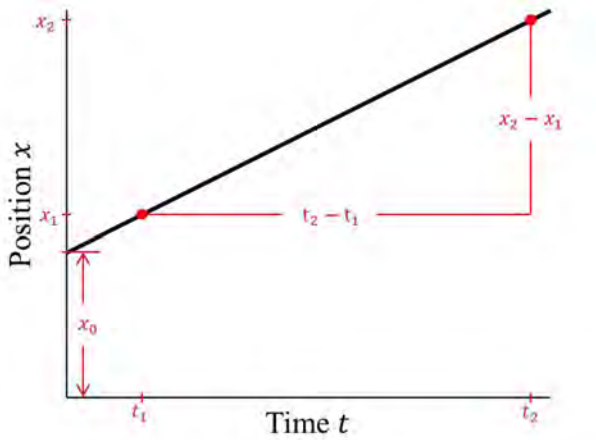


Fig. 1. Position of an object moving at constant speed along a straight path.

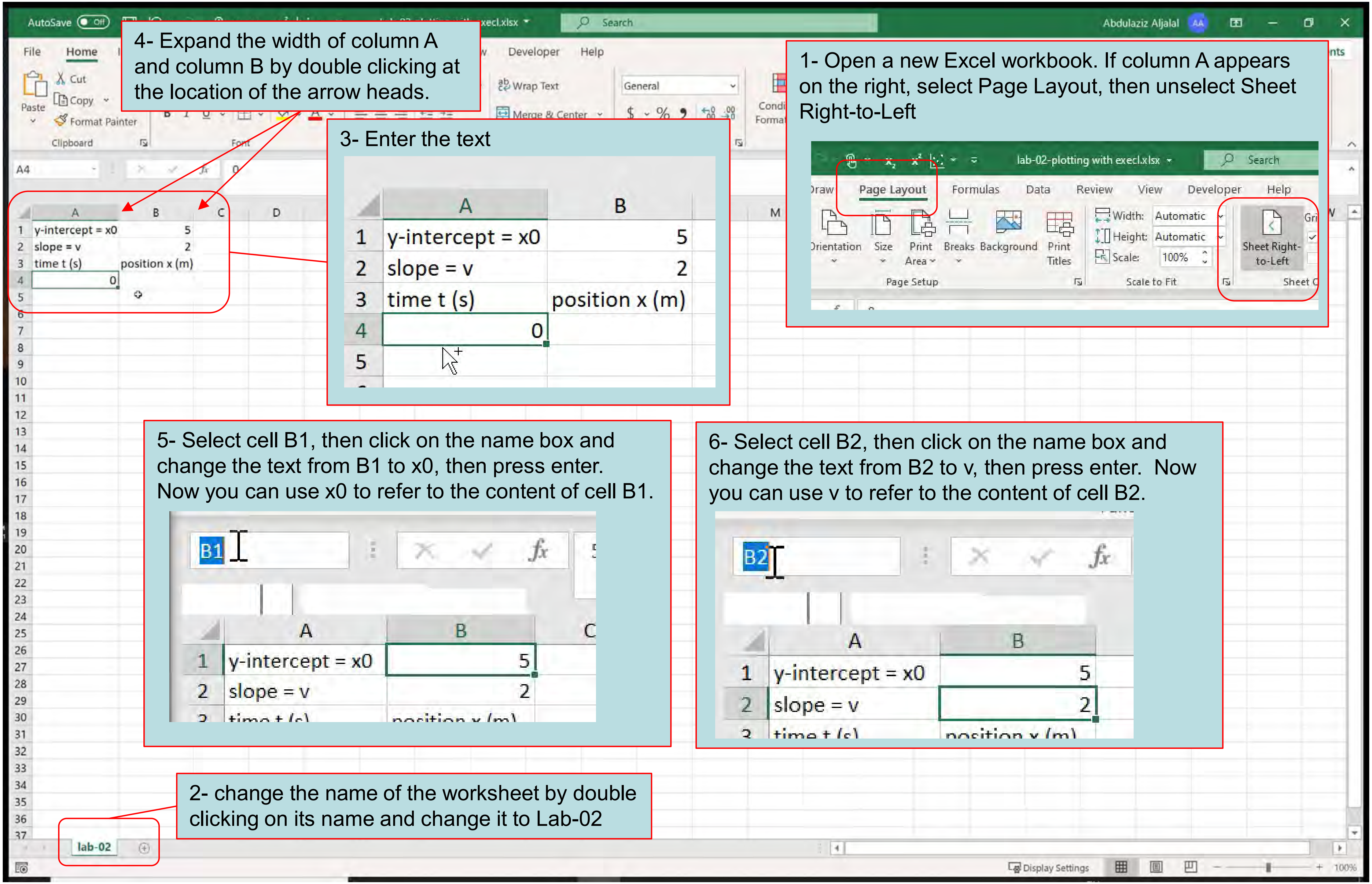
The y-intercept is the position x_0 and the slope of the line is the velocity v, which is the coefficient of the time variable. You can find the value of the slope from two points on the line, say (x_1, t_1) and (x_2, t_2), using the following relation:

$$slope = \frac{x_2 - x_1}{t_2 - t_1} = \frac{(x_0 + vt_2) - (x_0 + vt_1)}{t_2 - t_1} = v.$$

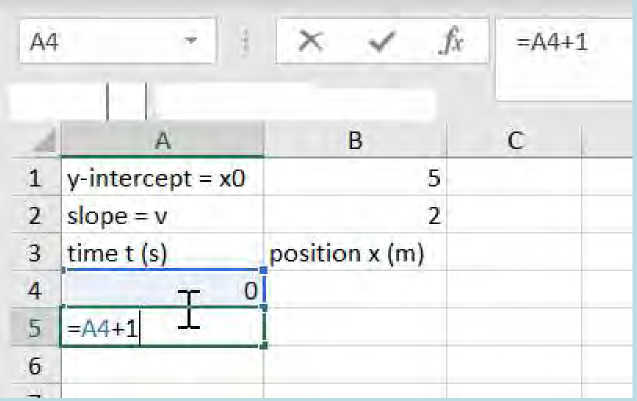
Exercise 1:

You will use Excel and Eq. 1 to calculate the position of the object at different times for specific values of x_0 and v, then you will plot the data. Then you will study the effect of changing the values of x_0 and v on your plot.

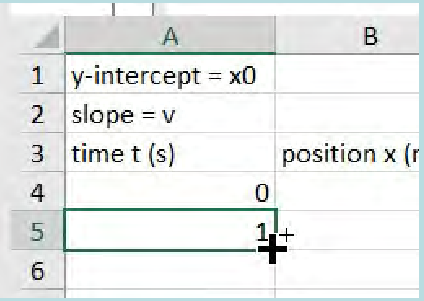
In the following, you can see step-by-step instructions for this exercise.


1- Open a new Excel workbook. If column A appears on the right, select Page Layout, then unselect Sheet Right-to-Left
2- change the name of the worksheet by double clicking on its name and change it to Lab-02
3- Enter the text
4- Expand the width of column A and column B by double clicking at the location of the arrow heads.
5- Select cell B1, then click on the name box and change the text from B1 to x0, then press enter. Now you can use x0 to refer to the content of cell B1.
6- Select cell B2, then click on the name box and change the text from B2 to v, then press enter. Now you can use v to refer to the content of cell B2.
y-intercept = x0
5
slope = v
2
time t (s)
position x (m)
0
lab-02

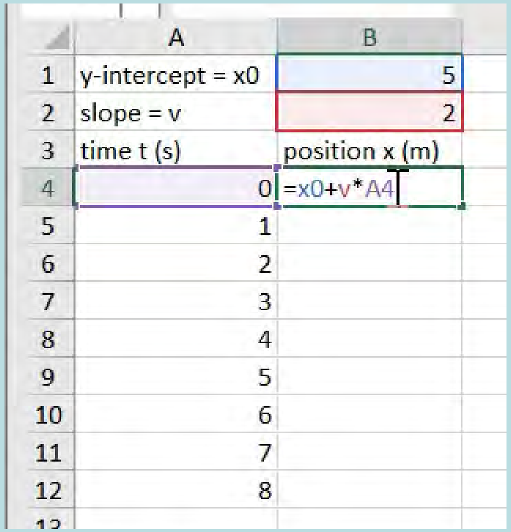
1- In cell A5, type the formula =A4+1 as shown, then press enter.



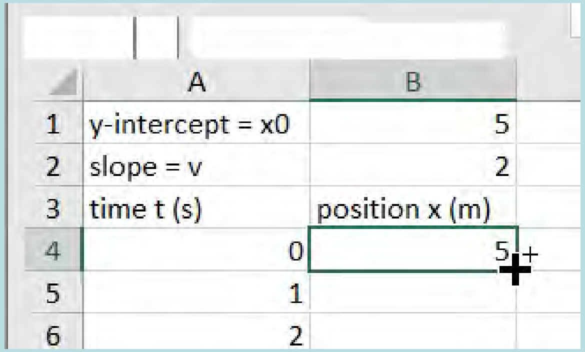
2- Move the mouse to the right-bottom corner of cell A5 until the mouse pointer changes into a cross as shown. Click, hold, and move the mouse down to cell A12 then release the mouse.



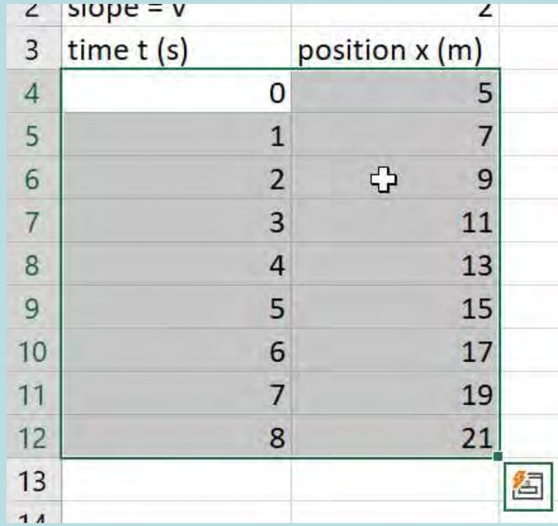
3- In cell B4, type the formula =x0+v*A4 as shown, then press enter.



