Workshop # 38, Sharing Inspiration, Bruxelles, 2017, March, 24-27

Physics Workshop:

Simple mechanical, thermodynamical, optical and electrical experiment and calculations with the TI-Nspire and LabCradle Technology

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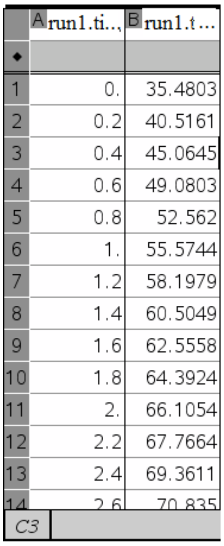
Contents

1. Response Time of an Electronic Thermometer

With a Temperature sensor connected to a TI-*n*spire (or a TI-84) calculator, temperature data can be measured as a function of time.

In this experiment the sensor is plunged into a Dewar Vessel of boiling water ($\vartheta_B \approx 97°C$).

The temperature is then measured with a rate of 5 samples per second during 10 seconds (green points in Fig. 1, right).



	A run1.ti...	B run1.t...
◆		
1	0.	35.4803
2	0.2	40.5161
3	0.4	45.0645
4	0.6	49.0803
5	0.8	52.562
6	1.	55.5744
7	1.2	58.1979
8	1.4	60.5049
9	1.6	62.5558
10	1.8	64.3924
11	2.	66.1054
12	2.2	67.7664
13	2.4	69.3611
14	2.6	70.835
C3		

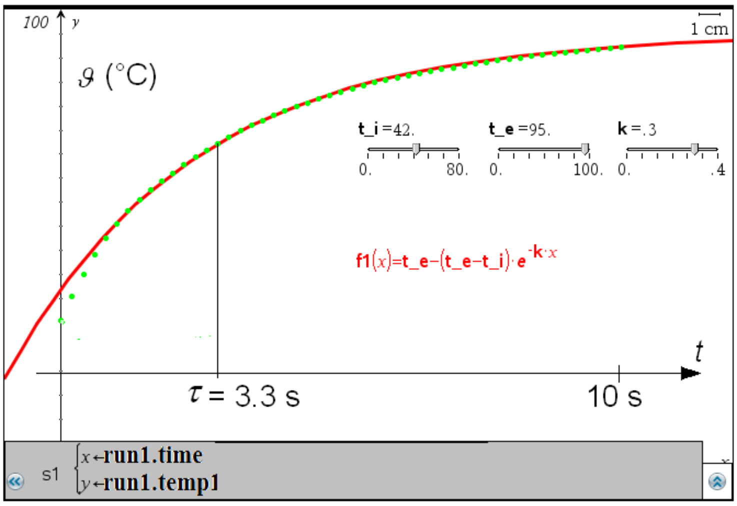


Figure 1 Temperature Response Curve of an EasyTemp-Temperature Sensor

According to Newton's law the temperature response function $\vartheta = \vartheta(t)$ (TI-*n*spire: $f_1 = f_1(x)$) of the sensor is delayed in respect to this Heaviside temperature step (figure 1):

$$f_1(x) = t_e - (t_e - t_i) \cdot e^{-k \cdot x}$$

The parameters t_e, t_i and k can be determined by *"optical fitting"* with three sliders (works with TI-*n*spireCX CAS only): $k = 0.3 \frac{1}{s}$, *t_e* =95°C and *t_i*=42°C

The scatter plot of the measured values (green points in Figure 1) is in quite good accordance with the calculated function $f_1(x)$ (red curve in figure 1). Deviation may be observed in the range from 0 seconds to 0.8 seconds.

The inverse of the parameter k is the response time $\tau = \frac{1}{k} = 3.3$ s of the temperature sensor. During this time the temperature signal of the temperature sensor reaches 63% of its final value.

Alternatively to this type of analysis a regression analysis of $\frac{\vartheta_{environ} - \vartheta(t)}{\vartheta_{environ} - \vartheta_{initial}} = e^{-k \cdot t}$ may be performed (for TI-84 and for TI-*n*spireCX CAS).

Equipment : insulated e.g. Dewar vessel, boiling water,
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adaptor
TI-temperature probe (Vernier)

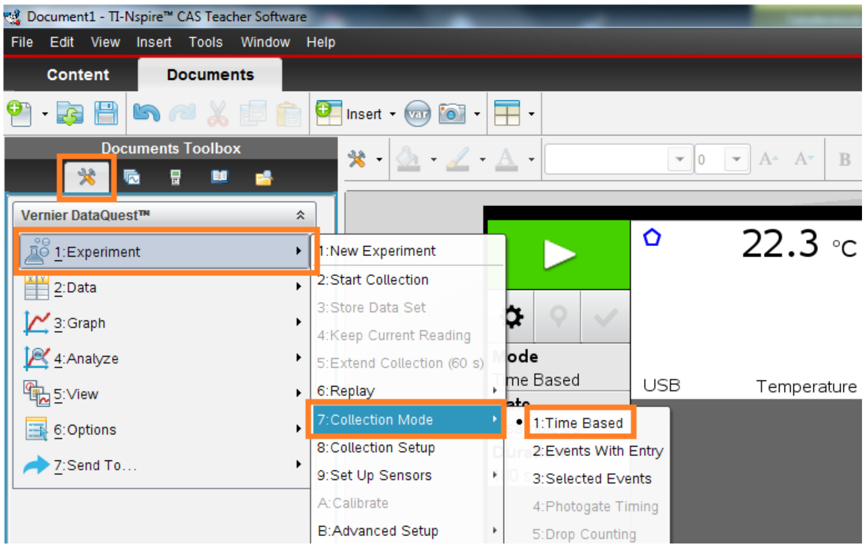


Figure 2 TI-*n*spire Start screen

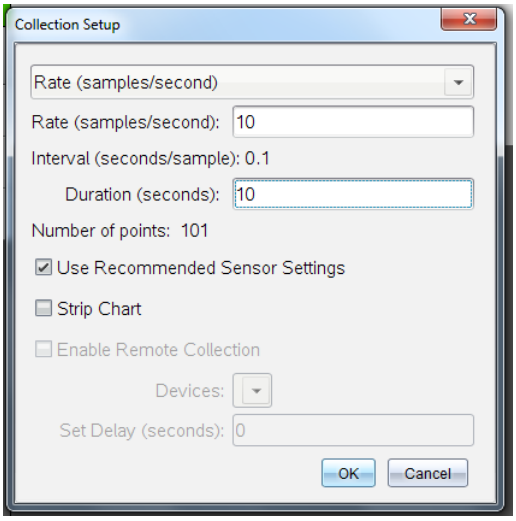


Figure 3 Collection Setup

2. Evaporation Heat medical Benzine or Pentane

A precise exponential temperature decay $\vartheta = \vartheta(t)$ in function of time can be obtained by evaporation of medical benzine from a cotton fixed pad at the measuring area of an temperature sensor.

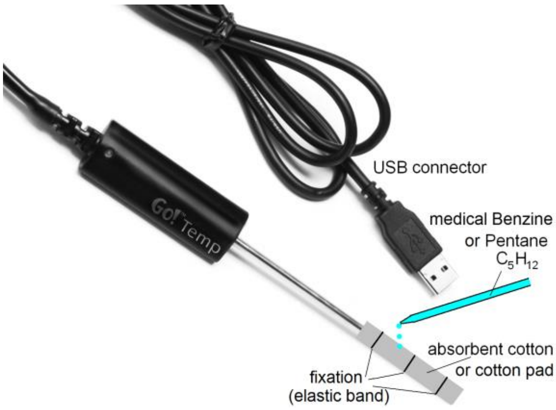


Figure 1 Measuring the evaporation cold of benzine or pentane from an cotton pad on a temperature probe

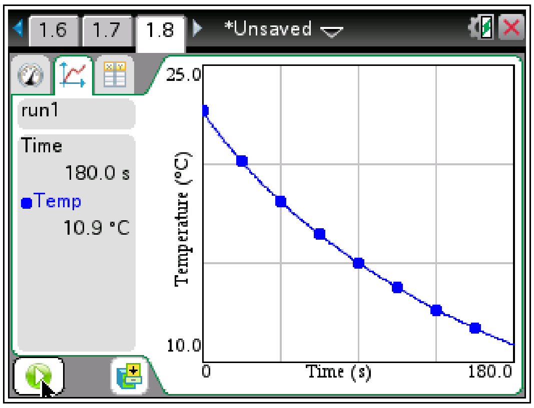


Figure 2 Exponential Decay of the temperature on a cotton pad moist with benzine.

Fig. 2 shows a temperature decay from 23°C to 11°C in 180 seconds.

An even faster decay can be obtained by evaporating pentane (C_5H_{12}) which shows a decay from 20°C to 0°C in 150 seconds (Fig. 6).

Again this decay could be modelled by "optical fitting" of an exponential function with a constant value added.

However this curve is analysed by a built in regression function (TI-*n*spire) $y = a \cdot b^x$ with the variables *y* and *x* (Fig. 4). The parameters *a* and *b* are determined by an internal Gaussian least square fit algorithm. This algorithm works however only if the zero line of the exponential growth or decay lies at *y=0* (corresponds to $\vartheta = 0°\text{C}$). The zero line of the exponential function shown in Figure 3 is at $\vartheta_{\text{environ}} \approx -17.2\,°\text{C}$.

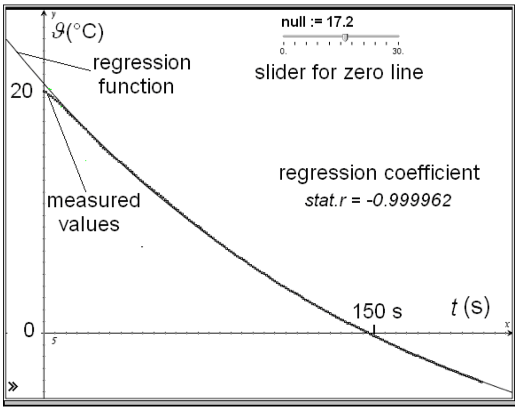
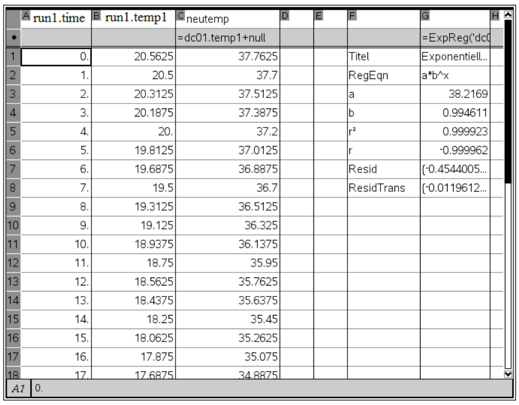


Figure 3 Temperature Decay from evaporating Pentane



	A run1.time	B run1.temp1	C neutemp	D	E	F	G	H
◆			=dc01.temp1+null				=ExpReg('dc(	
1	0.	20.5625	37.7625			Titel	Exponentiell...	
2	1.	20.5	37.7			RegEqn	a*b^x	
3	2.	20.3125	37.5125			a	38.2169	
4	3.	20.1875	37.3875			b	0.994611	
5	4.	20.	37.2			r²	0.999923	
6	5.	19.8125	37.0125			r	-0.999962	
7	6.	19.6875	36.8875			Resid	{-0.4544005...	
8	7.	19.5	36.7			ResidTrans	{-0.0119612...	
9	8.	19.3125	36.5125					
10	9.	19.125	36.325					
11	10.	18.9375	36.1375					
12	11.	18.75	35.95					
13	12.	18.5625	35.7625					
14	13.	18.4375	35.6375					
15	14.	18.25	35.45					
16	15.	18.0625	35.2625					
17	16.	17.875	35.075					
18	17.	17.6875	34.8875					

A1 0.

Figure 4 Regression Data analysis in a *n*spire sreadsheet

If the corresponding data have to be fitted using this algorithm $\vartheta_{environ}$ must be subtracted from the temperature values first.

Since $\vartheta_{environ}$ is unknown a parameter *"null"* which is added to the temperature data is introduced.

The procedure is shown in Figure 4:

Column A contains the time data dc01.time with one-second-steps, *column* B the temperature data dc01.temp1.

Column C shows the temperatures corrected by the *"null"* value. In this case the *"null"* value is 17.2°C.

The regression is now performed in *columns C* and *A*, the results are shown at the right of Figure 4 (*columns F* and *G*).

In a corresponding geometric application (Figure 3) the regression function (solid line) and the measured data (columns *A* and *B*) are shown (dotted line). A slider for the parameter *"null"* is introduced. If this slider is animated the regression is calculated for every *k*-value and the results are represented dynamically in the geometric application (Figure 4).

A "quality factor" for the correspondence between the measured data and the calculated regression function is the *regression coefficient stat.r* calculated in a regression analysis.

In the best case the regression coefficient reaches a value of 0.999962 showing a very good correspondence between experimental data and theoretical regression function.
With a *regression analysis* we get a numeric (quantitative) information about the accordance of the measured data and the modelling function. This is the net advantage over the qualitative method of *"optical fitting"* only.

Equipment **:**
- medical benzine
- Absorbent cotton or cotton pads for cosmetic use
- TI-*n*spire CX CAS, handheld or software, Version 4.4 or later
- TI-*n*spire lab cradle or GoLink/EasyLink adapter
- TI-temperature probe (Vernier)

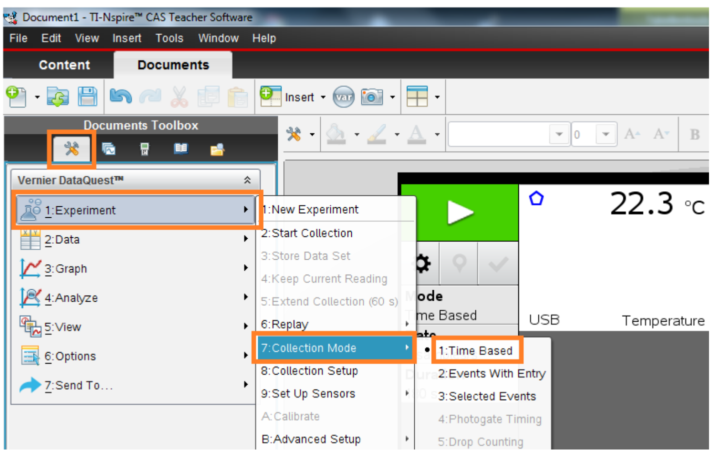


Figure 5 TI-*n*spire Start screen

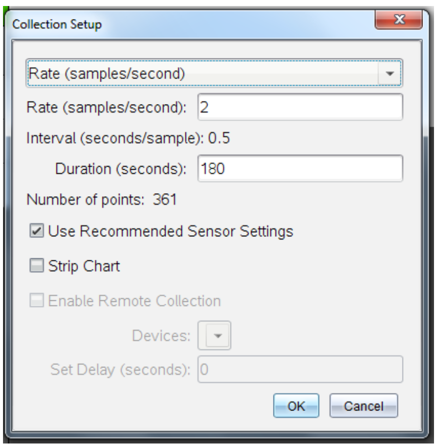


Figure 6 Collection Setup

3. Discharging a Capacitor with a Resistor

An electrolytic capacitor ($C = 10'000\,\mu\text{F}$) is charged with a 9-Volt-battery. Then the charging switch is opened and the capacitor is discharged with a resistor $(R = 4'700\,\Omega)$. The voltage across the resistor (and the capacitor) is measured with a Vernier Voltage probe which is connected to the *n*spire/TI-84 calculators with an EasyLink Interface (Figures 1, 2, 3). The following instruction to perform a regression analysis is for *n*spire only.