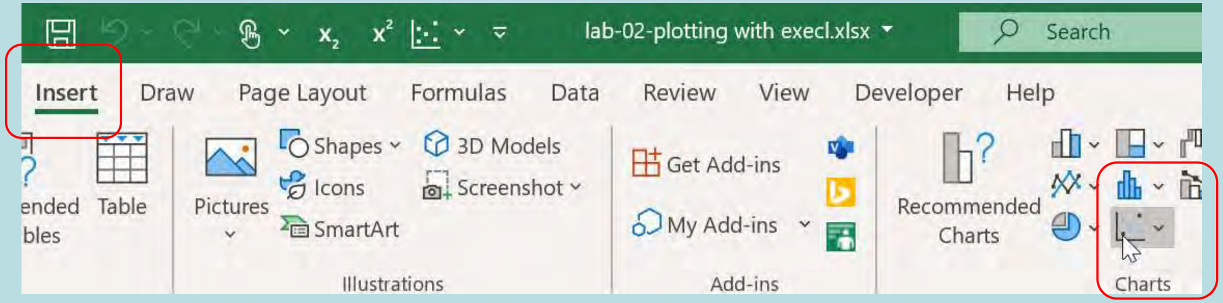
4- Move the mouse to the right-bottom corner of cell B4 until the mouse pointer changes into a cross as shown. Click, hold, and move the mouse down to cell B12 then release the mouse.



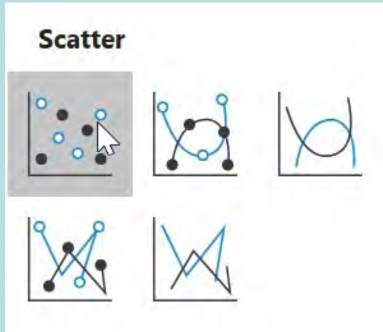
5- Select the cells as shown



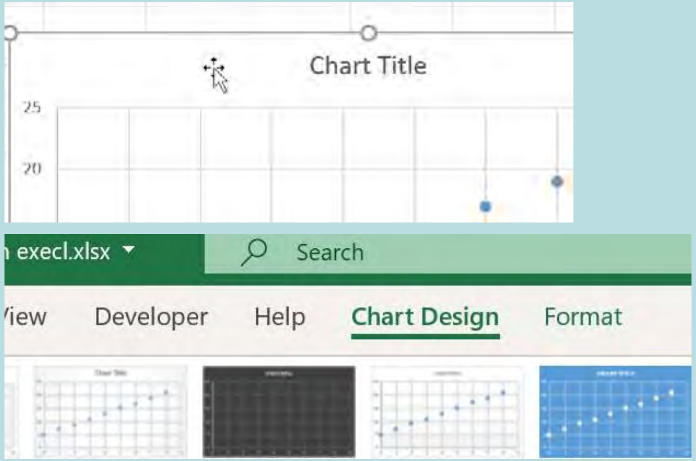
5- From the menu, select Insert, then click on the dropdown menu of charts group as shown.



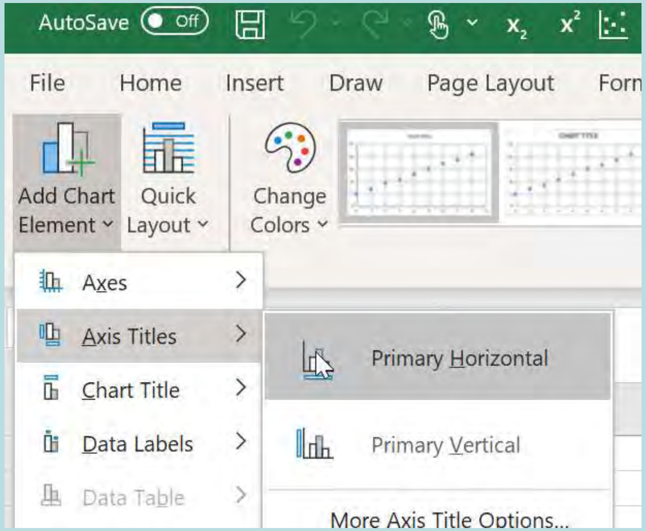
6- Select Scatter plot from the dropdown menu as shown



1- Double click on the chart you made to make the Chart Design menu active.

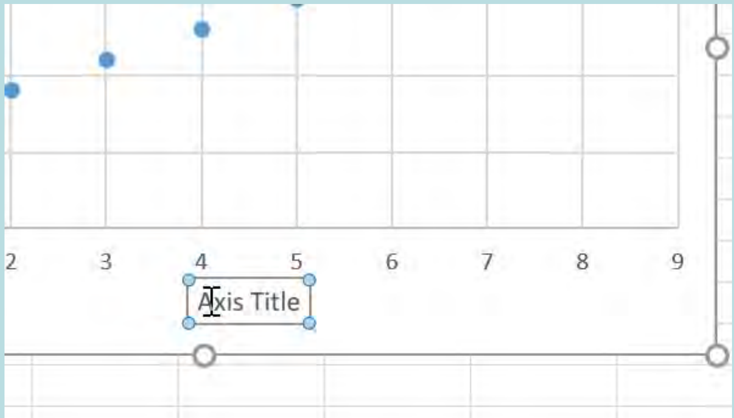


2- Click on Add Chart Element dropdown menu, select Axis Titles, click on Primary Horizontal as shown.

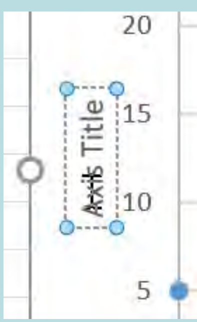


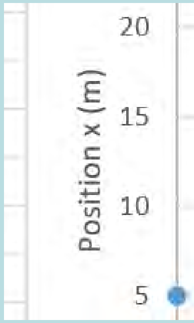
3- Repeat step 2 but select Primary Vertical.

4- Select Axis Title of the horizontal axis and change its text to **Time t (s)** as shown.

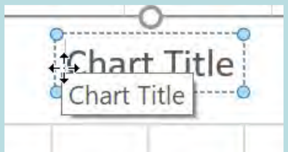


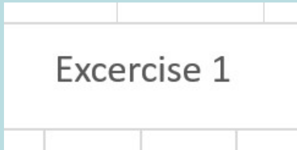
5- Select Axis Title of the vertical axis and change its text to **Position x (m)** as shown.



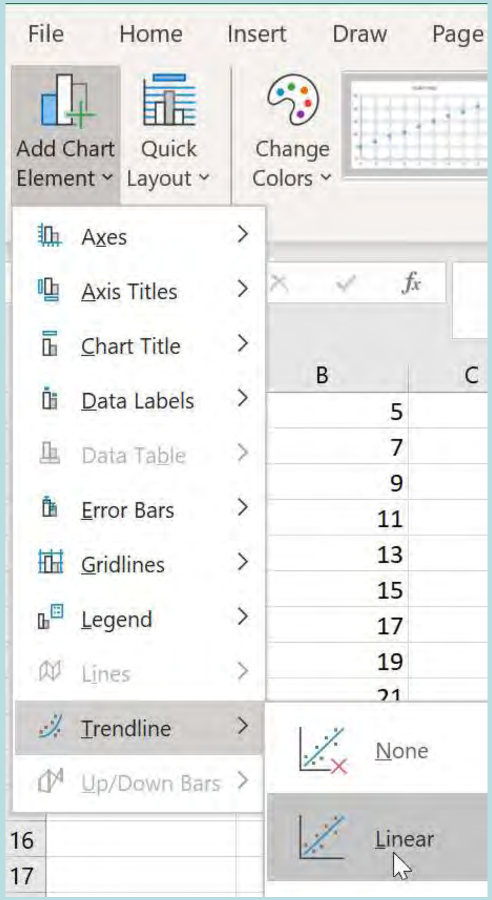


6- Select Chart Title and change its text to **Exercise 1** as shown.

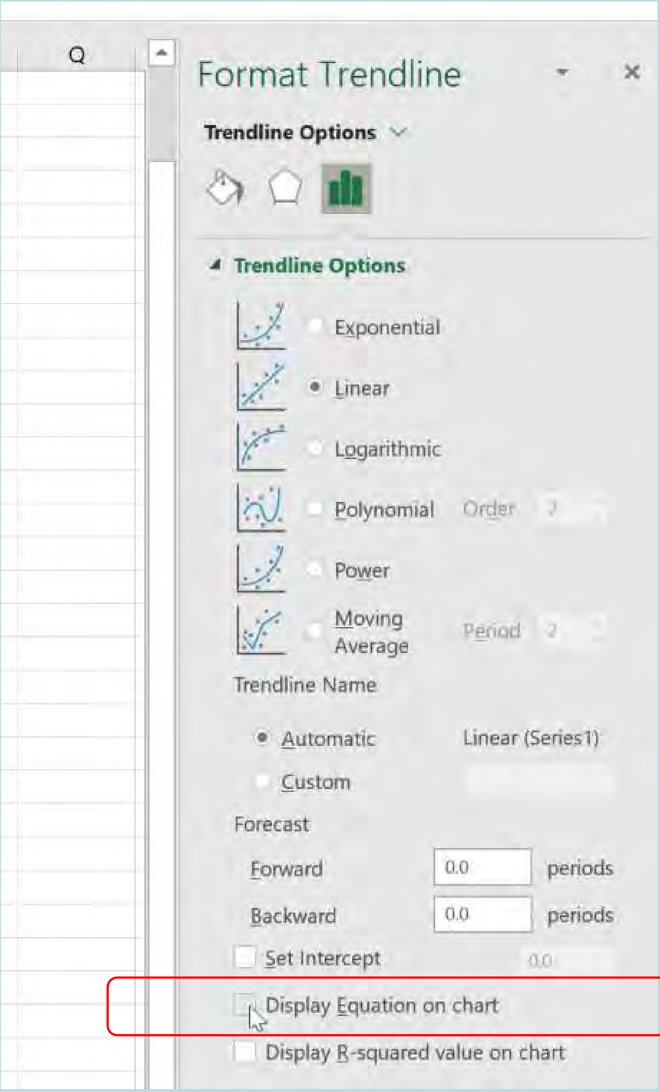




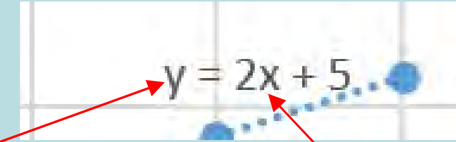
7- Double click on the chart to make the Chart Design menu active. Then, click on Add Chart Element dropdown menu, select Trendline, click on Linear as shown.



1- Double click on the trendline to make Format Trendline menu appear on the right of the worksheet. Near the bottom of the menu, select Display Equation on chart as shown.



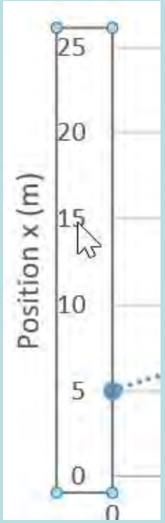
2- You should see the following equation on your chart.



Variable plotted on the vertical axis **Position x**

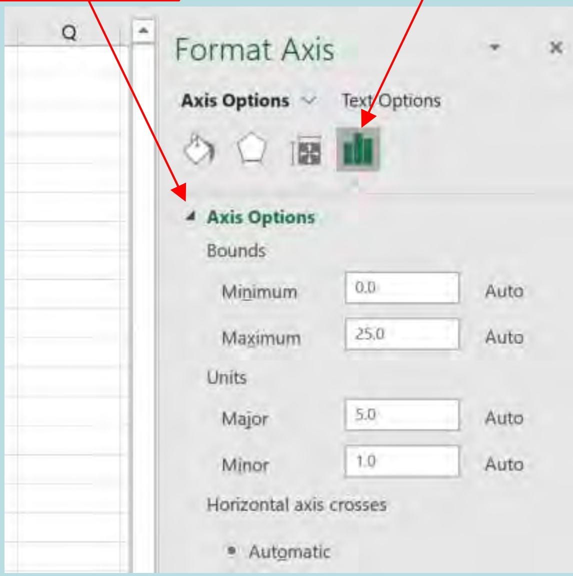
Variable plotted on the horizontal axis **Time t**

3- To fix the range of the vertical axis, double click on any number of the vertical axis to make Format Axis menu appear on the right of the worksheet.

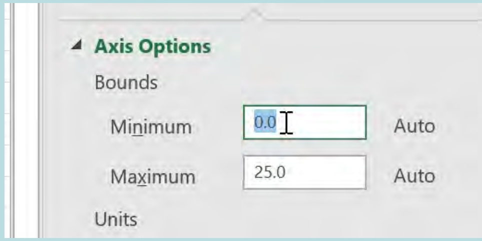


Open if not open

Select if not selected



4- Select the text of Minimum, delete it and write 0.0 and press enter. You should see Auto changed to Reset. Select the text of Maximum, delete it, and write 25.0 and press enter. You should see Auto changed to Reset. Now the range of the vertical axis does not change automatically.



5- Change the value of the y-intercept in cell B1 and observe what happens to the line. Change the value of the slope in cell B2 and observer what happens to the line.

	A	B	C
1	y-intercept = x0	5	
2	slope = v	2	
3	time t (s)	position x (m)	
4	0	5	

Linear relationship with measured quantities

If you measure the position as a function of time of an object moving at constant velocity along a straight path, you will find that not all your data points fall on a straight line, as shown in Fig. 2. This is because of the uncertainty in your measurements. In the following, you will use Excel to generate data points imitating real measurements, then you will plot them. From the plot, you will find the best value of the velocity and you will estimate the error associated with it.

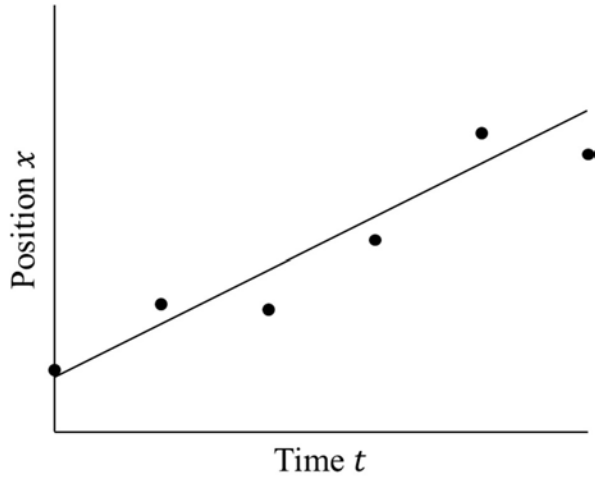


Fig. 2. Position measurements for an object moving at constant speed along a straight path.

Excel function NORM.INV(RAND(), mean, standard_dev) can be used to generate values for positions similar to real measurements if we assume that our measurements have only random errors which are normally distributed around the actual positions. “mean” is the actual position and “standard_dev” is the error. We will assume our position measurements have the same relative error. We will also assume that the error in time measurements is very small, and we will use the time values used in Exercise 1.

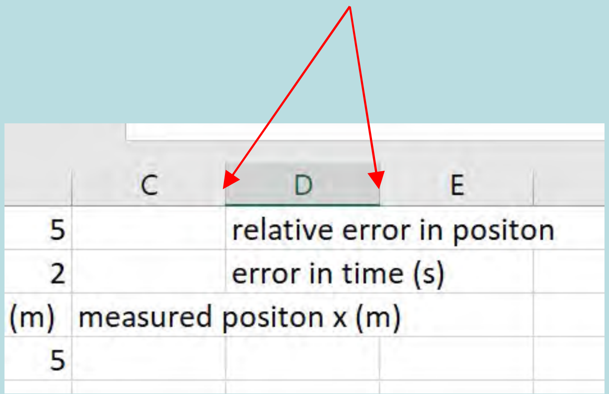
The process of finding the best line that represents your data is called line fitting, which is done in Excel by selecting Trendline/Linear. The best line is found by a method called, the “least squares” method, which minimizes the squares of the vertical distances between the data points and the line. To find the error in the slope and in the y-intercept, we need to use Excel Function Linest which produces some statistics related to the line.

Exercise 2:

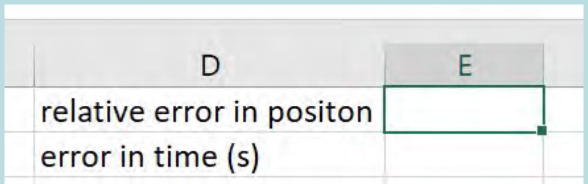
You will use Excel to generate position measurements that are normally distribute around the position values of Exercise 1 with same relative error. You will generate a plot similar to that of Exercise 1, then you will estimate errors in the slope v and the y-intercept x_0 using Excel function Linest.

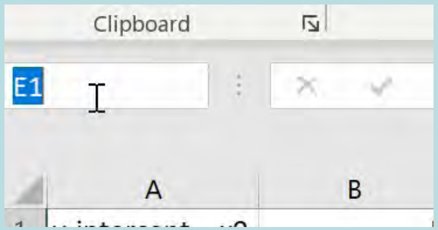
In the following you can see step-by-step instructions for this exercise.

1-
In cell C3 type measured position x (m)
In cell D1 type relative error in position
In cell D2 type error in time (s)
Expand the width of column C and column D by double clicking at the location of the arrow heads.

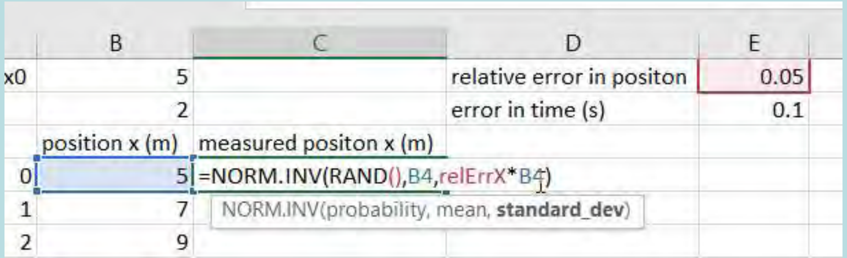


2- Select cell E1, then click on the name box and change the text from E1 to relErrX, then press enter. Now you can use relErrX to refer to the content of cell E1.

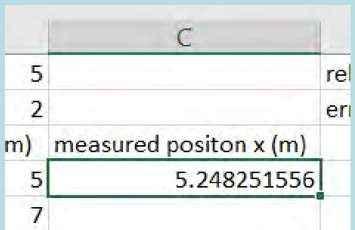


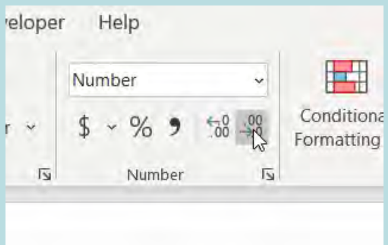


3- In cell E1, type 0.05 and in cell E2, type 0.1.
In cell C4, type the formula
=NORM.INV(RAND(),B4,relErrX*B4)
as shown, then press enter.

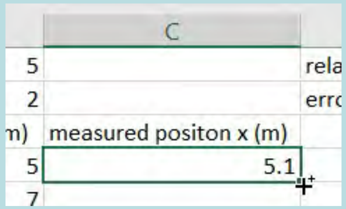


4- Select cell C4, then repeat clicking on Decrease Decimal box of Number group of Home menu to show one decimal place.

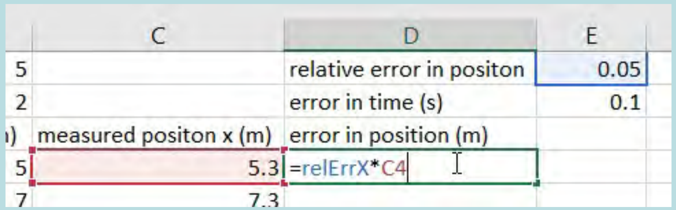




5- To copy the formula of cell C4 to lower cells, move the mouse to the right-bottom corner of cell C4 until the mouse pointer changes into a cross as shown. Click, hold, and move the mouse down to cell C12 then release the mouse.



6- In cell D4, type error in position (m).
In cell D5, type the formula
=relErrX*C4
as shown, then press enter.