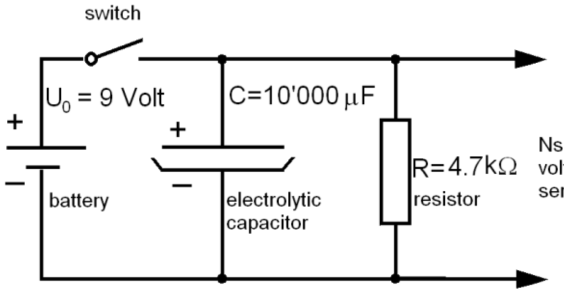


Figure 1 Discharging Circuit

Figure 2 Electrolytic Capacitor $(4'700\,\mu\text{F})$, Resistor $(1'000\,\Omega)$ and Battery (9 Volt

Figure 12 Voltage Probe and EasyLink-Interface (Vernier)

	A run1.time	B run1.potential	C	D
◆				=ExpReg('dc01.time,'dc01.vol
1	0.	6.53931	Titel	Exponentielle Regression
2	0.1	6.52924	RegEqn	a*b^x
3	0.2	6.51398	a	6.55888
4	0.3	6.50391	b	0.98292
5	0.4	6.49384	r²	0.999966
6	0.5	6.47858	r	-0.999983
7	0.6	6.47369	Resid	{-0.019571644988969,-0.018...
8	0.7	6.46332	ResidTra...	{-0.002988453692649,-0.002...
16	1.5000000223517			

Figure 3 Discharging and Regression Data

1. Choose "New Document" on the home screen of the TI-Nspire (Vs. 4.4) handheld calculator.
2. Choose "Lists & Spreadsheet". A spreadsheet appears (1.1)
3. Connect the voltage probe at one side (clips) to the R-C-circuit, on the other side to the EasyLink or lab cradle interface.
4. Connect the EasyLink mini-USB-con-nector or the lab cradle with the TI-*n*spire handheld calculator.
5. The calculator automatically recognises the voltage sensor and starts the measuring program (DataQuest, 1.2)
6. Press the menu-key, then 1: Experiment > 7: Collection Mode>Time Based.
7. Choose "Rate (samples/second)", Rate "1 second" for the time between the samples and 100 seconds for the Experiment Duration. Press OK.
8. Charge the capacitor by shortly dipping its + pole with the + wire of the 9 volt battery. The – pole of the battery is connected with the – pole of the capacitor.
9. Press [icon] to start the measurement. The measurement data are written in the lists run1.time and run1,potential.
10. Select the spreadsheet (ctrl <).
11. Write run1.time in the head-field of column A and run1.potential in the head field of column B (Fig. 12).
12. Press the menu-key and select 4: Statistics>1: Stat Calculations>A: Exponential Regression, select run1.time for the X List and run1.potential for the Y List. Press OK. The regression data appear in *column D* (figure 3, right).
13. On the Home-Page of the calculator select a graph page.
14. Press the menu key. Select the "Graphs"- icon [icon].
15. Press the menu-key. Select 3; Graph Entry/Edit=> 5: Scatter Plot. Enter $s1\begin{cases} x \leftarrow \text{run1.time} \\ y \leftarrow \text{run1.potential} \end{cases}$
16. Press the menu key. Select 4: Window/Zoom > 1; Window Settings. Enter: XMin 0, XMax 100, YMin 0 YMax 10. Press OK. The measured data are shown (Figure 3).

Press the menu key. Select 3: Graph

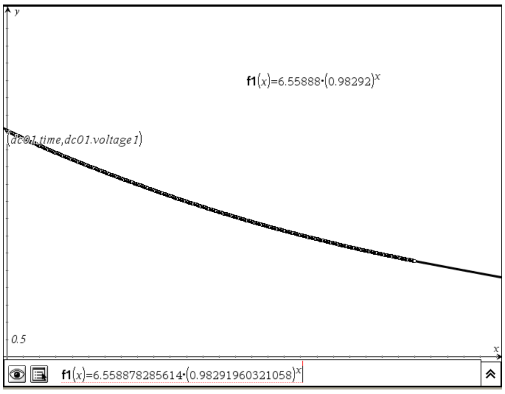


Figure 4 Voltage vs. Time: Measured Data and Regression Curve

Entry/Edit=>Type> 1: Function. Press enter. The regression function calculated in step 11 is now available (normally as function **f1**(x)).

From the exponential regression data

$$y = a \cdot b^x \quad \text{with} \quad a \approx 6.56 \text{ Volt} \quad \text{and}$$
$$b = 0.98292 \quad \text{(Figures 3 and 4)}$$

the time constant τ of the discharging process can now be calculated.
Press the menu key. Select 3: Graph
Entry/Edit=>Type> 1: Function. Press enter. The regression function calculated in step 11 is now available (normally as function **f1**(x)).

The time constant τ of the discharging process can now be calculated.

Because $b^x = e^{-k \cdot t}$ we get $\ln b = -k$.

The time constant τ of this discharging process can now be calculated

$$\tau = \frac{1}{k} = -\frac{1}{\ln b} = -\frac{1}{\ln 0.98202}\,\text{s} = 55\,\text{seconds}$$

After 55 seconds the voltage of the discharging process reaches 37% of its initial value.

Thus the time constant is the product of the resistance *R* and the capacity *C*
$\tau = R \cdot C = 4'700\,\Omega \cdot 10'000\,\mu\text{F} = 47\,\text{seconds}$
The difference to the value obtained by the regression calculation is probably due to the inaccurate value of the capacitance oft the electrolytic condenser which normally has a tolerance of about 20%.

Equipment : 9 Volt battery, electrolytic capacitor $10'000\ \mu\text{F}$ **,** Resistor $4'700\ \Omega$, cables
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adapter
TI-voltage probe (Vernier)

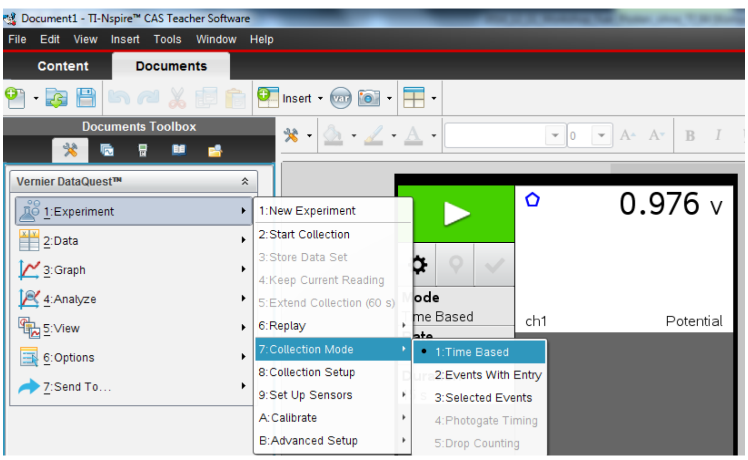


Figure 5 TI-*n*spire Start screen

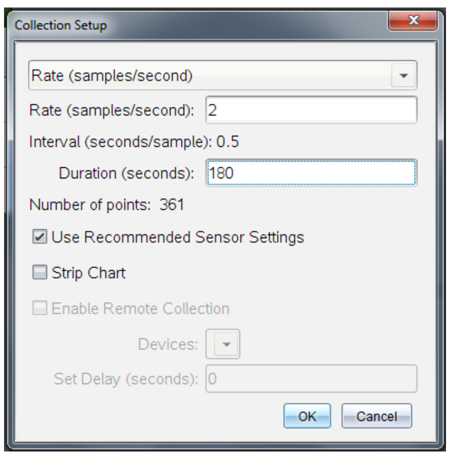


Figure 6 Collection Setup

4. Pendulum

A pendulum is a weight suspended from a pivot so it can swing freely (Figure 1).

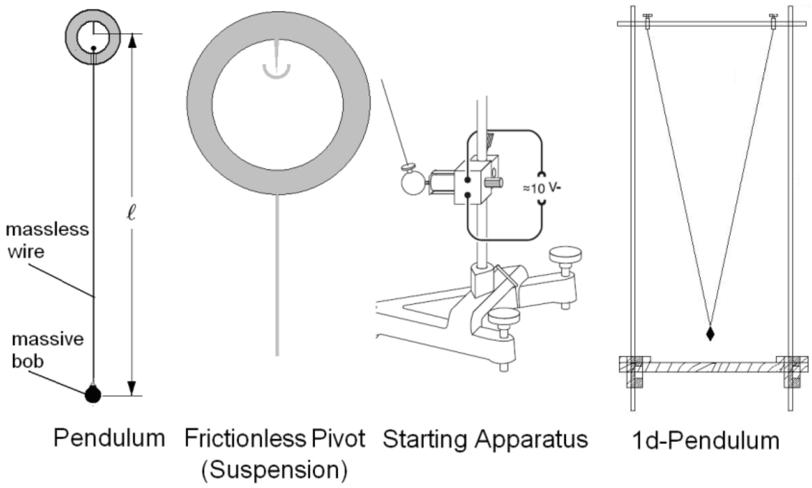


Figure 1 Pendulum: Construction

The oscillation period T is given by Galilei's formula $T = 2 \cdot \pi \cdot \sqrt{\frac{\ell}{g}}$ where ℓ is the length of the pendulum (figure 9, left) and g is the local acceleration of gravity $\left(g \approx 9.81 \frac{\mathrm{m}}{\mathrm{s}^2} \right)$.

Figure 2 CBR-2 ultrasonic distance sensor

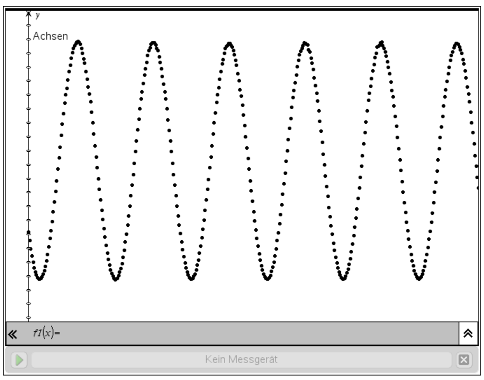


Figure 3 Oscillation measured with CBR-2

	A run1.time	B run1.position	C run1.velocity	D run1.acceleration	H
◆					=SinReg('dc01.time,'dc01.dist1
1	0.	0.406352	-0.591177	0.132373	Sinusförmige Regression
2	0.05	0.376796	-0.581136	0.480766	a*sin(b*x+c)+d
3	0.1	0.347223	-0.543003	0.831777	0.422493
4	0.15	0.322228	-0.483552	0.735495	1.86368
5	0.2	0.298822	-0.416392	0.61319	-2.48931
6	0.25	0.280269	-0.3386	0.805989	0.661522
7	0.3	0.265224	-0.268437	0.838294	{0.0012836719171499,0.0018...

Figure 4 Results and sinusoidal Regression

The oscillation can then be described by a sinusoidal function: $y = y_0 \cdot \cos(\omega \cdot t)$ with $\omega = \frac{2 \cdot \pi}{T}$

The movement of a pendulum is measured contactlessly with a CBR-2 ultrasonic distance sensor (Vernier/Texas Instruments, figure 2).

Figure 3 shows a scatter plot and figure 21 the numerical results of the oscillations of a pendulum with a nearly frictionless suspension (figure 1, left) (mass of the bob 500 g).

The TI-*n*spire-Software in this case delivers time values (run1.time, column *A*), the distance (run1.position, column *B*), the velocity (run1.velocity, column *C*) and the acceleration (run1.acceleration, column D) every 0.05 seconds (Fig. 4).

Figures 5 and 6 show the corresponding scatter plots.

The velocity- and particularly the acceleration- plots are much "noisier" than the original distance-plot.

The reason for deterioration of these signals is their calculation method. The velocity is calculated by finite

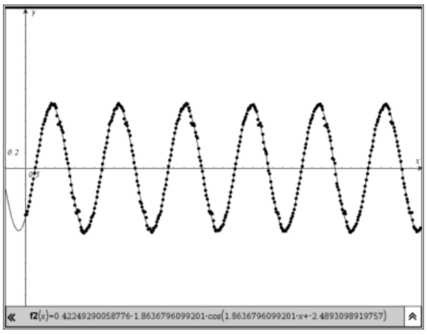


Figure 5 velocity vs. time

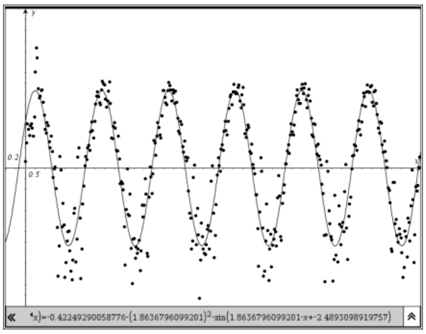


Figure 6 acceleration vs. time

differences of distance values, the acceleration by finite *differences* of velocity values.

Because the relative error $\Delta d/d$ of a difference $d = s_1 - s_2$ is *always greater* than the relative errors $\Delta s_1/s_1$ and $\Delta s_2/s_2$ of the original values, the difference signal must be noisier than the original signal: the velocity plot (Figure 5) noisier than the distance plot (Figure 4) and the acceleration plot (Figure 6) noisier than the velocity plot (Figure 5).

With the simple example of distance-, velocity- and acceleration-measurements of a pendulum, students can learn this very important fact of numerical mathematics also known (and dreaded) in computer science (in german: "Stellenauslöschung").

Sinusoidal regression works only with the distance data, velocity- and acceleration data leads to an error message (singular matrix).

Therefore it could be a good idea to measure the oscillation of a pendulum, with an acceleration sensor (Vernier) and to determine the velocity and the distance by numerical integration. With this procedure the signals become smoother!

Equipment : pendulum
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adaptor
CBR 2 distance sensor (TI/Vernier) : connected directly to the *n*spire

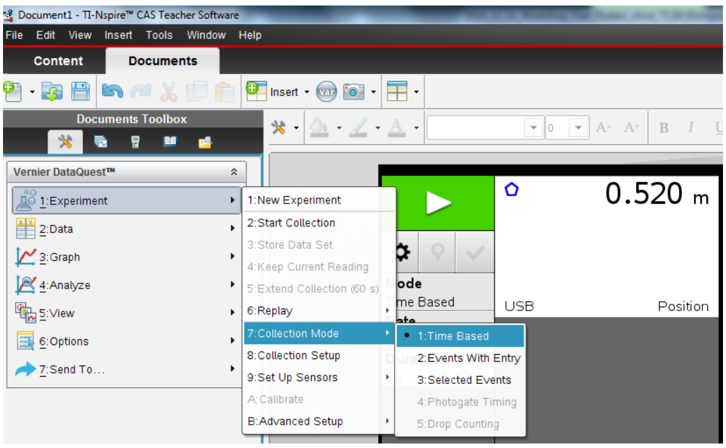


Figure 7 TI-*n*spire Start screen

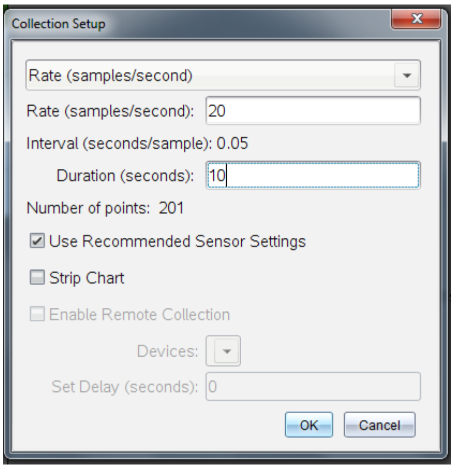


Figure 8 Collection Setup

5. Force Plate

Force plates are biomechanical instruments to measure the ground reaction force generated by a body standing on or moving across them. Force plates are used in medicine and sports e.g. for motion and gait analysis. The simplest force plates measure only the vertical component of a force in the geometric centre of the platform. More advanced models measure the force in three dimensions.