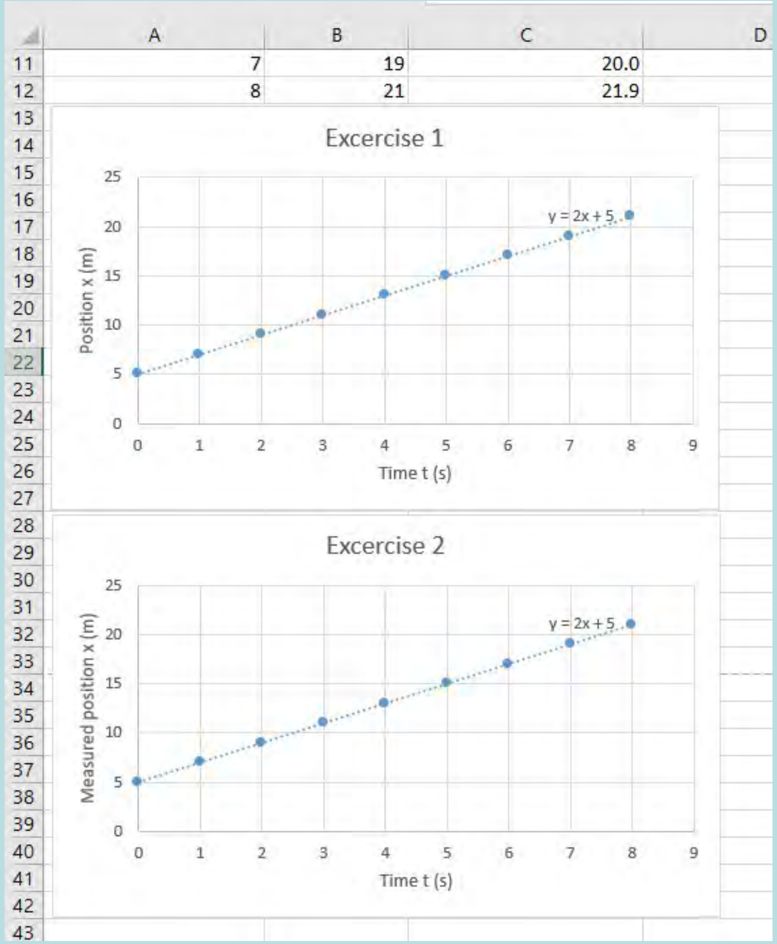
7- Like step 4, show one decimal point in cell D4.

8- Like step 5, copy the formula of D4 to the cells below it until cell D12.

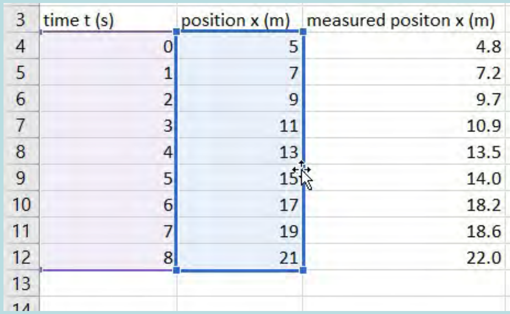
1- You need to create a copy of the chart you used in Exercise 1.
One way to do this is
Select the chart, then press Ctrl key and c key as the same time.
Select any empty space on the worksheet and then
press Ctrl key and v key as the same time.

2- Select the title of the copied chart and change it into Exercise 2.
Select the vertical axis title and change it into Measured position x (m).

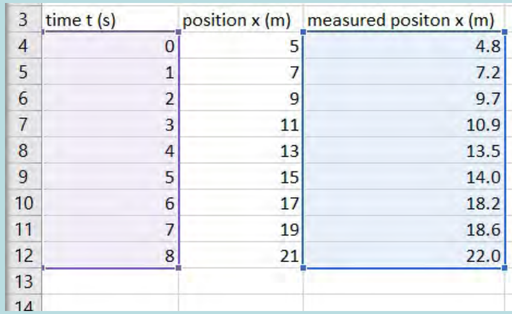
3- Move charts for Exercise 1 and Exercise 2 below your data as shown.



4- To plot the measured position versus time on the chart of Exercise 2, select the chart, then move the mouse over the edge of the blue box, shown below, until the mouse pointer changes to across with arrows. Click on the edge of the box while pressing the mouse and move it to the right as shown, then release the mouse.

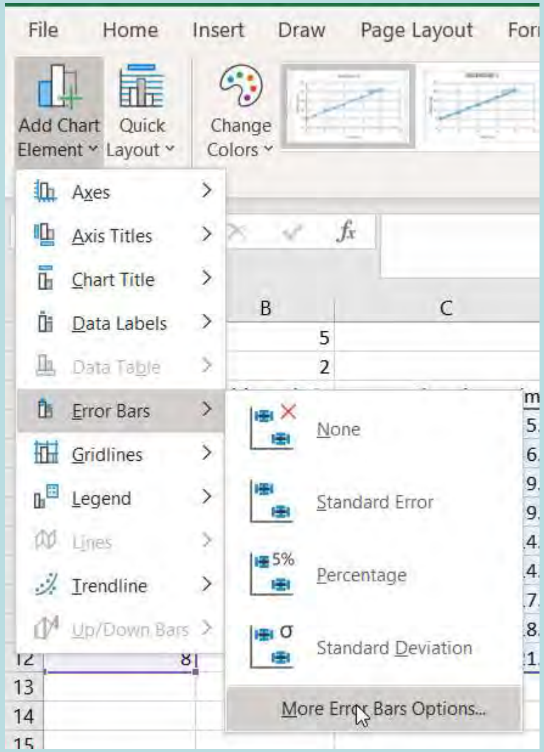


3	time t (s)	position x (m)	measured positon x (m)
4	0	5	4.8
5	1	7	7.2
6	2	9	9.7
7	3	11	10.9
8	4	13	13.5
9	5	15	14.0
10	6	17	18.2
11	7	19	18.6
12	8	21	22.0
13			

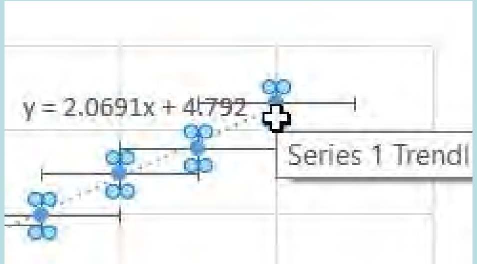


3	time t (s)	position x (m)	measured positon x (m)
4	0	5	4.8
5	1	7	7.2
6	2	9	9.7
7	3	11	10.9
8	4	13	13.5
9	5	15	14.0
10	6	17	18.2
11	7	19	18.6
12	8	21	22.0
13			

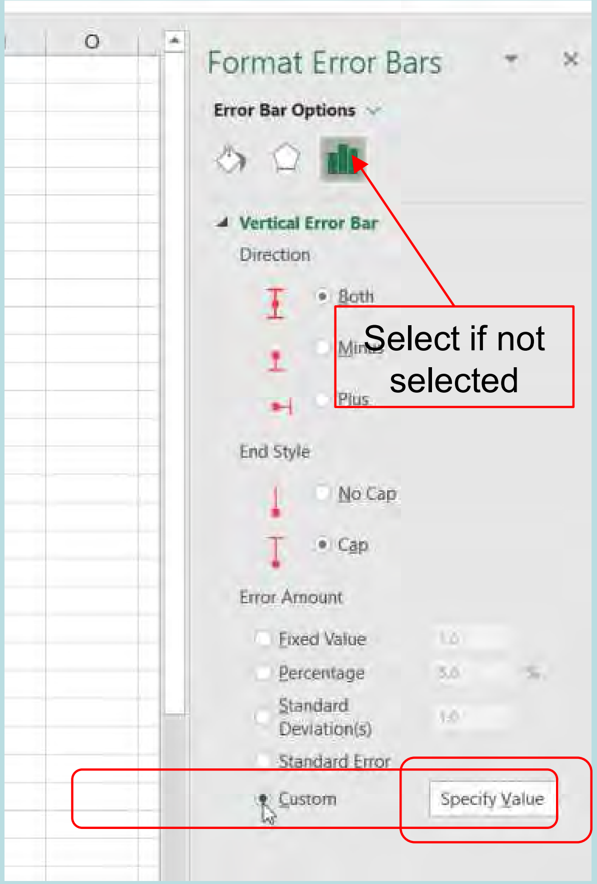
5- To plot the error bars, double click on the chart of Exercise 2 to activate the Chart Design menu. From the Add Chart Element drop menu select Error Bars, then select More Error Bars Options… as shown.



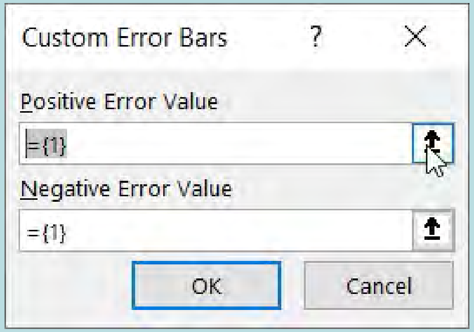
1- select one of the vertical error bars as shown



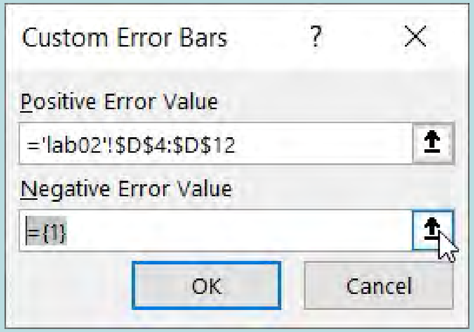
2- From the menu on the right of the worksheet, select Custom found at bottom of the menu as shown. Then select Specify Value button on the right.



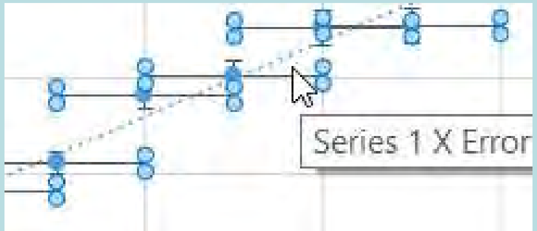
3- Click on the arrow as shown and then select the the range of the error in position cell D4 down to cell D12 then press enter.



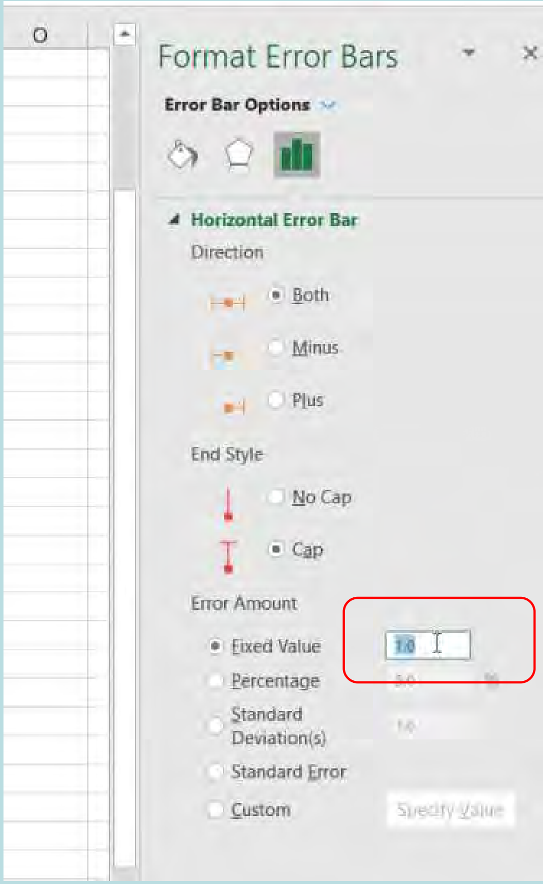
4- Select ={1} under Negative Error Value, then click of the arrow as shown. Select the range of the error in position cell D4 down to cell D12 then press enter. Then press OK.