Figure 1 shows a 3-d-force plate of the swiss company Kistler designed for gait and balance analysis (Figure 2) app-lications. The glass plate allows simulta-neous force measurement and photo-graphic or cinematographic recording of the contact surface from below.

For school applications this type of highly professional force plates is much too expensive. A quite inexpensive 1d-force plate (306$) for nonprofessional applications is produced by the US-American company Vernier (figure 3).

This instrument can be connected to an *n*spire system (computer or calculator) by an USB connector and is recognized automatically.

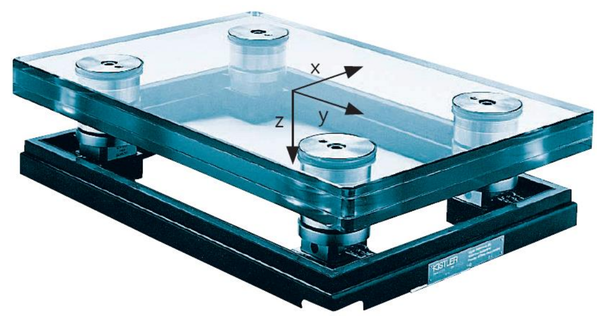


Figure 1 Force Plate Kistler 0285 BA

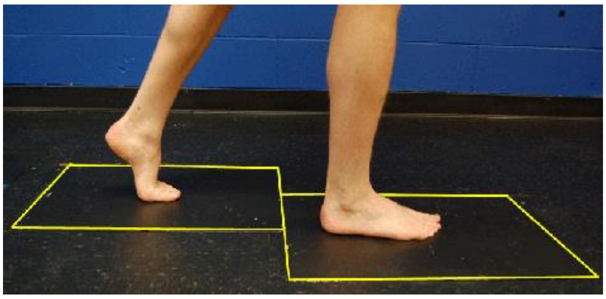


Figure 2 Gait Analysis with 2 Force Plates (Kistler)

Figure 3 Vernier Force Plate: Newtons 3rd law

1st Experiment

Figure 4 shows a force to time diagram of a jump from a Vernier force plate measured with the Nspire software. Analysing this diagram the height *h* of this jump (center of mass) can be calculated with the linear momentum Δp and the conservation of mechanical energy:

Linear Momentum (Impulse) :

$$\Delta p = m \cdot \Delta v = \int_0^t (F - m \cdot g) \cdot dt$$

Conservation of Mechanical Energy :

$$\frac{1}{2} \cdot m \cdot \Delta v^2 = m \cdot g \cdot h$$

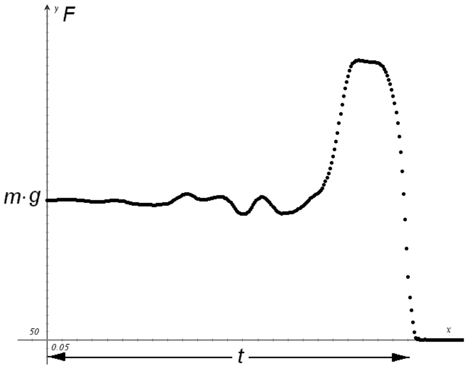


Figure 4 Jumping from the Force Plate:
Force to Time Diagram

Height of the Jump:

$$h = \frac{\Delta v^2}{2 \cdot g} = \frac{\left(\int_0^t \left(\frac{F}{m} - g \right) \cdot dt \right)^2}{2 \cdot g}$$

Figure 5 shows some measured force values, figure 6 the numerical calculations with *n*spire. The numerical calculation of the integral has been performed by the trapezoidal rule

	A run1.time	B run1.force
◆		
1	0.	839.691
2	0.005	839.691
3	0.01	838.47
4	0.015	839.691
5	0.02	839.691
6	0.025	839.691
7	0.03	842.285
A1	0.	

Figure 5 Measured force to time values pairs

$$f(n) := \sum_{i=2}^{n} \left(\frac{dc01.force1[i+1] + dc01.force1[i]}{2} \cdot (dc01.time[i] - dc01.time[i-1]) \right)$$

$$h(n,m) := \frac{\left(\frac{f(n)}{m} - 9.81 \cdot dc01.time[n] \right)^2}{2 \cdot 9.81}$$

$h(249,84)$ 0.138419

©Sprunghöhe 13.8 cm

Figure 6 Evaluation of a jump from the force plate

Equipment : Vernier Force Plate
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adapter or

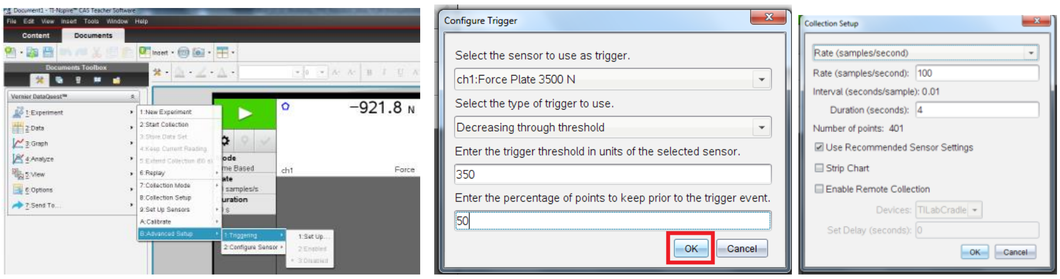


Figure 7 Force Plate : TI-*n*spire trigger, pretrigger and collection setup

2nd Experiment

The momentum of a free falling steel-Ball (5 kg) may be measured as an integral of the force to time diagram. Figures 8 and 9 show the experimental setup and the evaluation of this experiment.

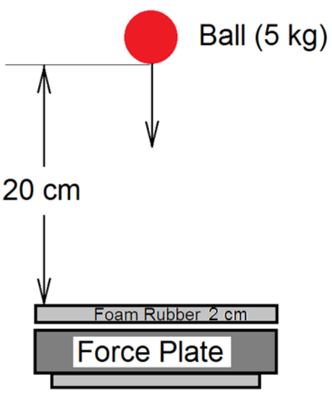


Figure 8 Experimental setup

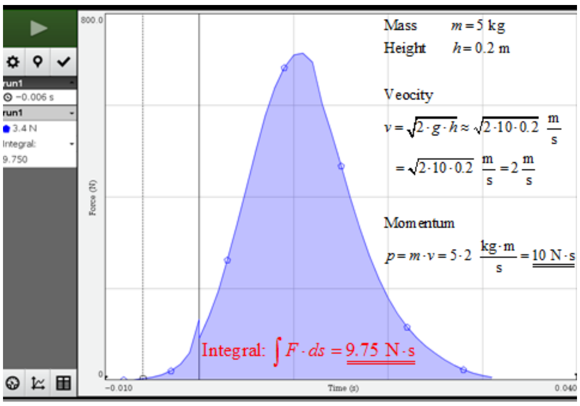


Figure 9 Mathematical Evaluation

6. R-L-C-Oscillator (Oscillating Circuit)

A slowly oscillating electric circuit can be realised with a 500 H-/630 H-high inductivity coil (Leybold 517 011), a $40\ \mu\text{F}$ capacitor (Leybold 517 021) and a 9-Volt-battery (figures 1 and 2).

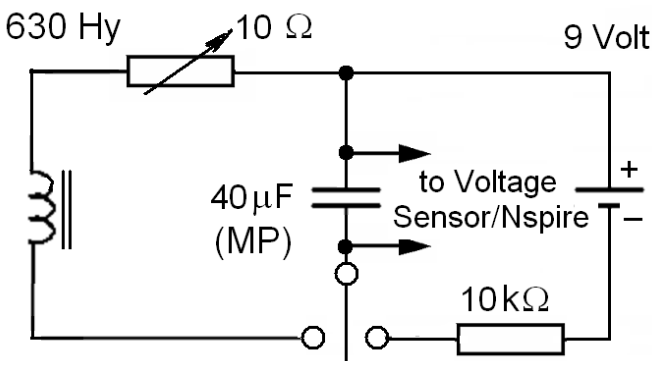


Figure 1 Slowly oscillating Circuit (1 Hertz)

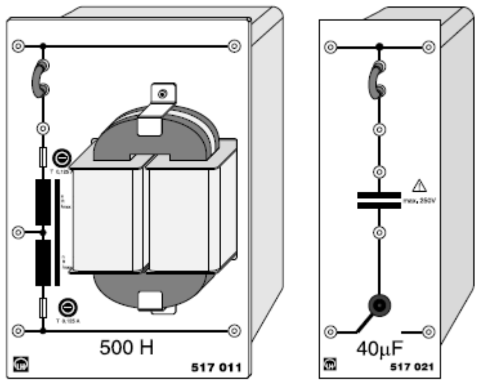


Figure 2 High Inductivity Coil (500 H) and Capacitor (Leybold 517 011/021)

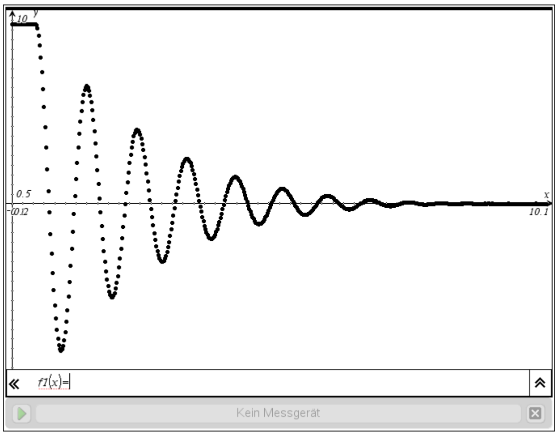


Figure 3 Damped Electric Oscillation

The resulting damped oscillations (figure 11) can be described by the function

$$U(t) = U_0 \cdot e^{-k \cdot t} \cdot \cos(\omega \cdot t)$$

for the voltage *U(t)*. Again this function can be evaluated by "optical fitting".

Nspire has no data model for the regression of this function.

Following Kirchhoff's Voltage rule the sum of the three voltages across the coil, the capacitor and the resistor must be zero:

$$U_R + U_C + U_L = 0 \rightarrow \underbrace{R \cdot I}_{\text{Ohm}} + \underbrace{\frac{Q}{C}}_{\text{Capacitance C}} + \underbrace{L \cdot \frac{dI}{dt}}_{\text{Self Inductance}} = 0 \quad \text{differentiated:} \quad R \cdot \frac{dI}{dt} + \frac{I}{C} + L \cdot \frac{d^2 I}{dt^2} = 0 \text{ or}$$

$$\frac{d^2 I}{dt^2} + \frac{R}{L} \cdot \frac{dI}{dt} + \frac{1}{L \cdot C} \cdot I = 0$$

This is the differential equation of a damped harmonic oscillator with the solution

$$I(t) = I_0 \cdot e^{-k \cdot t} \cdot \cos(\omega \cdot t) \text{ and } U_R = \underbrace{I_0 \cdot R}_{U_0} \cdot e^{-k \cdot t} \cdot \cos(\omega \cdot t) \text{ with } k = \frac{R}{2 \cdot L} \text{ and } \omega = \frac{1}{\sqrt{L \cdot C}} \text{ (Thomson)}.$$

The voltage functions $U_C(t)$ across the resistor R and $U_L(t)$ across the inductance L can be calculated by integration or differentiation respectively. The $k-$ and the $\omega-$ values remain the same.

Analysing the damped oscillation (figure 11) the $k-$ and the $\omega-$ values can be determined by “optical fitting”. If one of the three electrical portions R, L or C is known, the others can be calculated.

Equipment : High Inductivity Coil (500 Henry)
Capacitor (Leybold 517 011/021)
9 Volt battery
cables
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adapter

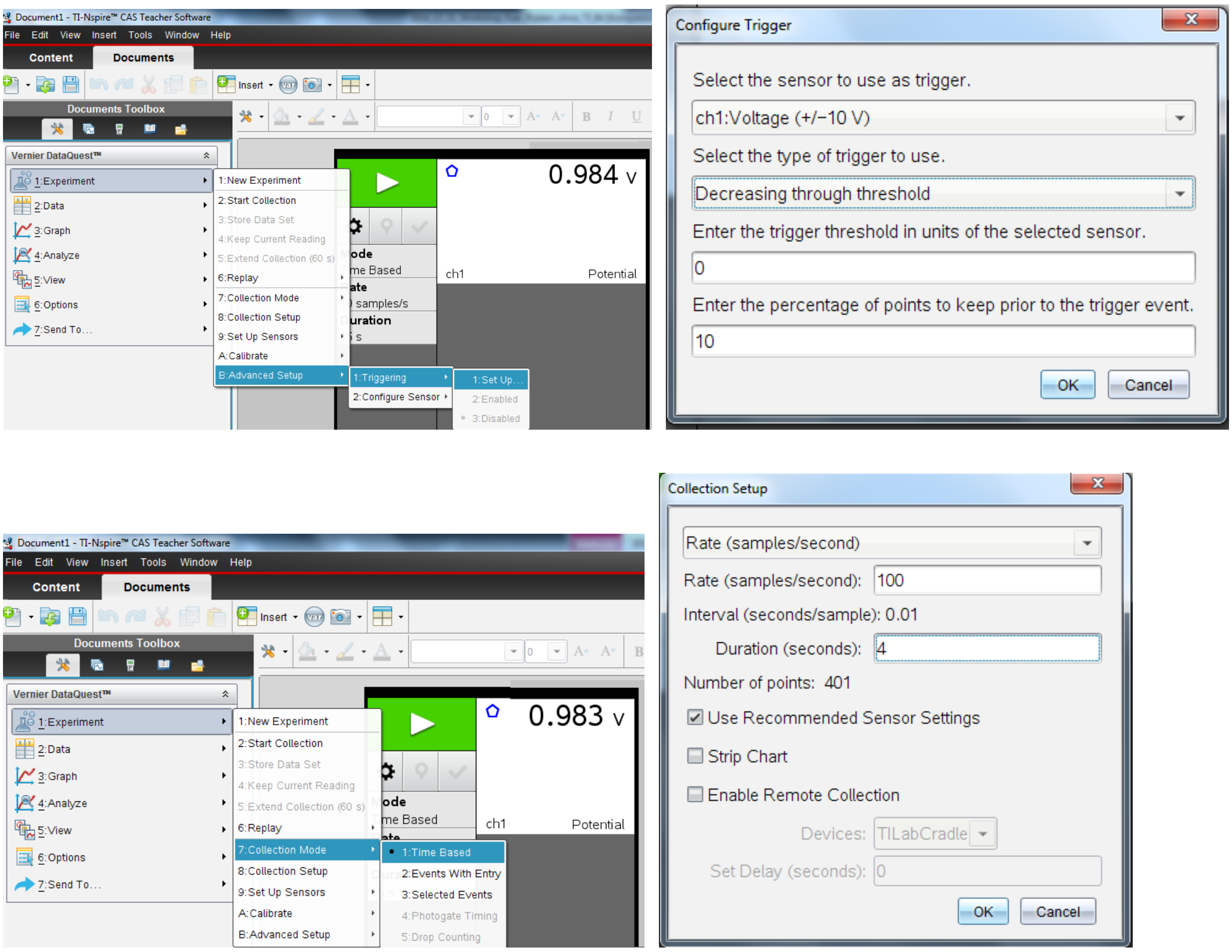


Figure 4 Voltage Probe : TI-*n*spire trigger, pretrigger and collection setup

Alternative : We work here with a 15 Henry inductor (Digikey) and a (unpolarized!) 2.2μF foil capacitor instead of the heavy (and very expensive) Leybold components. This setup works with 1.5 Volt AAA battery and produces peak voltages till ± 5 Volts. Oscillation Frequeny 18 Hertz.

7. Faraday's Induction Law

If a bar magnet (length) is uniformly moved through a coil (Figure 1) a voltage is induced which depends on the *velocity* of the magnet. If the magnet is not moved no voltage is induced. This voltage generated in a coil can be measured with the voltage sensor, the EasyLink adapter and a *n*spire handheld calculator.

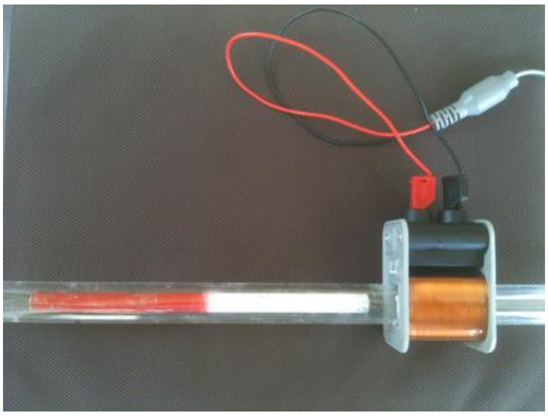


Figure 1 bar magnet in a plexiglass rod, coil

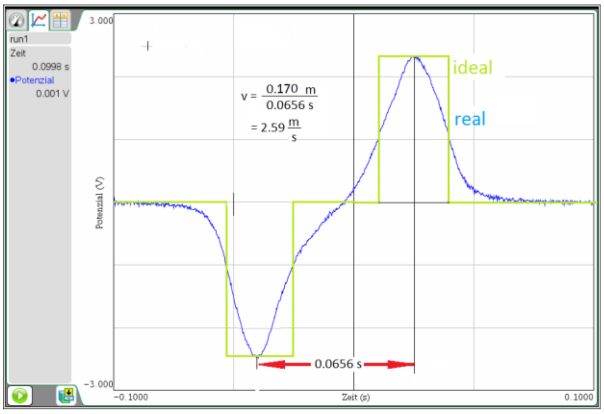


Figure 2 Voltage surge, real and idealised

The magnetic flux

$$\Phi = -\frac{1}{n} \cdot \int U_{\text{ind}} \cdot dt$$

Can be calculated by a numeric integration

$$\varphi(k,l,\mathbf{n}) := \frac{-1}{\mathbf{n}} \cdot \sum_{i=k}^{l} \left(\frac{\mathbf{spannung}[i+1] + \mathbf{spannung}[i]}{2} \cdot (\mathbf{zeit}[i] - \mathbf{zeit}[i-1]) \right)$$

We get

$$\Phi(2,386,800) = (83.6 \pm 0.5) \cdot 10^{-6} \text{ Wb (V} \cdot \text{s)},$$

for the left part of the signal and

$$\Phi(387,772,800) = -(82.7 \pm 0.5) \cdot 10^{-6} \text{ Wb (V} \cdot \text{s)}$$

for the right part. The magnetic flux does not depend on the velocity which can be shown with this experiment.

For the magnetic field we get an averge value (coil A=9 cm²)

$$\bar{B} = \frac{\Phi}{A} \approx \frac{83 \cdot 10^{-6}}{9 \cdot 10^{-4}} \cdot \frac{\text{V} \cdot \text{s}}{\text{m}^2} \approx 0.092 \text{ Tesla}$$

If we suppose that the distance between minimum and maximum value of the induction signal corresponds tot he length of the bar magnet ($\Delta s = 17$ cm) the velocity of the magnet may be estimated to

$$v \approx \frac{\Delta s}{\Delta t} = \frac{17 \text{ cm}}{0.0656 \text{ s}} = 2.59 \frac{\text{m}}{\text{s}}$$

Equipment : bar magnet (Frederiksen) or Neodymium-magnet (supermagnet)
plexiglass rod (length 40 cm, diameter 2 cm) ,
coil (Frederiksen Nr. 4625.25)
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adapter
TI-voltage probe (Vernier)

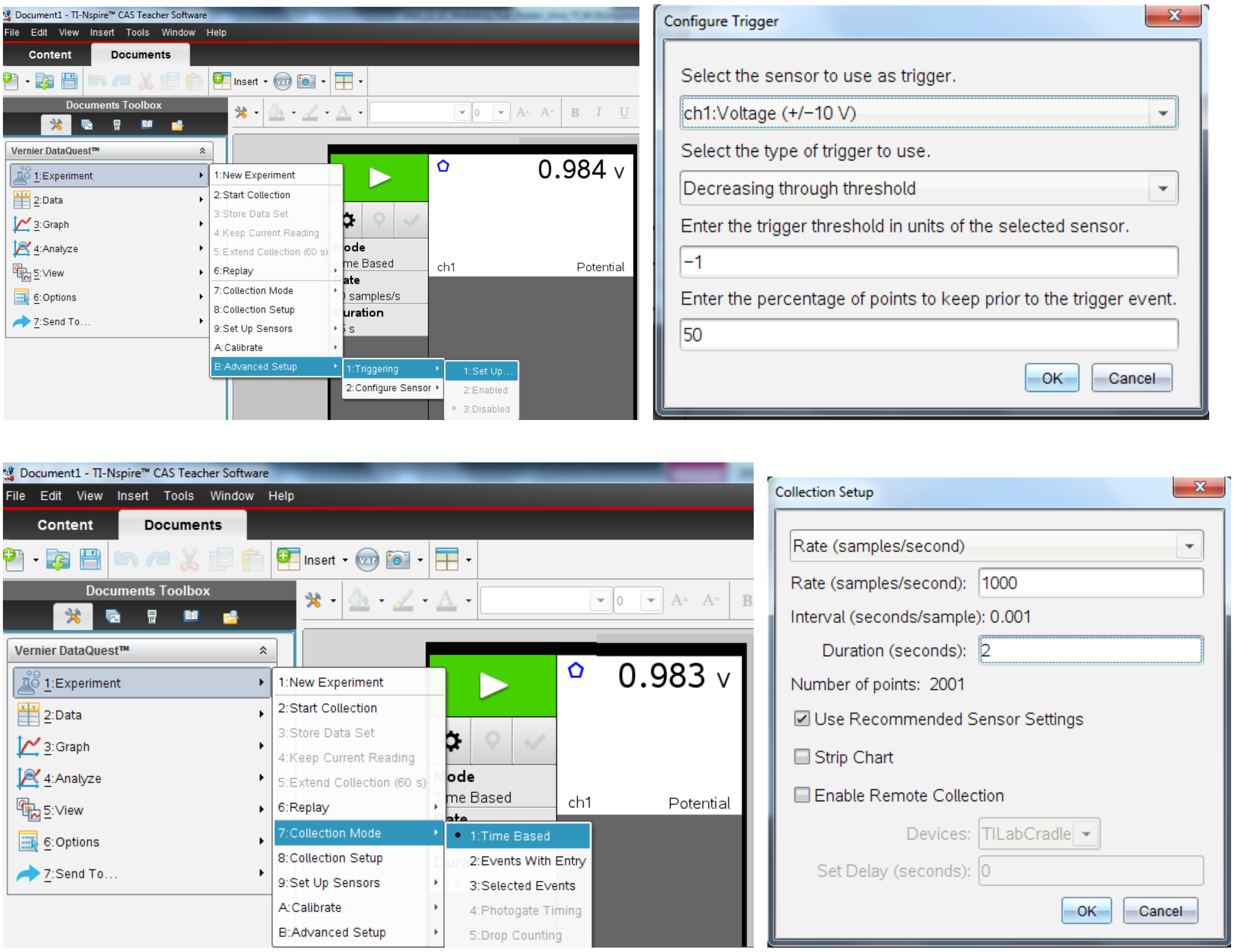
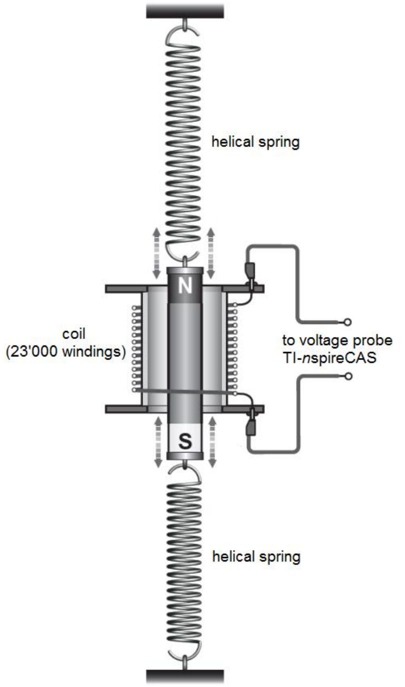


Figure 4 Voltage Probe : TI-*n*spire trigger, pretrigger and collection setup

8. Induction Pendulum

A bar magnet mountd on two helical springs oscillates vertically in a coil and induces a voltage which can be measured. The resulting oscillation voltage consists of two modes, which can be separeted by a discrete Fourier analysis with TI-*n*spire (see TI-Nachrichten 2/11, p. 19).



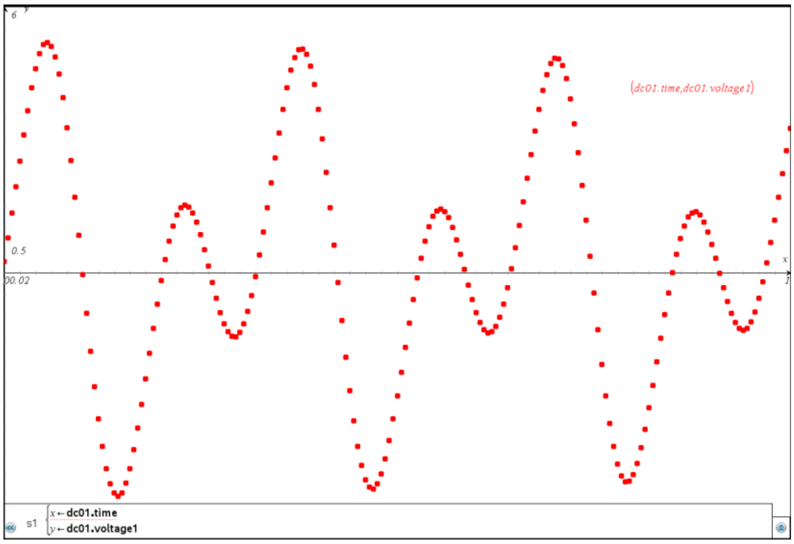


Figure 2 right: twin mode signal of an oscillating magnet in a coil**:** 66 points per period. Oscillating time T=0.3235 s

Figure 1 left: Oscillating magnet in a coil

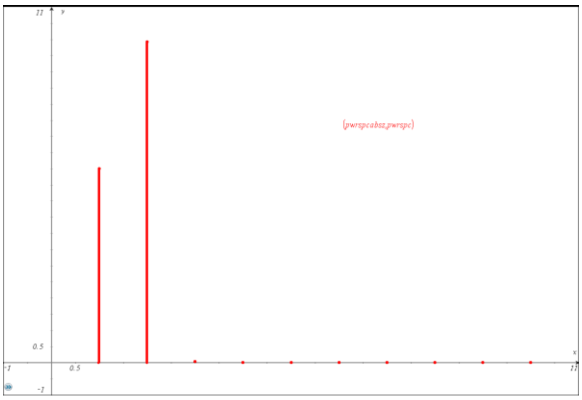


Figure 3 power spectrum oft hie oscillation

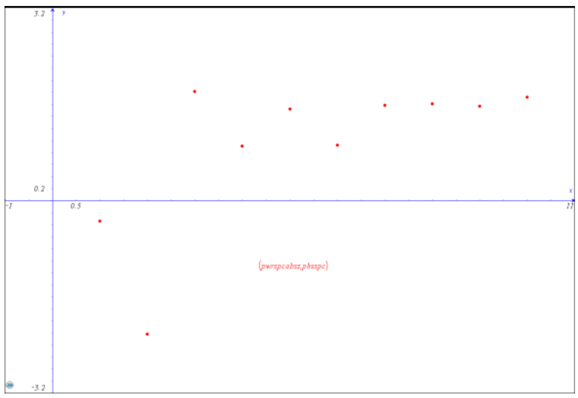


Figure 4 phase spectrum of this oscillation

Equipment : bar magnet (Frederiksen) with two spring mounts (self construction)
2 helical springs (Leybold)
Coil with 23'000 windings (Leybold)
mounting material (Leybold)

TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adapter
TI-voltage probe (Vernier)

To perform this measurement proceed as follows:

Connect the voltage probe to the coil (Fig. 1) and to the lab cradle or the GoLink/EasyLink adaptor. Connect the lab cradle or the GoLink/EasyLink adaptor with the TI-*n*spire handheld or the computer (PC/mac), switch the handheld/computer on and do these steps :