5- select one of the horizontal error bars as shown



6- From the menu on the right of the worksheet, change Fixed Value to 0.1 then press enter.



1- To find the error in the slope and in the intercept, in cell E29 type the formula =LINESR(C4:C12,A4:A12,TRUE,TRUE) as shown, then press enter.

	D	E	F	G
28				
29		=LINEST(C4:C12,A4:A12,TRUE,TRUE)		
30		LINEST(known_ys, [known_xs], [const], [stats])		
31				

2- Excel LINEST function generates 10 different statistics of the line, as shown.

	E	F
28		
29	1.962050863	4.990032
30	0.114260282	0.543988
31	0.976811176	0.885056
32	294.8695601	7
33	230.9786153	5.483273
34		

Most probable value for the slope $\bar{v}$ (E29)

Most probable value for the y-intercept $\overline{x_0}$ (F29)

Standard deviation (error) for the slope δv (E30)

Standard deviation (error) for the y-intercept δx_0 (F30)

3- type all cells that contain letters.

	D	E	F
34			
35			
36		expected v (m/s)	2.00
37		measured v (m/s)	1.96
38		error in v (m/s)	0.11
39			
40	10.0	expected x0 (m)	5.00
41		measured x0 (m)	4.99
42		error in x0 (m)	0.54
43			

4- In cell F36, type the formula =v, press enter.

expected v (m/s) | =v

5- In cell F37, type the formula =E29, press enter.

measured v (m/s) | =E29

6- In cell F38, type the formula =E30, press enter.

error in v (m/s) | =E30

7- In cell F40, type the formula =x0, press enter.

expected x0 (m) | =x0

8- In cell F41, type the formula =F29, press enter.

measured x0 (m) | =F29

9- In cell F42, type the formula =F30, press enter.

error in x0 (m) | =F30

10- Press F9 to update the random numbers. If you press F9 couple of times, you can notice that most of the time the expected value for the velocity in cell B2 is between $\bar{v} - \delta v$ and $\bar{v} + \delta v$. Similarly, most of the time, the expected value for the y-intercept in cell B1 is between $\overline{x_0} - \delta x_0$ and $\overline{x_0} + \delta x_0$.

Power-law relationship

For a simple harmonic oscillator having a spring constant k, the frequency f is related to its mass m by:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}. \tag{2}$$

Suppose you do not know this relationship, but you expect that the frequency f is related to the mass m by the following power law:

$$f = a\, m^s, \tag{3}$$

and you want to determine the values of the two constants, the coefficient a and exponent s by doing an experiment where you measure the frequency as a function of mass. In the following you will learn how to find the most probable values for a and s and to estimate their uncertainties.

If you take the logarithm of both sides of Eq. 2, you will get:

$$\log f = \log a + s \log m.$$

This a linear relationship between $\log f$ and $\log m$. If you plot $\log f$ on the vertical axis and $\log m$ on the horizontal axis, the y-intercept will be $\log a$ and the slope will be s.

Exercise 3:

You will use Excel to generate a list of frequencies as a function of mass according to Eq. 2 for a specific value of the spring constant k. From these frequencies you will generate another list of frequencies which you call measured frequencies by assuming that the frequency measurements are normally distribute around the original frequencies and having the same relative error. You will also assume that the measurement error of mass is very small such that you can use the mass values in the original list as your measured mass. You will generate three plots. You will plot in the first one the measured frequency versus mass and you will use Excel Trendline/Power to find the best estimate of a and s. You will plot in the second plot the logarithm of the measured frequencies versus the logarithm of mass values. From this plot, you will use Excel Trendline/linear and Excel function LINEST to find the best estimate for a and s and their errors. You will plot in the third plot the measured frequency versus mass, but you will use logarithmic scales for both axes.

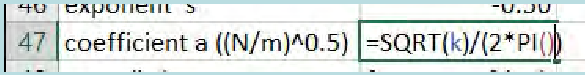
In the following you can see detailed instructions for this exercise.

1- type all cells that contain letters.

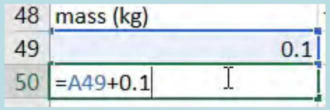
2- Name cell B45 as k and enter its value.
Name cell B46 as s and enter its value.
Name cell B47 as a and enter its value.
Name cell E45 as relErrF and enter its value.

	A	B	C	D	E
43					
44					
45	spring constant k (N/m)	1000.0		relative error in frequency	0.01
46	exponent s	-0.50			
47	coefficient a ((N/m)^0.5)	5.03			
48	mass (kg)	frequency f (Hz)	measured frequency f (Hz)	log (m)	log (f)
49	0.1	15.9	15.7	-1.00	1.20
50	0.2	11.3	11.4	-0.70	1.06
51	0.3	9.2	9.1	-0.52	0.96
52	0.4	8.0	7.8	-0.40	0.89
53	0.5	7.1	7.1	-0.30	0.85
54	0.6	6.5	6.6	-0.22	0.82
55	0.7	6.0	6.0	-0.15	0.78
56	0.8	5.6	5.6	-0.10	0.75
57	0.9	5.3	5.3	-0.05	0.72
58	1.0	5.0	5.0	0.00	0.70
59	1.1	4.8	4.8	0.04	0.68
60	1.2	4.6	4.6	0.08	0.66

3- In cell B47, type the formula =SQRT(k)/(2*pi()), press enter.

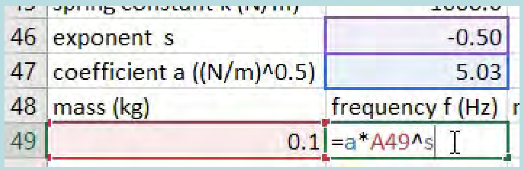


4- In cell A49 enter 0.1, then in cell A50, type the formula =A49+0.1, press enter.



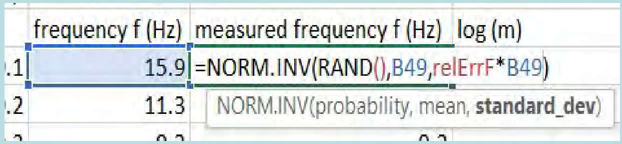
Generate the value below this cell by pulling the cell down to cell A60.

5- In cell B49, type the formula =a*A49^s, press enter.



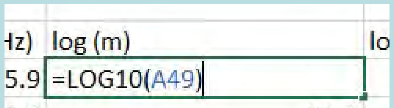
Generate the value below this cell by pulling the cell down to cell B60.

6- In cell C49, type the formula =NORM.INV(RAND(),B49,relErrF*B49), press enter.



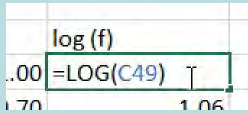
Generate the value below this cell by pulling the cell down to cell C60.

7- In cell D49, type the formula =LOG10(A49), press enter.



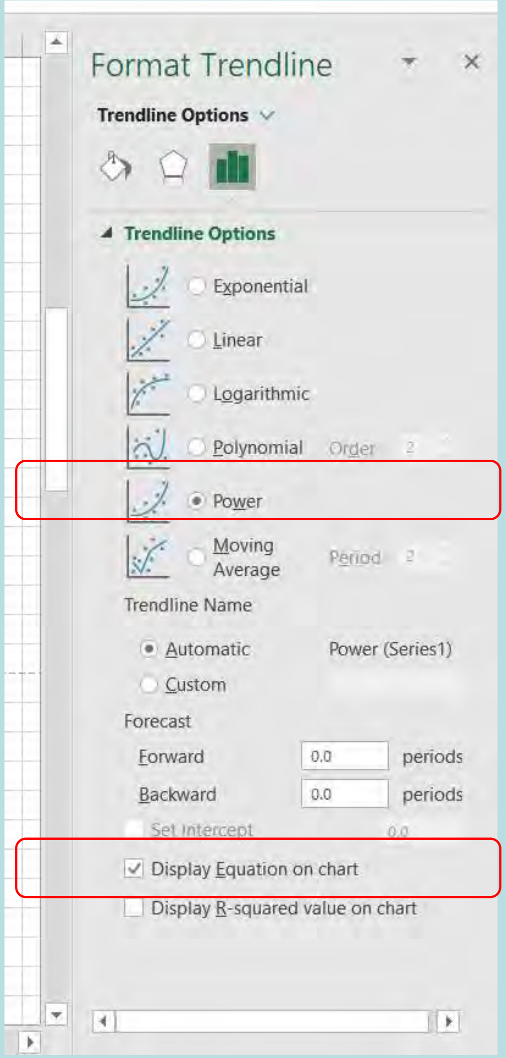
Generate the value below this cell by pulling the cell down to cell D60.

8- In cell F49, type the formula =LOG10(C49), press enter.

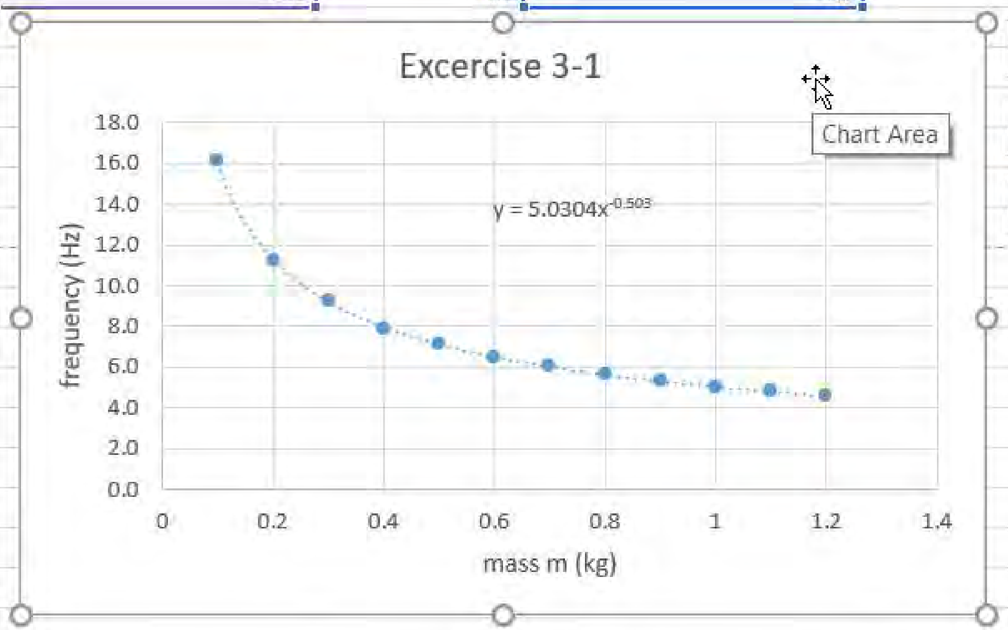


Generate the value below this cell by pulling the cell down to cell F60.