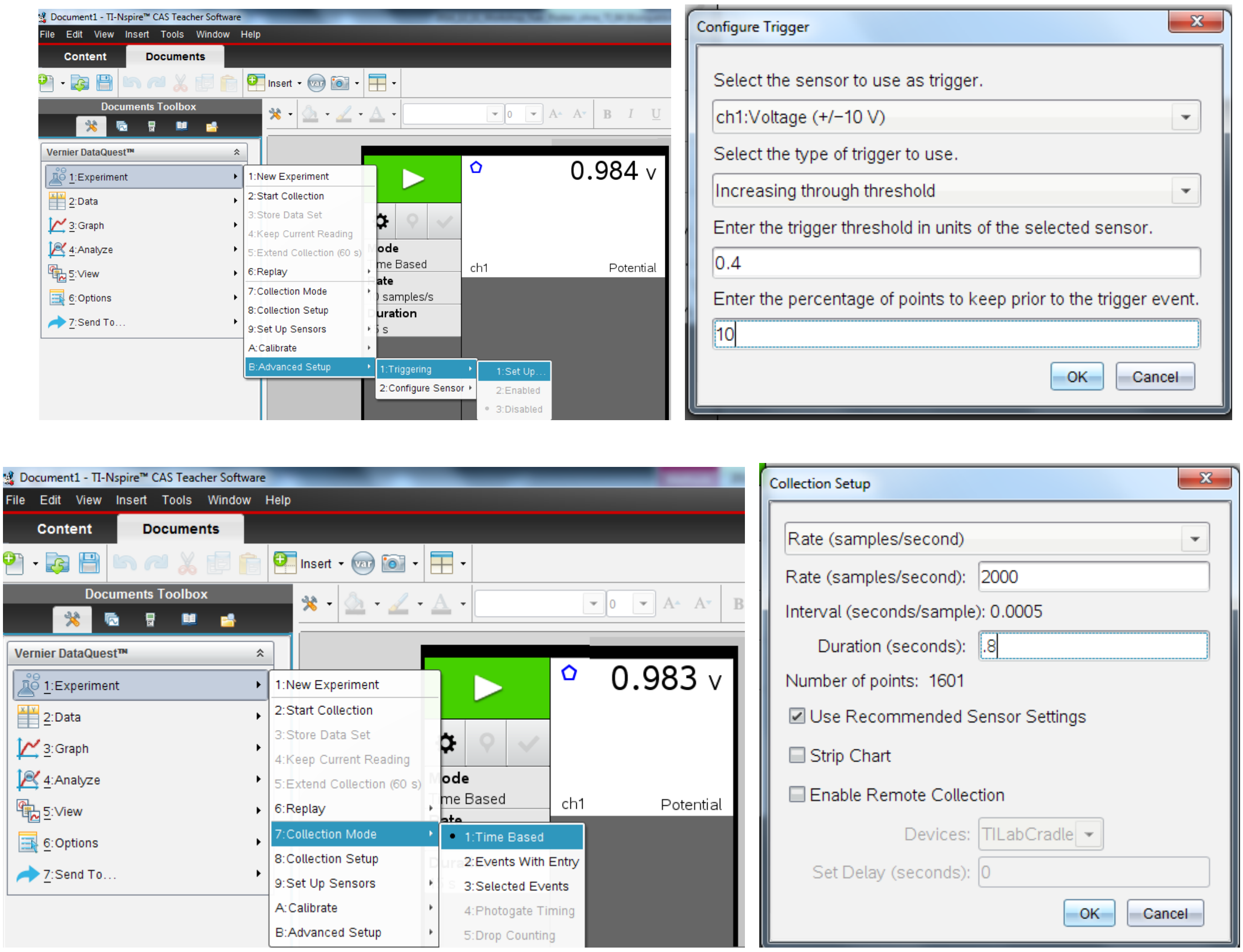


Figure 4 Voltage Probe : TI-*n*spire trigger, pretrigger and collection setup

9. Induction Signals generated by a free falling Magnet

A free falling magnet in plexiglass rod generates 4 induction signals in the 4 coils placed along the rod. Because the velocity of the falling magnet increases linearly with time, the amplitude of the induction signals does it as well. This is a experimental proof of Faraday’s induction law.

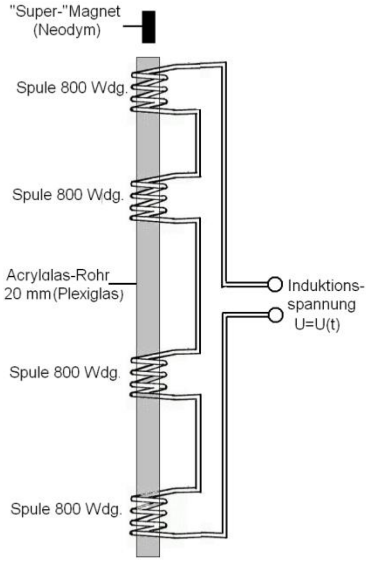
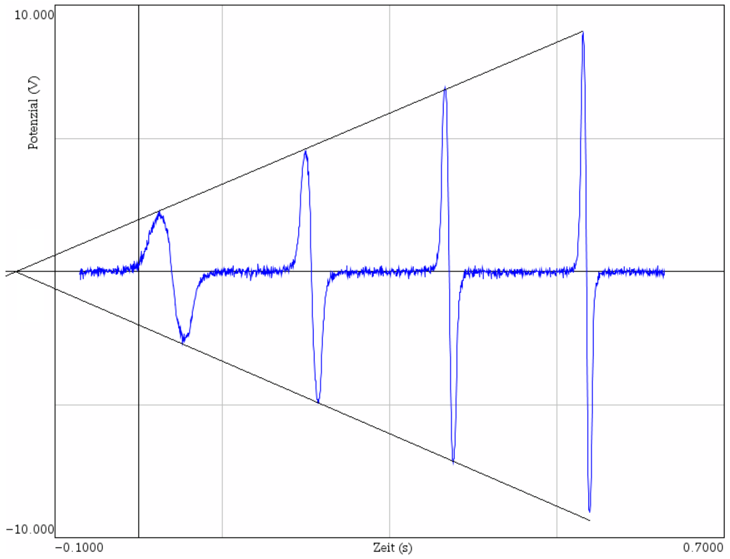


Figure 1 Plexiglass rod with 4 coils

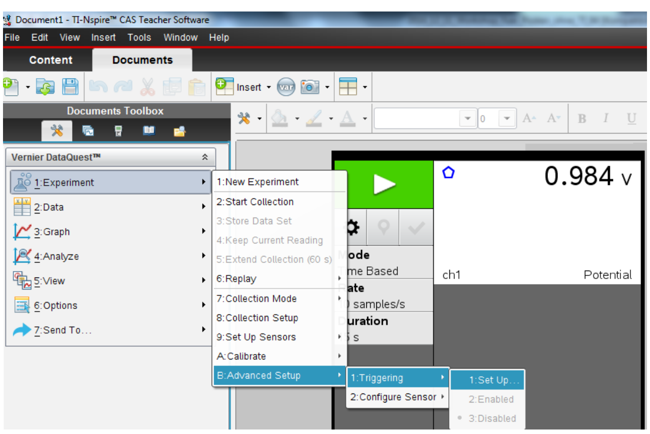


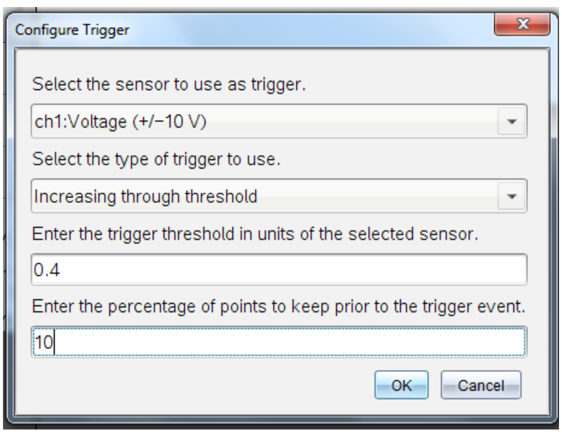
Figur 2 free falling magnet generates 4 induction signals => Time Based

Equipment : Plexiglass rod length 2 m, diameter 2 cm
cylindical supermagnet (neodymium)
4 coils (Frederiksen, 800 windings)
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adapter
TI-voltage probe (Vernier)

To perform this measuerement proceed as follows:

Connect the voltage probe to the 4 coils (fig.) and to the lab cradle. Connect the lab cradle with the TI-*n*spire handheld or the computer (PC/mac), switch the handheld/computer on and do these steps :





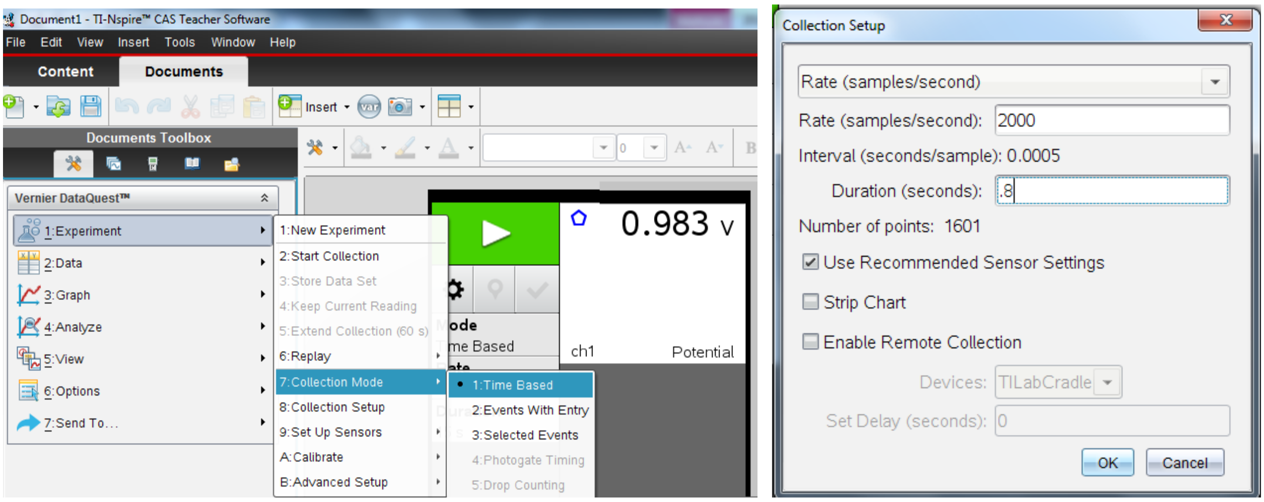


Figure 4 Voltage Probe : TI-*n*spire trigger, pretrigger and collection setup

With a measuring time of 0.8 seconds 2‘000 measurements are performed. The measurement starts then automatically as soon as the falling magnet induces a voltage of .4 Volts. 10% of the range before this trigger point will also been shown after measurement.

10. Electric Characteristics (Bulb or LED)

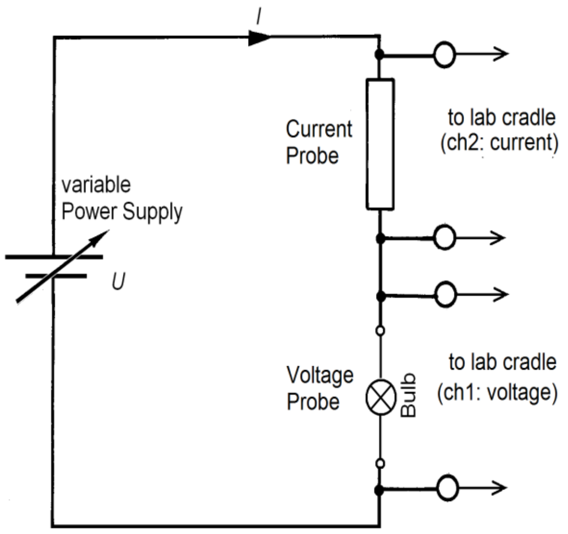


Figure 1 Circuit to measure Electric Characteristics
Alternative: Vernier Energy Sensor VES BTA, Variable Load VES-VL, 9 V Battery

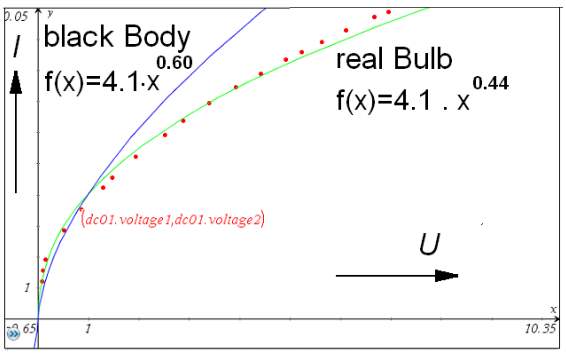


Figure 2 Characteristics of a Filament Bulb

To measure the characteristics of an electronic/electric component, e.g. a resistor, a diode (LED) or a filament bulb, *two* measurements have to be done, one for the voltage, the other for the electric current (figure 1).

A bulb has a positive temperature coefficient, this means that the resistance at room temperature is much smaller than at its working temperature.

The corresponding characteristics is a power function as can be shown with 2 assumptions:

1. The resistance *R* of the bulb is proportional to the absolute temperature *T* of the filament $R = \frac{U}{I} = c_1 \cdot T$.
2. Following Stefan Boltzmann's law the (radiation) power is proportional to the 4th power of the absolute temperature

$$P = U \cdot I = \sigma \cdot S \cdot T^4 \quad (S \text{ Surface of the bulb})$$

$$\rightarrow U \cdot I = \sigma \cdot S \cdot \frac{U^4}{c_1^4 \cdot I^4}$$

$$\rightarrow I^5 \propto U^3 \quad \text{or} \quad I \propto U^{0.6}$$

Figure 2 shows the ideal (blue) and real (green) characteristics of a bulb. The real bulb values follow fairly well a power function, but its exponent has only a value of 0.44 (gray body) instead of 0.60 (black body).

Equipment: filament bulb 6 Volts and socket E10 or an other electronic component, e.g. a LED
regulated power supply
cables
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle or GoLink/EasyLink adapter
TI-voltage probe (Vernier)
Current probe (Vernier)

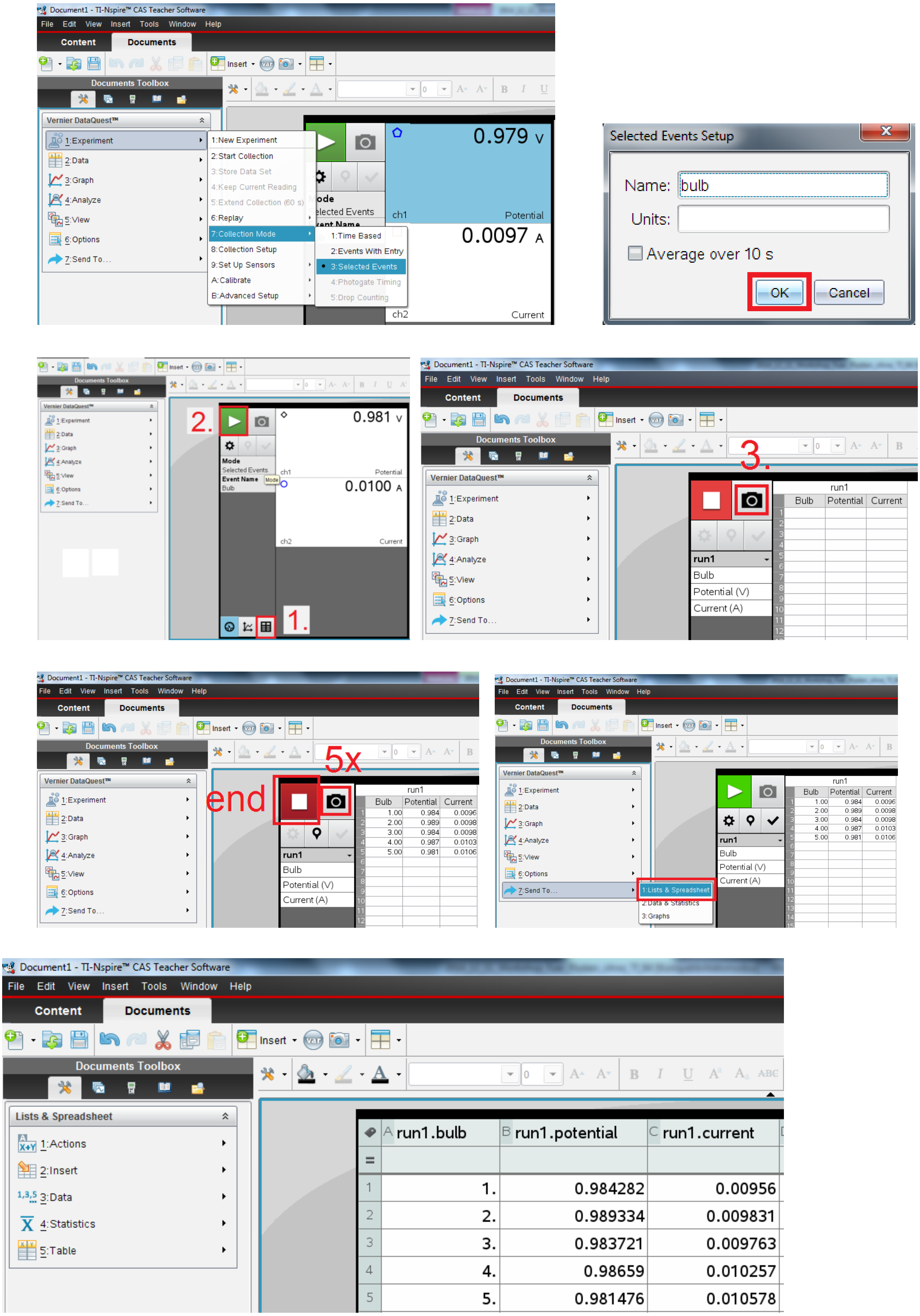


Figure 3 Single Point Measurement and Data Transfer to « Lists&Spreadsheet »

11. Light Measurements

Figures 1 and 2 show two light measurements near a commercial fluorescent tube (Philips Master TL5 HO 49 W /840). A 100-Hz ripple light signal (100 lux peak to peak) which is superimposed on a 3'800 lux DC light signal can clearly be seen. Because a relatively slow light sensor is used, a part of the DC signal might be a result of the sensors lag.