1- generate a plot, as you did in the previous exercise, but for measured frequency versus mass. For the fit, select Power and Display Equation on chart as shown. Select the equation and move it to the middle of your plot.

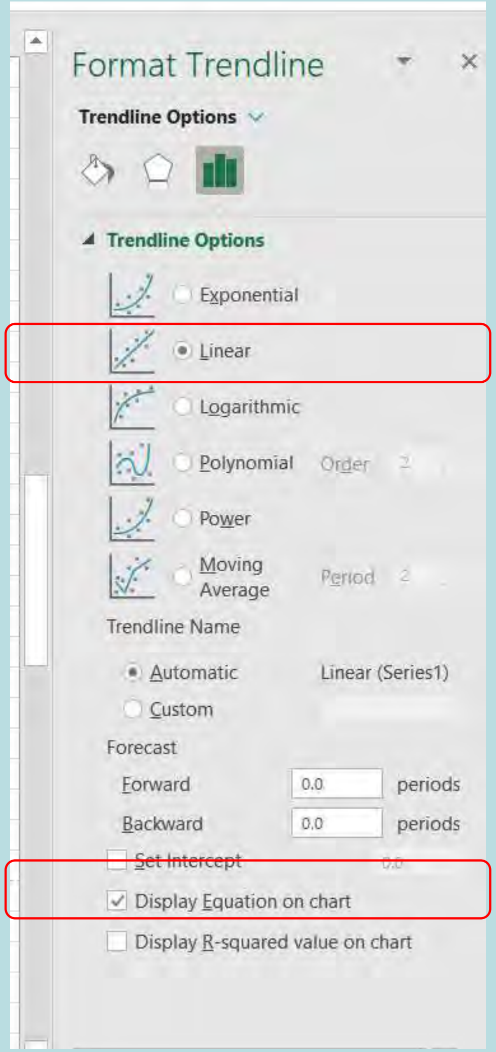


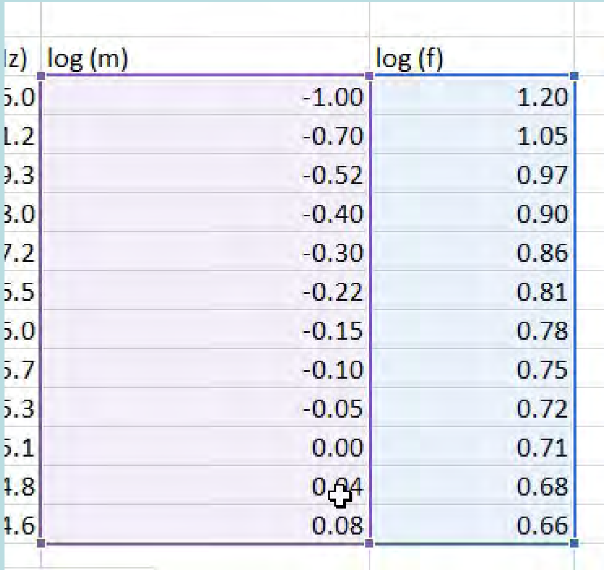
47	coefficient a ((N/m)^0.5)	5.03			
48	mass (kg)	frequency f (Hz)	measured frequency f (Hz)	log (m)	
49	0.1	15.9	16.1		
50	0.2	11.3	11.3		
51	0.3	9.2	9.2		
52	0.4	8.0	7.9		
53	0.5	7.1	7.1		
54	0.6	6.5	6.4		
55	0.7	6.0	6.0		
56	0.8	5.6	5.6		
57	0.9	5.3	5.3		
58	1.0	5.0	5.0		
59	1.1	4.8	4.8		
60	1.2	4.6	4.6		



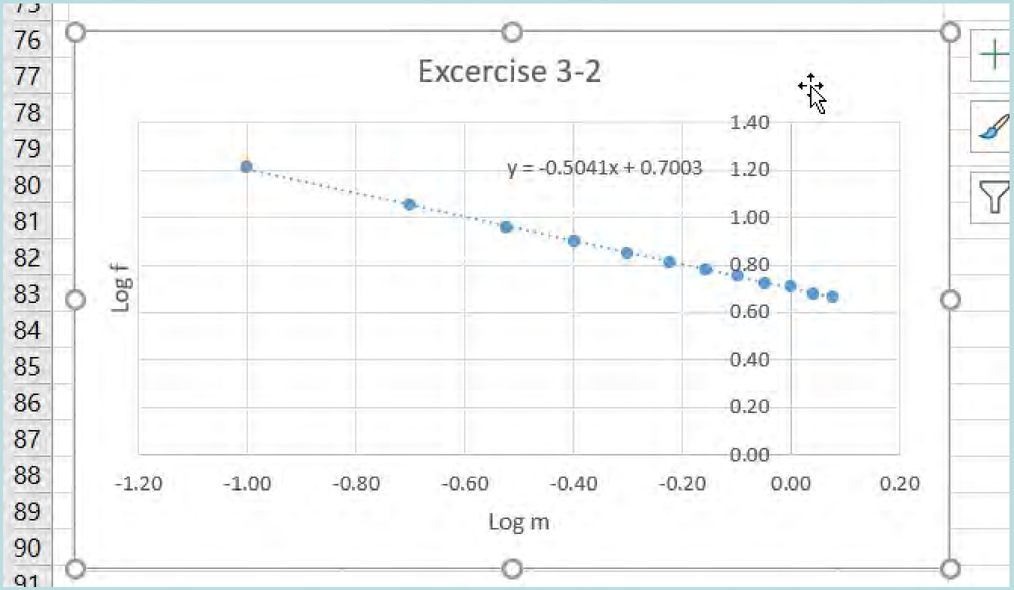
2- select your chart and move it below your data as shown above.

1- generate a plot, as you did in the previous exercise, but for log f versus log m. For the fit, select Linear and Display Equation on chart as shown. Select the equation and move it to the middle of your plot.





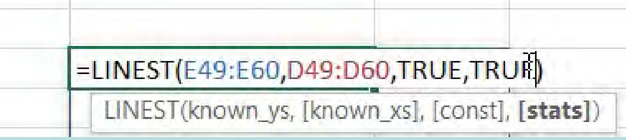
log (m)	log (f)
-1.00	1.20
-0.70	1.05
-0.52	0.97
-0.40	0.90
-0.30	0.86
-0.22	0.81
-0.15	0.78
-0.10	0.75
-0.05	0.72
0.00	0.71
0.04	0.68
0.08	0.66



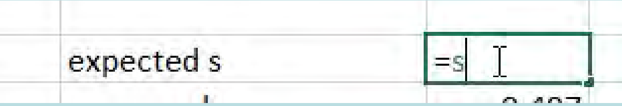
2- select your chart and move it below the plot for Exercise 3-1 as shown above.

1- type all cells that contain letters.

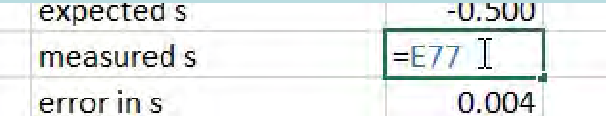
2- In cell E77, type the formula =LINEST(E49:E60,D49,D60,TRUE,TRUE), press enter.



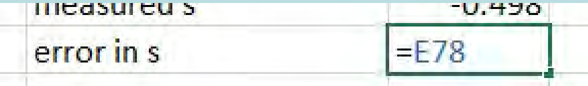
3- In cell F84, type the formula =s, press enter.



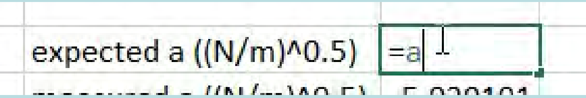
4- In cell F85, type the formula =E77, press enter.



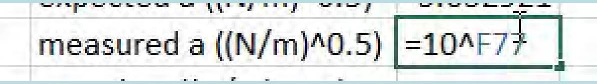
5- In cell F86, type the formula =E78, press enter.



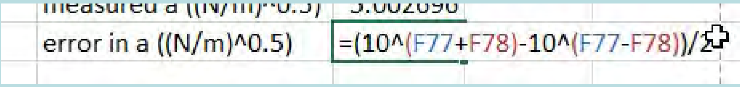
6- In cell F88, type the formula =a, press enter.



7- In cell F89, type the formula =10^F77, press enter.



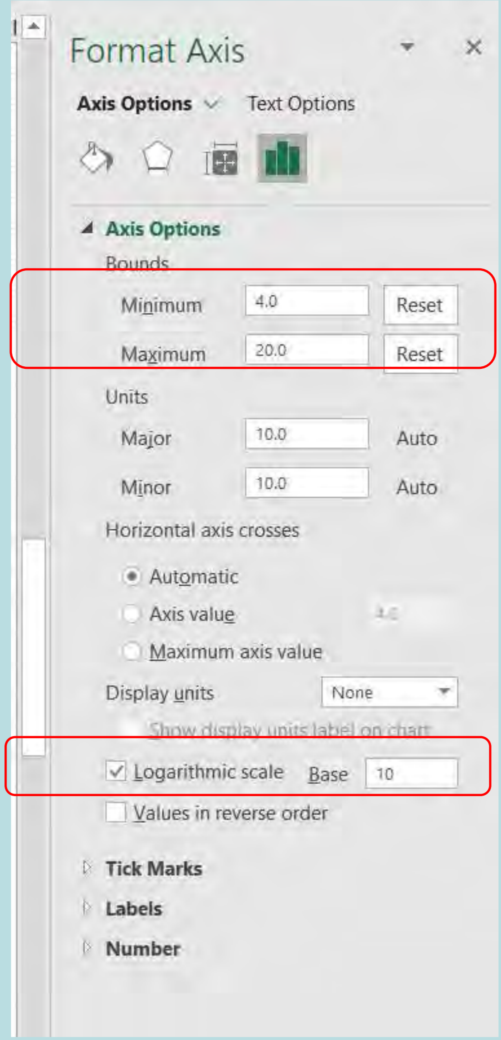
8- In cell F90, type the formula =(10^(F77+F78)-10^(F77-F78))/2, press enter.