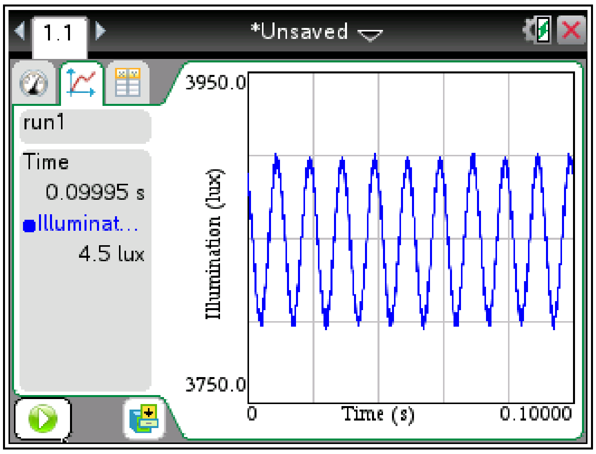


Figure 1 Light Measurement 0.1 seconds

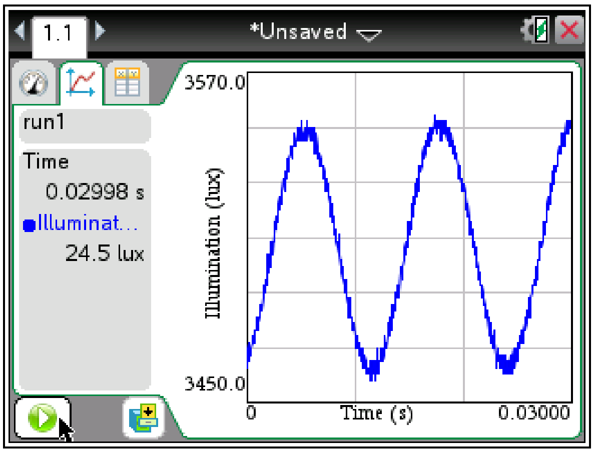


Figure 2 Light Measurement 0.03 seconds

Equipment : commercial fluorescent tube

TI-*n*spire CX CAS, handheld or software, Version 4.4

TI-*n*spire lab cradle or GoLink/EasyLink adapter

TI-light probe (Vernier, ranges 0-6'000 lux, 0-600 lux and 0-150'000 lux)

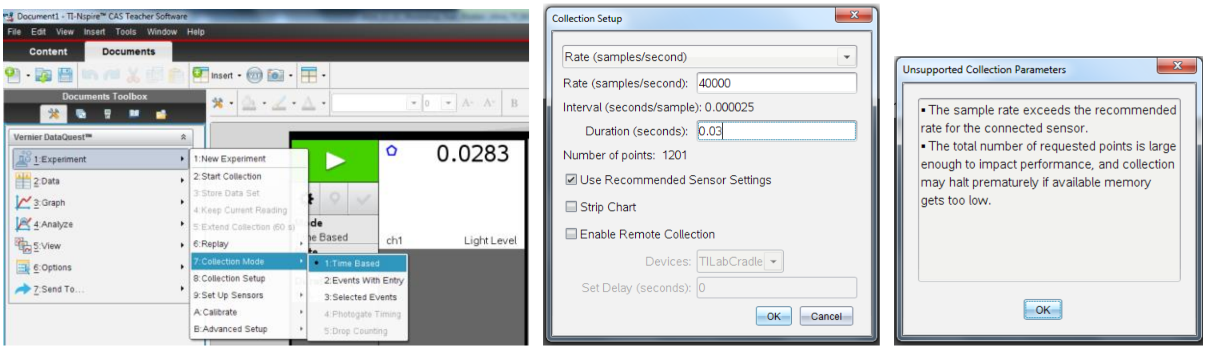
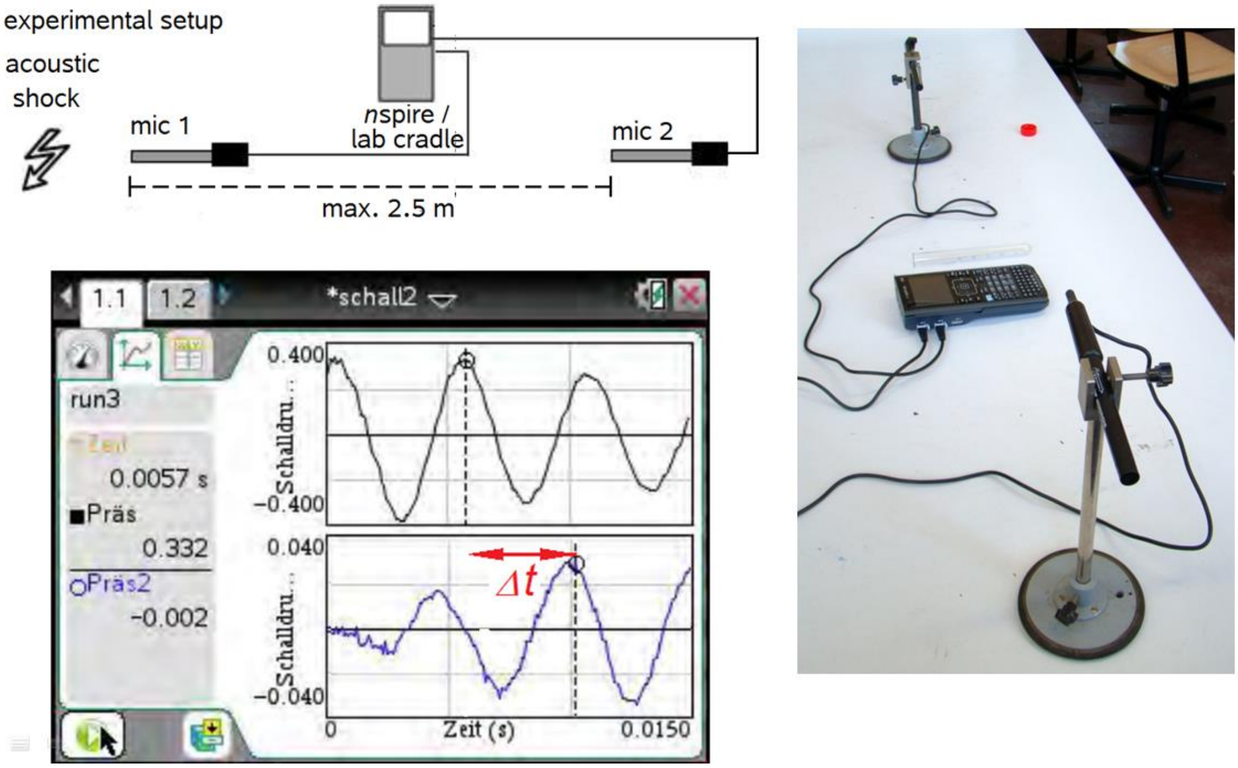


Figure 3 Perform a time based measurement with 1201 mesurements in 0.03 seconds

12. Velocity of Sound Measurement with two Microphones

The velocity of sound is measured by an acoustic shock propagating from one microphone to another in a distance of $\Delta\ell = 1 \cdots 2.5$ meters .The resulting signals are recorded and compared. The time difference Δt between two peaks is measured. The velocity of sound can now be calculated by $c = \Delta\ell / \Delta t$ (Figure



1).

Figure 1 Experimental setup for the measurement of the velocity of sound with 2 mics

Equipment : 2 Vernier mics with mounts
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle

Reference : Mirco Teewes ed., T^3 – Physik, Schülerexperimente im Physikunterricht mit digitaler Messwerterfassung, T^3 – Deutschland (2013), p.36 -41

Measuring proceedure

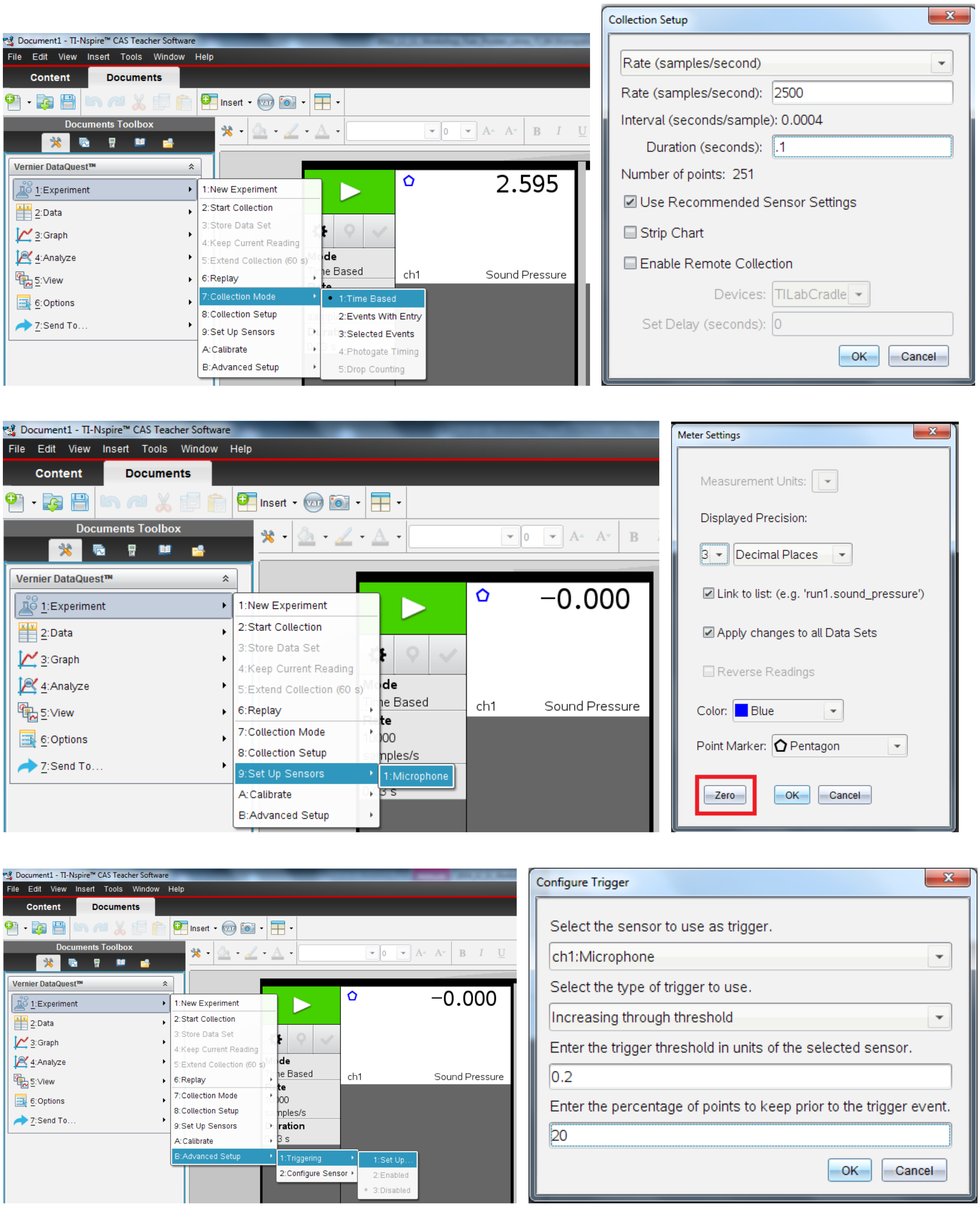


Figure 2 Measuring Procedure with 2Microphones : collection setup (0.1 s, 2500 samples/s / 0.015 s, 5’000 samples/s), setup sensors zero,trigger level 0.2, pretrigger 20%

13. Radioactivity Measurements

With a Student Vernier Radiation Monitor (Geiger-Müller-Tube) the counting rate of the $\gamma -$ radiation of a weak Co-60 source has been measured in function of the thickness (0 … 30 mm) of a lead shielding. The measuring time was 10 minutes. In Figure 77 the corresponding 10 Se-cond-Rates are shown. If the indicated rate is $17.93\frac{1}{10\text{ s}}$ the really measured rate is $1076\frac{1}{600\text{ s}}$. Following Poissons statistics the corresponding measuring error is $\pm\sqrt{1076} \approx \pm 33$ i.e. $(1076 \pm 33)\frac{1}{600\text{ s}}$ or $(17.93 \pm 0.55)\frac{1}{10\text{ s}}$. In Figure 77 the rate, the logarithm of the rate, the maximum and the minimum rates are shown as a function of the thickness of the shielding lead in millimeters (dicke). In figure 78 the rate and the corresponding minimum and maximum values are shown, in figure 80 the logarithm of the rate (as a straight line). In figure 79 the half thickness value of lead is evaluated with these data by $\underline{\underline{(13.0 \pm 0.9)\text{mm}}}$

A dicke	B rate	C lograte	D	E ratemax	F ratemin
0	17.93	1.25358		18.4767	17.3833
6	12.35	1.09167		12.8037	11.8963
12	9.8	0.991226		10.2041	9.39585
18	6.92	0.840106		7.25961	6.58039
24	5.	0.69897		5.28868	4.71132
30	3.8	0.579784		4.05166	3.54834

Figure 1 measurements

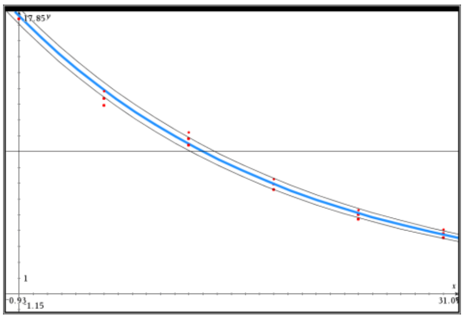


Figure 2 rate vs. time

Half Value Thickness of Lead

solve(f1(x)=9,x)	x=12.9877	mean Value
solve(f4(x)=9,x)	x=13.8511	maximum Value
solve(f5(x)=9,x)	x=12.123	minimum Value

Figure 3 evaluation

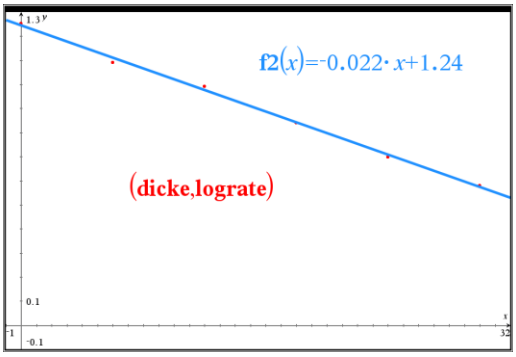


Figure 4 log-lin-representation

Equipment : Sample holder (wood)
Co-60 source,
10 lead shielding plates (3 mm),
Aluminium-Beta-shielding (2 mm)
TI-*n*spire CX CAS, handheld or software, Version 4.4
TI-*n*spire lab cradle
Student radiation monitor (Vernier)

Measuring Procedure

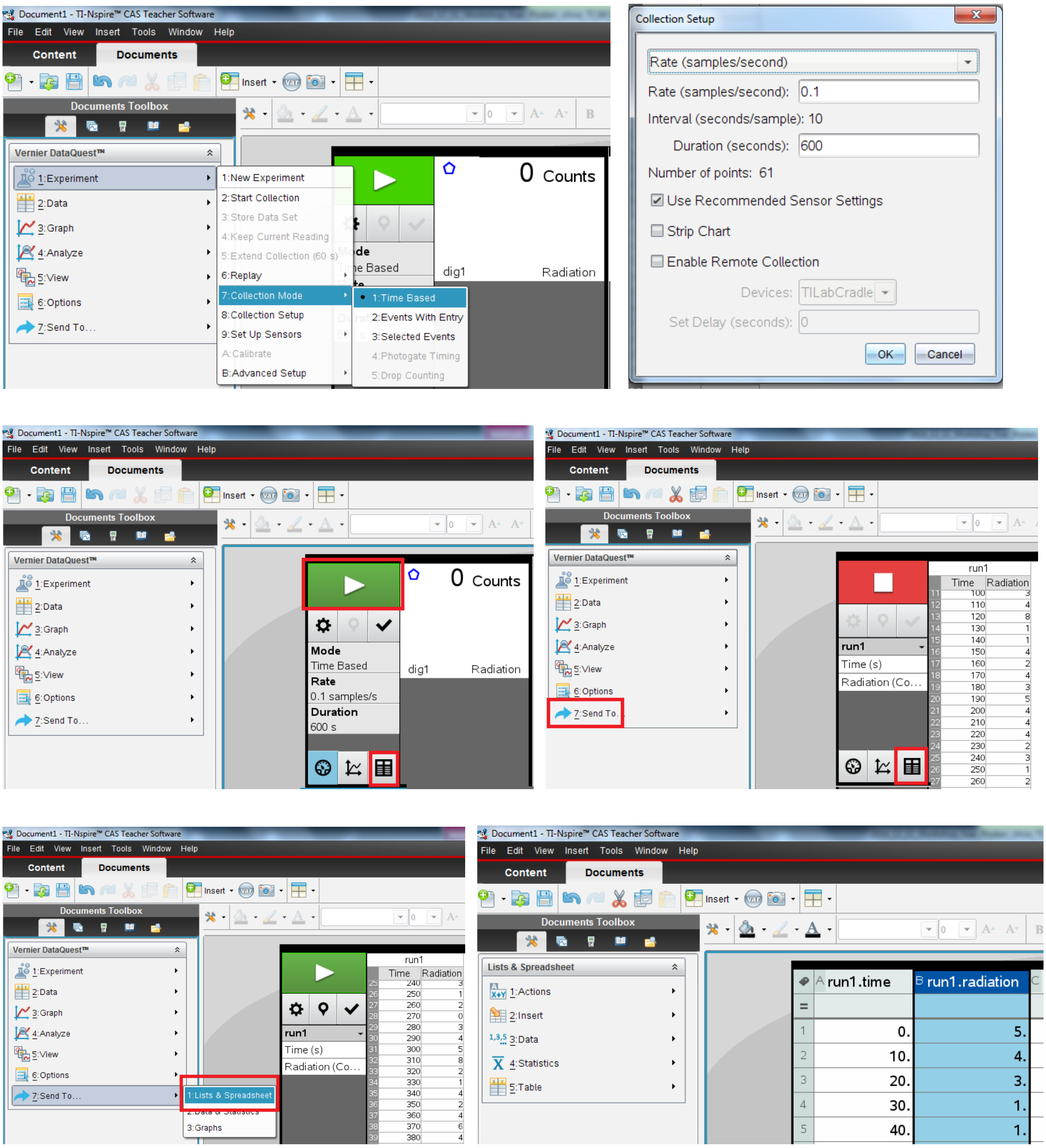
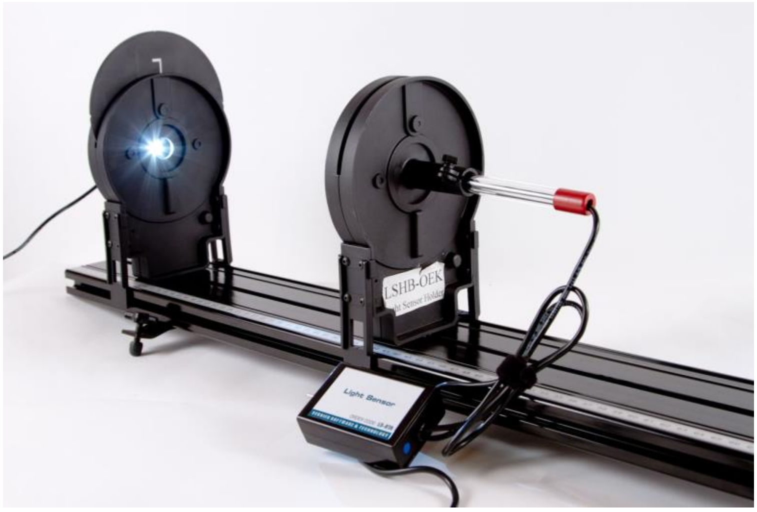


Figure 5 Measuring Procedure with Student Radiation Monitor : collection setup (600 s, 0.1 samples/s), Start, Send Data to lists & spreadsheet

14. Light, Brightness and Distance: $\frac{1}{r^2}$ - Law



In this experiment, we use a Light Sensor to measure the illumination generated by a nearby point light LED source as a function of distance. We will observe how illumination varies with distance, and compare our results to a $1/r^2$ mathematical model.

(Components: Optics Expansion Kit OEK, Vernier).

Figure 1 Experimental Setup: Track, LED Light Source, Light Sensor, Sensor Holder

Experimental Procedure

1. Manual Measurement in 1 cm-steps with the Vernier DatQuest App of the TI-nspire CX CAS software.
2. Data Transfer (distance, illumination) to the lists&Spreadsheet App and to the graph App of the TI-nspire CX CAS software.
3. Data evaluation with the function $y = a/(x-b)^2$ (*y* illumination in Lux, *x* distance from light source to light detector) and « optical » curve fitting by means of two sliders for the parameters *a* and *b*. Best fitting with $a = 3.93 \cdot 10^5$ lux $\cdot$ cm^2 and $b = -1.63$ cm

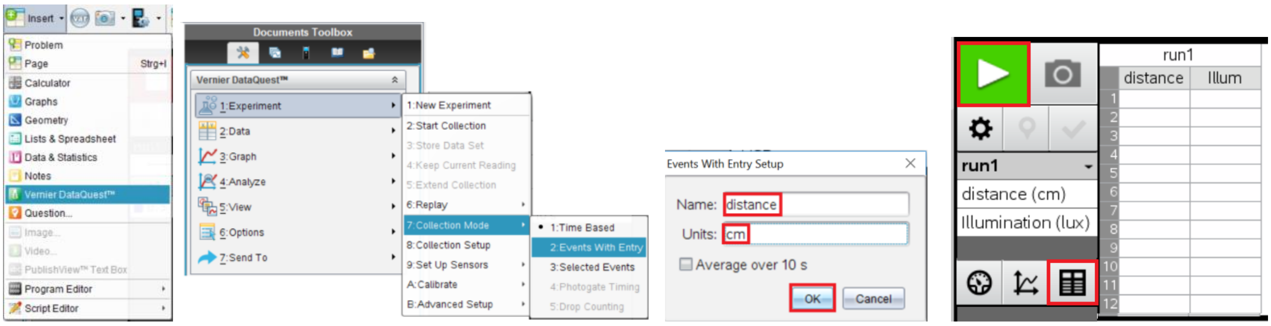
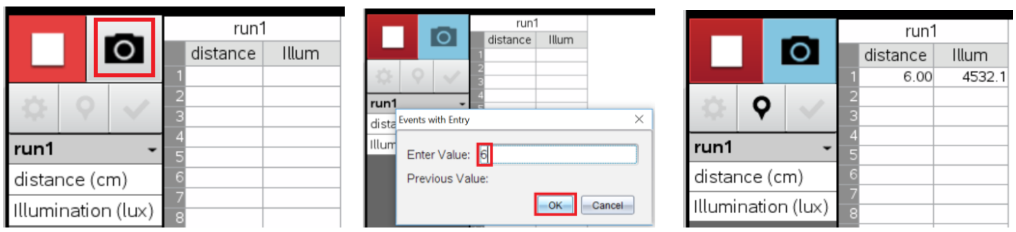


Figure 2 Start "Vernier DataQuest", single event mesasurements, start of the measurements



Figur 3 manual Measurement with "Vernier DataQuest"

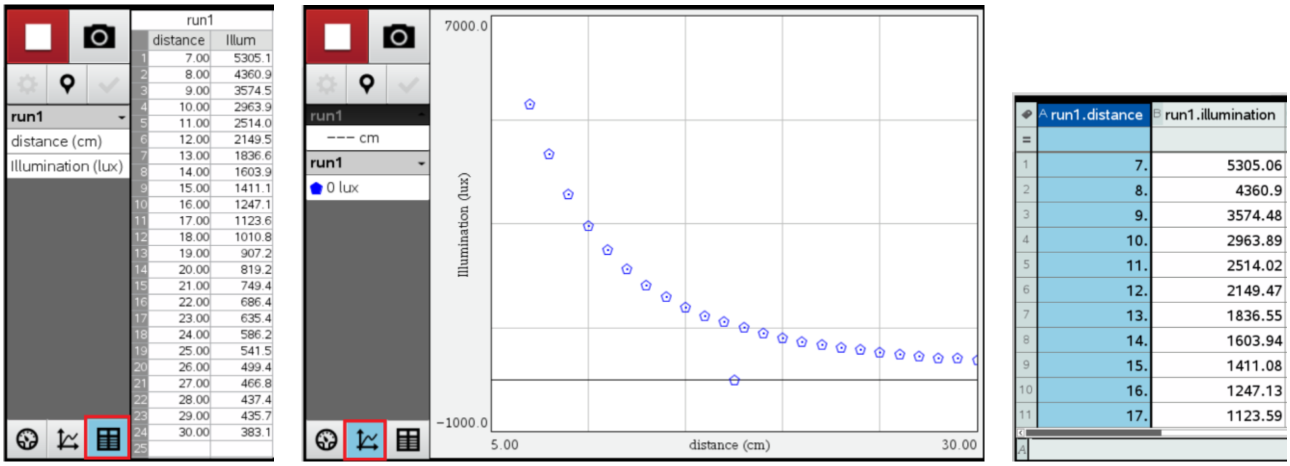


Figure 4 Experimental results in “Vernier DataQuest”. Data transfer to “lists and spreadsheet”

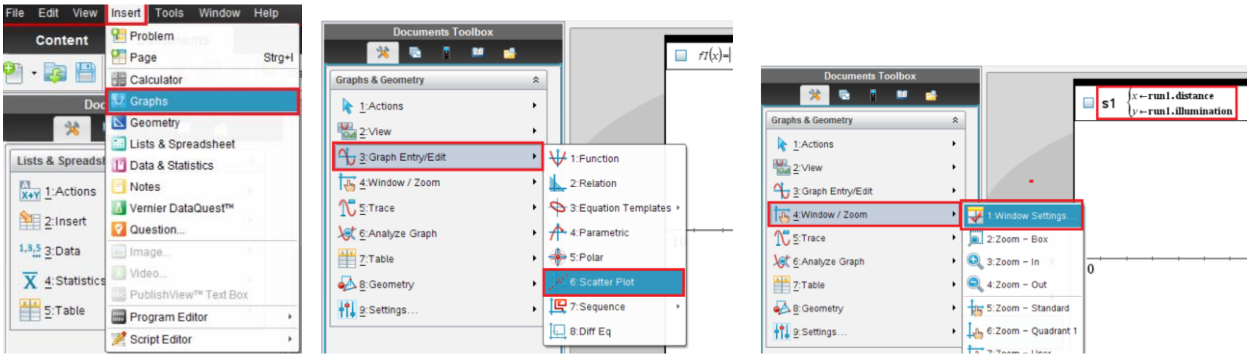


Figure 5 Preparation of a scatter plot representation of the measured data

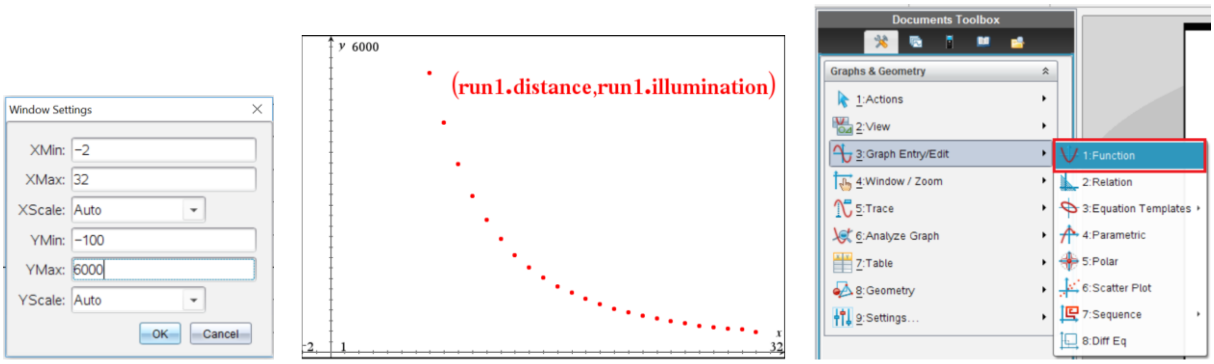


Figure 6 scatter plot of the measured data. Start of a new function fitting the data

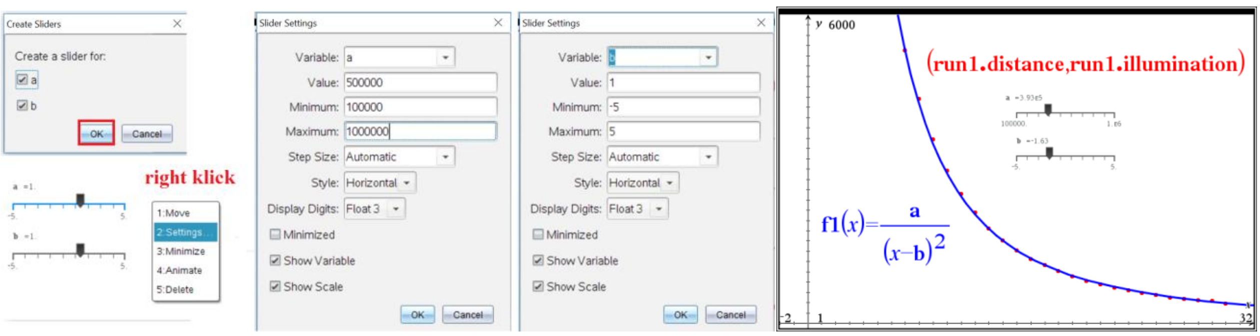


Figure 4 slider parameters, fitted data with $y = a/(x-b)^2$, where $a = 3.93 \cdot 10^5$ lux$\cdot$cm^2 and $b = -1.63$ cm

15. Dynamics Cart and Track System with Motion Encoder (Vernier)

Figure 1 Dynamics Cart and Track System with Motion Encoder (Vernier)

The dynamics Cart and Track System with Motion Encoder (figure 1) is a new way to study dynamics in secondary schools (Sek 2). The motion encoder is an optical position system similar to that of shaft encoder: A double black and white fringe pattern on the track is detected by two photore-flective sensors on the cart and is transmitted by an infrared beam to the motion encoder recei-ver (figures 2 and 3). The digital position signals are sent to a data interface (LabPro, Lab-quest 1 or 2, not TI nspire and labcradle!) and are evaluated by a corresponding app, e.g. LoggerPro 3.12).