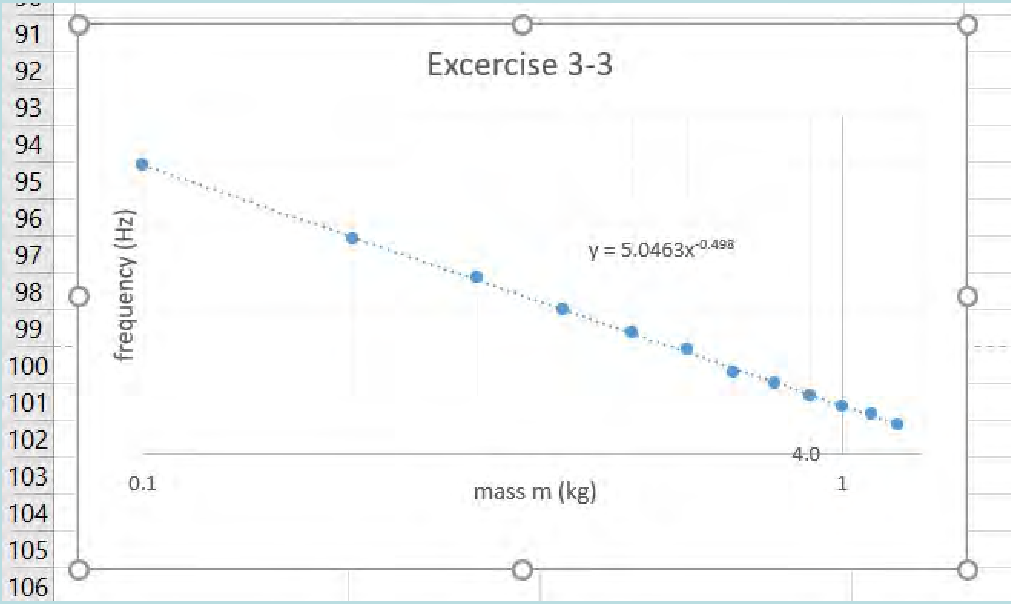
	D	E	F
76			
77		-0.5014	0.7014
78		0.0025	0.0010
79		0.9998	0.0027
80		40295.7760	10.0000
81		0.2979	0.0001
82			
83			
84		expected s	-0.5000
85		measured s	-0.5014
86		error in s	0.0025
87			
88	0.20	expected a ((N/m)^0.5)	5.033
89		measured a ((N/m)^0.5)	5.028
90		error in a ((N/m)^0.5)	0.012
91			

9- Press F9 to update the random numbers. If you press F9 couple of times, you can notice that most of the time the expected value for the exponent s in cell F84 is between $\bar{s} - \delta s$ and $\bar{s} + \delta s$. Similarly, most of the time, the expected value for the coefficient a in cell F88 is between $\bar{a} - \delta a$ and $\bar{a} + \delta a$. Where a bar on a symbol indicates the most probable value (measured) and δ indicates in the error in.

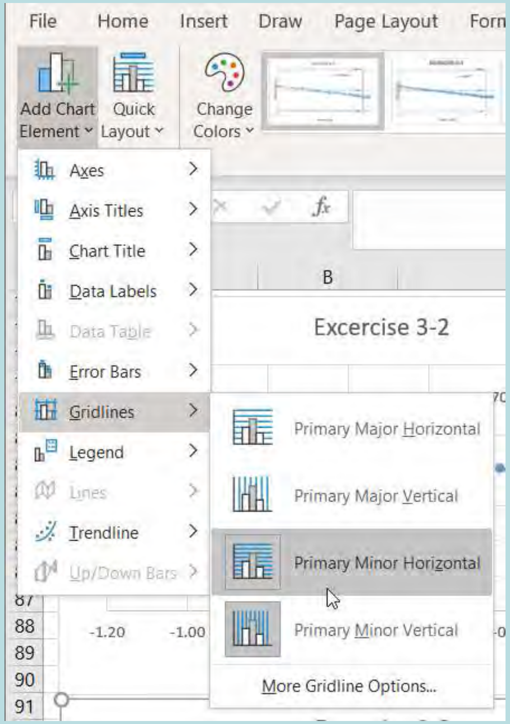
1- copy the chart of Exercise 3-1 and mover it below that of Exercise 3-2. click on the number of vertical axis to open Format Axis menu. Change Display units to Logarithmic scale and Bounds Minimum to 4.0 and Maximum to 20.



2- click on the number of horizontal axis to open Format Axis menu. Change Display units to Logarithmic scale and Bounds Minimum to 0.1 and Maximum to 1.3.



3- Select Gridlines/Primary Minor Horizontal and Primary Minor Vertical



Exponential relationship:
In this course, you will learn that, in an electric circuit consisting of a resistor R and capacitor C, the current i decreases exponentially with time according to the following equation:

$$i = i_0 e^{-t/\tau}. \quad (4)$$

Here i_0 is the current in the circuit at time $t = 0$ and τ is the time constant. The SI unit for current is Ampere (A) and the SI unit for the time constant is second. The circuit is called an RC circuit.

Suppose you do an experiment measuring the current i of an RC circuit as a function of time t and you want to determine the time constant τ of the circuit. In the following, you will learn how to find the most probable values for i_0 and τ and you will estimate their uncertainties.

If you take the natural logarithm of both sides of Eq. 4, you will get:

$$\ln i = \ln i_0 - \frac{1}{\tau} t.$$

This a linear relationship between $\ln i$ and t. If you plot $\ln i$ on the vertical axis and t on the horizontal axis, the y-intercept will be $\ln i_0$ and the slope will be$-\frac{1}{\tau}$.

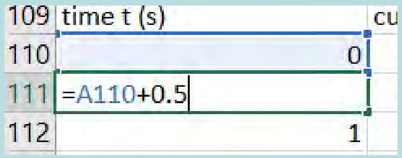
Exercise 4:
You will use Excel to generate a list of current values as a function of time according to Eq. 4 for a specific value for the initial current i_0 and a specific value of the time constant τ. From these current values you will generate another list of current values which you call measured current by assuming that the current measurements are normally distribute around the original current values and have the same relative error. You will also assume that the error in measuring the time is small such that you can use the time values in the original list as your measured time. You will generate three plots. In the first one, you will plot the measured current versus time and you will use Excel Trendline/Exponential to find the best estimate of i_0 and τ. In the second one, you will plot the natural logarithm of the measured current versus time. From this plot, you will use Excel Trendline/Linear and Excel function LINEST to find the best estimate of i_0 and τ and their uncertainties. In the third plot, you will plot the measured current versus time, but you will use natural logarithmic scale for the vertical axis.

In the following you can see detailed instructions for this exercise.

1- type all cells that contain letters.

2- Name cell B107 as tau and enter its value. Name cell B108 as i0 and enter its value. Name cell E107 as relErrl and enter its value.

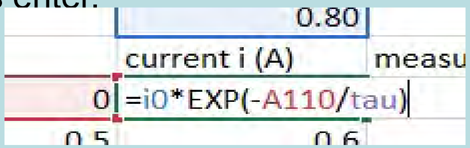
3- In cell A110 enter 0, then in cell A111, type the formula =A110+0.5, press enter.



Generate the value below this cell by pulling the cell down to cell A121.

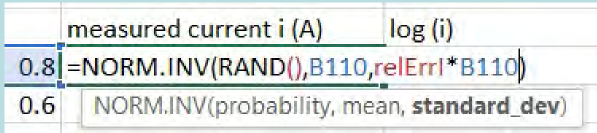
	A	B	C	D	E
106					
107	time constant (s)	1.5		relative error in current	0.05
108	initial current (A)	0.80			
109	time t (s)	current i (A)	measured current i (A)	ln (i)	
110	0.00	0.80	0.76	-0.28	
111	0.50	0.57	0.54	-0.61	
112	1.00	0.41	0.42	-0.87	
113	1.50	0.29	0.29	-1.23	
114	2.00	0.21	0.21	-1.55	
115	2.50	0.15	0.16	-1.86	
116	3.00	0.11	0.11	-2.19	
117	3.50	0.08	0.07	-2.62	
118	4.00	0.06	0.06	-2.88	
119	4.50	0.04	0.04	-3.32	
120	5.00	0.03	0.03	-3.52	
121	5.50	0.02	0.02	-4.01	

4- In cell B110, type the formula =i0*EXP(-A110/tau), press enter.



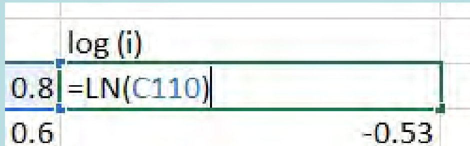
Generate the value below this cell by pulling the cell down to cell B121.

5- In cell C110, type the formula =NORM.INV(RAND(),B110,relErrl*B110), press enter.



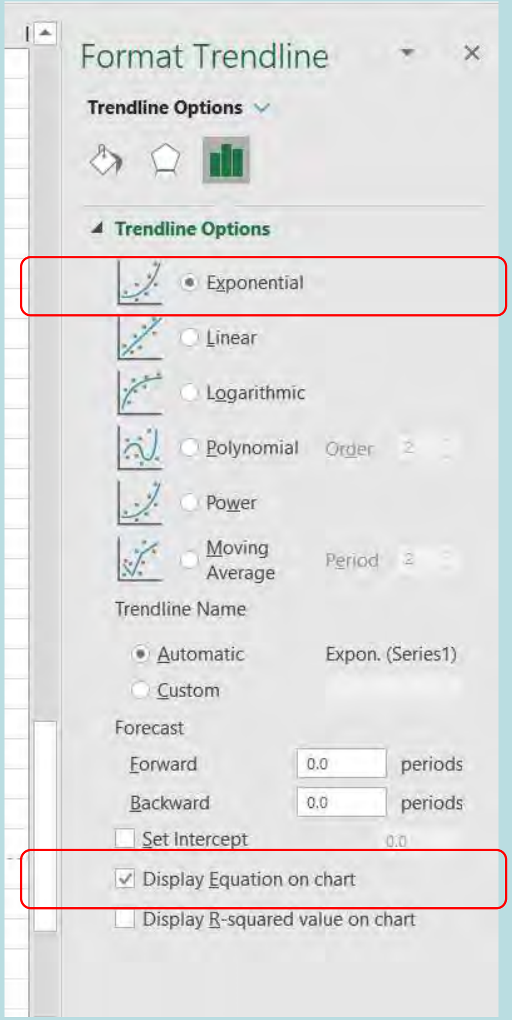
Generate the value below this cell by pulling the cell down to cell C121.