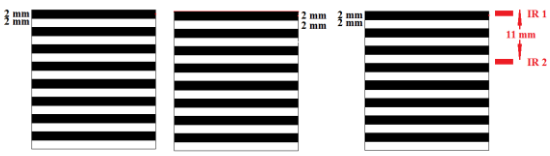


Figure 2 two fringe patterns on the track (left),
measuring principle (right)

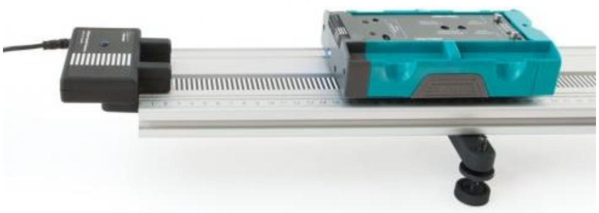


Figure 3 track, cart with motion detector, motion encoder transmitter (on cart) and detector fixed on track (left)

Linear motion with constant velocity

The motion encoder receiver will be conncted to a data logger (Lab-Pro, LabQuest), the data logger by an USB (mini/A) to a computer (PC/Mac) with loggerPro 3.12 -Software. The Cart with decoder electronics board is moved to its starting position, the distance measurement zeroed (Logger Pro: *Versuch => Auf null stellen => Encoderwagen*). With a slowly inclined track (to overcome friction) the cart is moved with a short kick and the measurements are started (Logger Pro: 

, figure 4).

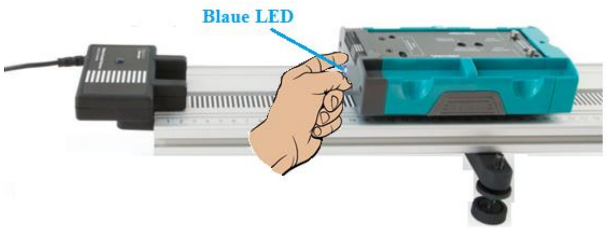
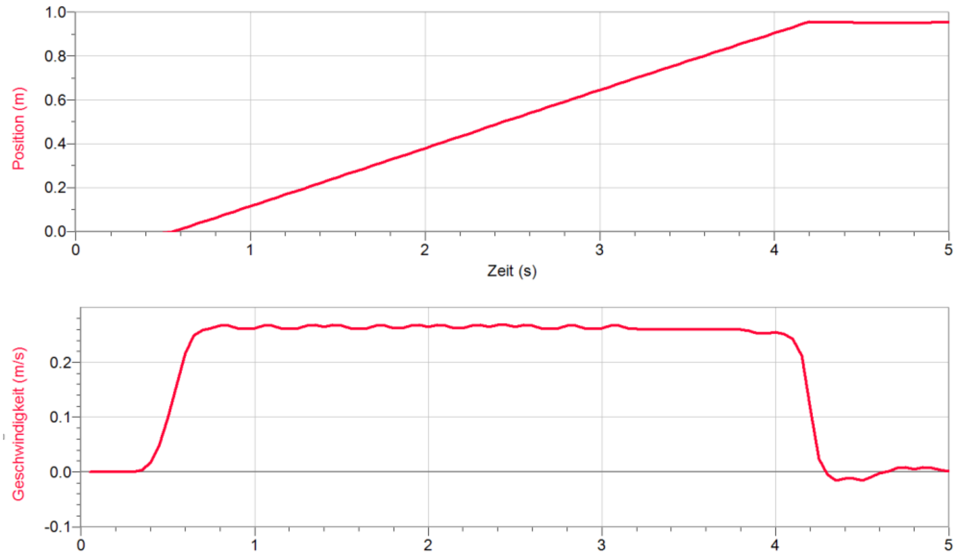


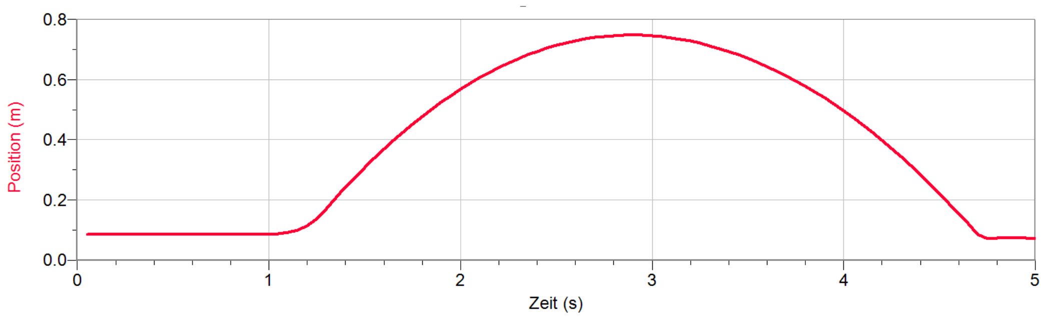
Figure 4 track, cart, decoder receiver. The blue Led is directed to the receiver



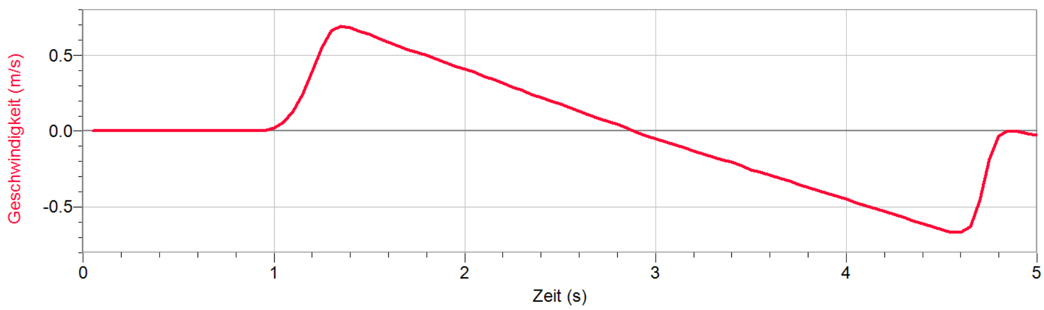
Figur 5 cart movement with constant velocity : position and velocity vs. Time

Linear motion with constant acceleration

The accelerated movement of the cart on a ramp (ascending slope 10 cm on the tracj length of 1 m) my be investigated in an analog way :



Figur 6 cart movement with constant acceleration: position vs. Time



Figur 7 cart muvement with constant acceleration: velocity vs. Time

16. Light Diffraction Apparatus **(Vernier)**

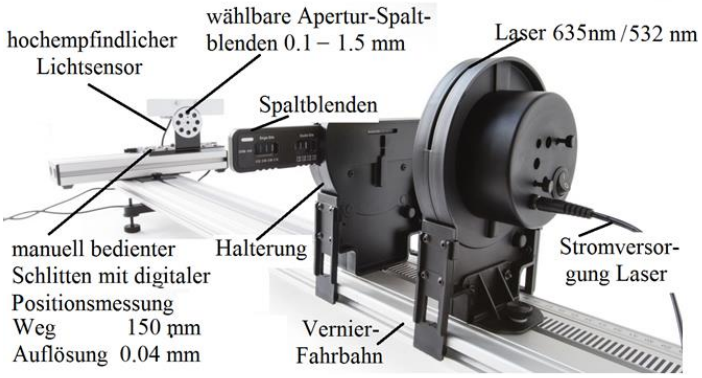


Figure 1 Vernier «Diffraction Apparatus» DAK

With this diffraction apparatus diffraction patterns of a variety of slits, double and multiple slits with laser light (635 nm and 532 nm) may be investigated and measured. The high precision slits, made by evaporation technique, allow quantitative evaluation of the diffraction patterns and the comparison of the measurements with the intensity-function $\sin^2(x)/x^2$ of Fraunhofer's theory. Figures 1 and 2 show the experimental setup. The light intensity is measured with a high sensitivity light sensor the position with a linear position sensor. This position sensor uses a precision optical encoder to measure translation with better than 50 micron resolution. Since it is optically based, without gears or racks, it has zero backlash.

Figure 2 Experimental Setup. Left: position and intensity sensors , Right: slits-slider and laser

In order to provide excellent spatial resolution, a selectable entrance aperture (0.1 mm, 0.2 mm, 0,3 mm, 0.5 mm, 1.0 mm, 1.5 mm, open and closed) restricts the width of the pattern viewed by the High Sensitivity Light Sensor. The light sensor has three ranges, allowing the study of fine details or gross features of patterns.

A measurement is performed by choosing first the appropriate entrance aperture (typically 0.3 mm) and the slit and by directing the (red or green) laser beam to the slit and the entrance aperture and the high sensitivity light sensor. The digital position and the analog light signals are sent to a data interface (LabPro, Lab-quest 1 or 2, not TI nspire and labcradle!) and are evaluated by a corresponding app, e.g. LoggerPro 3.12). The measurements are started (Logger Pro: 

). The position sensor is then moved slowly over a distance of 15 cm in 30 seconds whereby the diffraction pattern is detected digitally.

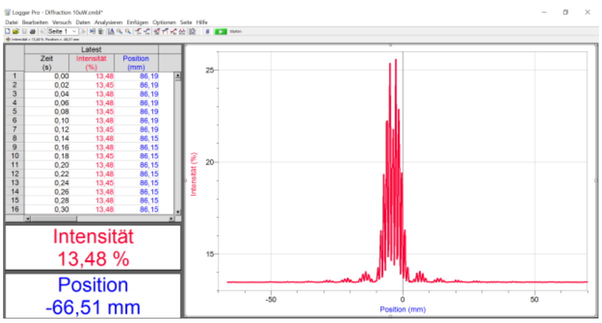


Figure 3 measurement of a diffraction (double Slit, b=0.08 mm, a=0,5 mm) with LoggerPro 3.12

Theory

The theory of optical diffraction is treated in Max Borns « Optik » (1932, p,154 ff). For the diffraction at a rectangular slit (width $2 \cdot A$, height $2 \cdot B$) he finds :

$$I_P = \left(\frac{2 \cdot A \cdot B}{\lambda}\right)^2 \cdot \left(\frac{\sin(k \cdot a \cdot A)}{k \cdot a \cdot A}\right)^2 \cdot \left(\frac{\sin(k \cdot b \cdot B)}{k \cdot b \cdot B}\right)^2 , \quad \text{Born, Optik, S. 157}$$

The central function for the local distribution oft he intensity of light is $\sin^2(x)/x^2$. For the corresponding function of the **double slit** $\sin^2(x)/x^2$ is the envelope which is modulated by a $\cos^2(x)/x^2$ function oft the distance oft he two slits. https://de.wikipedia.org/wiki/Doppelspaltexperiment

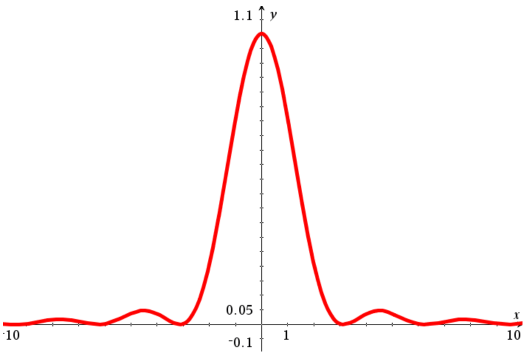


Figure 4 The function $\dfrac{\sin^2(x)}{x^2}$

$$I(\alpha) = I_0 \cdot \left(\frac{\sin\left(\frac{k}{2} \cdot b \cdot \sin\alpha\right)}{\frac{k}{2} \cdot b \cdot \sin\alpha} \cdot \cos\left(\frac{k}{2} \cdot a \cdot \sin\alpha\right) \right)^2$$

I_0 intesiy of the central peak
k wavenumber $2 \cdot \pi / \lambda$
a central distance of the two slits
b width of the two single slits
α angle with $\tan\alpha = \dfrac{x}{d}$
d distance slit – screen

©Wellenlänge lambda

lambda:=6.35E-7	© 635 Nanometer	6.35E-7

©Wellenzahl k

$k:=\dfrac{2\cdot\pi}{lambda}$	© Wellenzahl $9.89478E6 \cdot \dfrac{1}{Meter}$	9.89478E6

©Spaltabstand a

a:=2.5E-4	© Spaltabstand 0.25 mm	0.00025

©Spaltbreite b (der beiden Einzelspalte)

b:=4.E-5	© Spaltbreite 0.04 mm	0.00004

©Schirmabstand d

d:=0.9	© Abstand Doppelspalt–Schirm 90 cm	0.9

$$f1(x):=\left(\frac{\sin\left(\frac{k}{2}\cdot b\cdot \sin\left(\tan^{-1}\left(\frac{x}{d}\right)\right)\right)}{\frac{k}{2}\cdot b\cdot \sin\left(\tan^{-1}\left(\frac{x}{d}\right)\right)}\cdot \cos\left(\frac{k}{2}\cdot a\cdot \sin\left(\tan^{-1}\left(\frac{x}{d}\right)\right)\right)\right)^2 \quad \text{Done}$$

Figure 6 $f_1(x)$ (TI-nspire CX CAS)

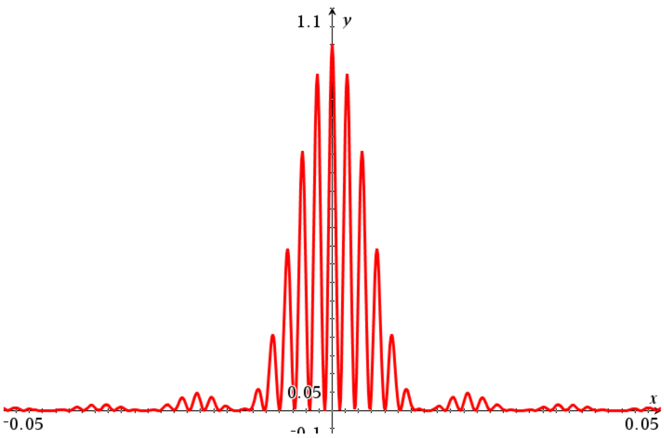


Figure 5 plot of the calculated intensity distribution $f_1(x)$ (TI-nspire CX CAS)

1	1	2	2
3	3	4	4
5	5	6	6
7	7	8	8
9	9	10	10
11	11	12	13
14	14	15	15

16 16 17 17