6- In cell D49, type the formula =LN(C110), press enter.

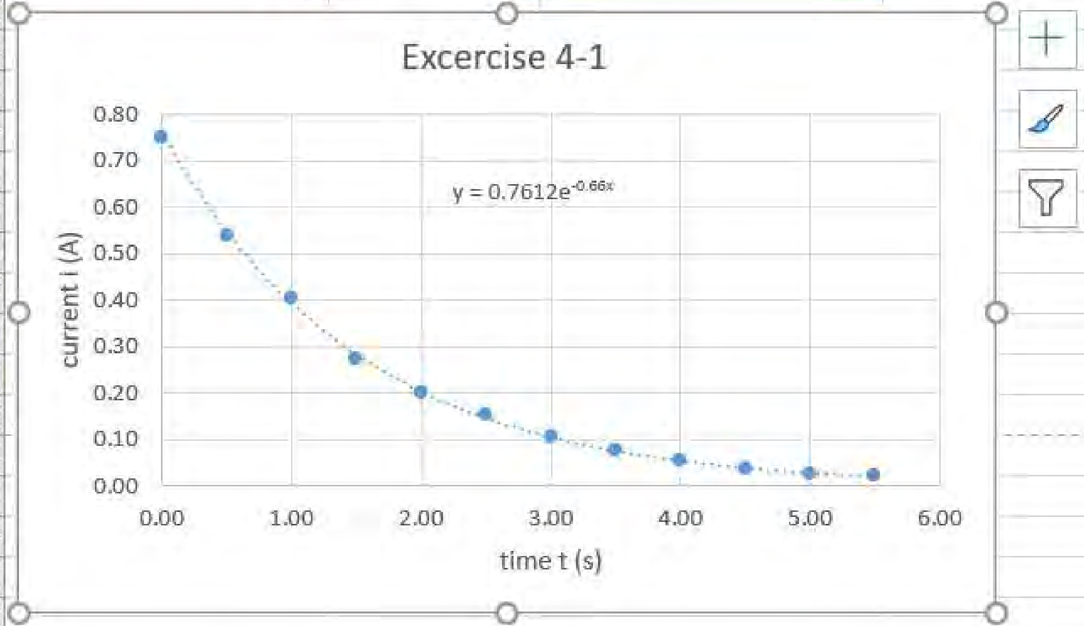


Generate the value below this cell by pulling the cell down to cell D121.

1- generate a plot, as you did in the previous exercise, but for measured current versus time For the fit, select Power and Display Equation on chart as shown. Select the equation and move it to the middle of your plot.

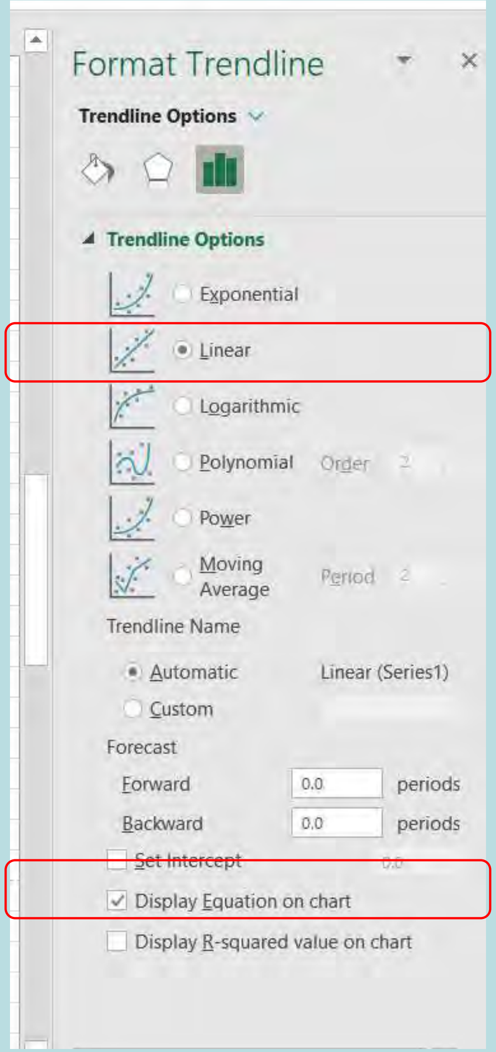


109	time t (s)	current i (A)	measured current i (A)	ln (i)
110	0.00	0.80	0.75	
111	0.50	0.57	0.54	
112	1.00	0.41	0.40	
113	1.50	0.29	0.27	
114	2.00	0.21	0.20	
115	2.50	0.15	0.15	
116	3.00	0.11	0.11	
117	3.50	0.08	0.08	
118	4.00	0.06	0.06	
119	4.50	0.04	0.04	
120	5.00	0.03	0.03	
121	5.50	0.02	0.02	

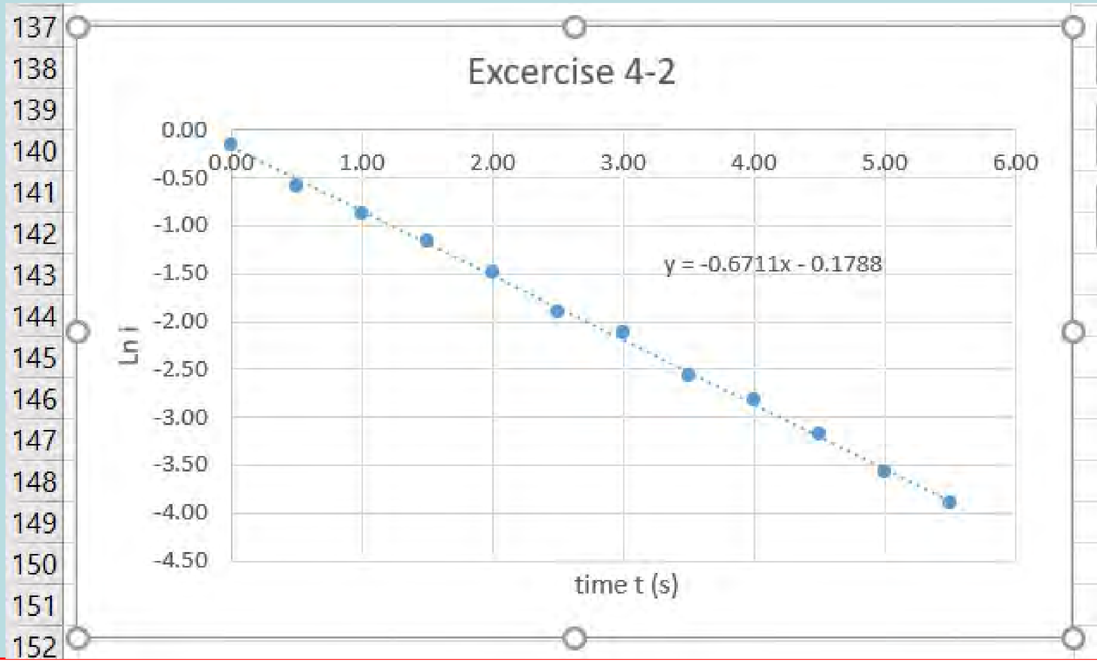


2- select your chart and move it below your data as shown above.

1- generate a plot, as you did in the previous exercise, but for Ln i versus time. For the fit, select Linear and Display Equation on chart as shown. Select the equation and move it to the middle of your plot.



106				
107	time constant (s)	1.5		relative error in current
108	initial current (A)	0.80		
109	time t (s)	current i (A)	measured current i (A)	ln (i)
110	0.00	0.80	0.86	-0.15
111	0.50	0.57	0.55	-0.59
112	1.00	0.41	0.42	-0.87
113	1.50	0.29	0.31	-1.16
114	2.00	0.21	0.23	-1.48
115	2.50	0.15	0.15	-1.90
116	3.00	0.11	0.12	-2.11
117	3.50	0.08	0.08	-2.56
118	4.00	0.06	0.06	-2.83
119	4.50	0.04	0.04	-3.18
120	5.00	0.03	0.03	-3.56
121	5.50	0.02	0.02	-3.90
122				



2- select your chart and move it below the plot for Exercise 4-1 as shown above.

1- type all cells that contain letters.

2- In cell E138, type the formula =LINEST(D110:D121,A110,A121,TRUE,TRUE), press enter.

=LINEST(D110:D121,A110:A121,TRUE,TRUE)

LINEST(known_ys, [known_xs], [const], **[stats]**)

3- In cell F145, type the formula =tau, press enter.

expected tau (s)	=tau

4- In cell F146, type the formula =1/E138, press enter.

measured tau (s)	=-1/E138

5- In cell F147, type the formula =(1/(F146-E139)-1/(F146+E139))/2, press enter.

measured tau (s)	1.484
error in tau (s)	=(1/(F146-E139)-1/(F146+E139))/2

6- In cell F149, type the formula =i0, press enter.

expected i0 (A)	=i0

7- In cell F150, type the formula =EXP(F138), press enter.

measured i0 (A)	=EXP(F138)

8- In cell F90, type the formula =(EXP(F138+F138)-EXP(F138-F139))/2, press enter.

measured i0 (A)	0.81
error in i0 (A)	=(EXP(F138+F139)-EXP(F138-F139))/2

	D	E	F
137			
138		-0.6714	-0.2306
139		0.0121	0.0393
140	6.00	0.9968	0.0723
141		3083.7619	10.0000
142		16.1158	0.0523
143			
144			
145		expected tau (s)	1.500
146		measured tau (s)	1.489
147		error in tau (s)	0.018
148			
149		expected i0 (A)	0.800
150		measured i0 (A)	0.794
151		error in i0 (A)	0.031
152			

9- Press F9 to update the random numbers. If you press F9 couple of times, you can notice that most of the time the expected value for the time constant τ in cell F145 is between $\bar{\tau} - \delta\tau$ and $\bar{\tau} + \delta\tau$. Similarly, most of the time, the expected value for the initial current i_0 in cell F149 is between $\bar{\imath}_0 - \delta i_0$ and $\bar{\imath}_0 + \delta i_0$. Where a bar on a symbol indicates the most probable value (measured) and δ indicates in the error in.

1- copy the chart of Exercise 4-1 and mover it below that of Exercise 4-2. click on the number of vertical axis to open Format Axis menu. Change Display units to Logarithmic scale.

2- Select Gridlines/Primary Minor Horizontal