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## **Physics Workshop:**

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

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## 



## 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 ( $\vartheta_{\rm B} \approx 97^{\circ}$ C).

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



Figure 1 Temperature Response Curve of an EasyTemp-Temperature Sensor

According to Newton's law the temperature response function  $\mathcal{G} = \mathcal{G}(t)$  (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 TInspireCX CAS only):  $k = 0.3 \frac{1}{s}$ ,  $t_e = 95^{\circ}$ C and  $t_i = 42^{\circ}$ 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  $\frac{\mathcal{G}_{environ} - \mathcal{G}(t)}{\mathcal{G}_{environ} - \mathcal{G}_{initial}} = e^{-k \cdot t}$  may be performed (for TI-84 and for TI-*n*spireCX CAS).



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**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-nspire Start screen

Collection Setup
Rate (samples/second)
Rate (samples/second): 10
Interval (seconds/sample): 0.1
Duration (seconds): 10
Number of points: 101
☑ Use Recommended Sensor Settings
Strip Chart
Enable Remote Collection
Devices:
Set Delay (seconds): 0
OK

Figure 3 Collection Setup



## 2. Evaporation Heat medical Benzine or Pentane

A precise exponential temperature decay  $\mathcal{G} = \mathcal{G}(t)$  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



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  $\vartheta = 0^{\circ}$ C). The zero line of the exponential function shown in Figure 3 is at  $\vartheta_{environ} \approx -17.2 \,^{\circ}$ C.



Figure 3 Temperature Decay from evaporating Pentane

	A run1.time	■ run1.temp1	l <sup>a</sup> neutemp	D	E	F	G	Ξè
٠			=dc01.temp1+null				=ExpReg('dcl	
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					- <b>V</b>
A	1 0.							

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



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

Since  $\mathcal{G}_{environ}$  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  $17.2^{\circ}$ 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-nspire CX CAS, handheld or software, Version 4.4 or later
- TI-nspire lab cradle or GoLink/EasyLink adapter
- TI-temperature probe (Vernier)





Figure 5 TI-nspire 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	<sup>■</sup> run1.potentia		D
٠				=ExpReg('dc01.time,'dc01.∨ol
1	0.	6.53931	Titel	Exponentielle Regression
2	0.1	6.52924	RegEqn	a*b^x
3	0.2	6.51398	а	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	1.5000002	23517		

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 **1** 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 🖳 .
- 15. Press the menu-key. Select 3; Graph Entry/Edit=>

5: Scatter Plot. Enter s1  $\begin{cases} x \leftarrow run1.time \\ y \leftarrow run1.potential \end{cases}$ 

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



# $\mathbf{fl}(x) = 6.55888 \cdot (0.98292)^{\times}$ $\mathbf{fl}(x) = 6.55888 \cdot (0.98292)^{\times}$ $\mathbf{fl}(x) = 6.55888 \cdot (0.98292)^{\times}$ $\mathbf{fl}(x) = 6.558878285614 \cdot (0.98291960321058)^{\times}$

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

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

the time constant  $\tau$  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  $\tau$  of the discharging process can now be calculated.

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

The time constant  $\tau$  of this discharging process can now be calculated

$$\tau = \frac{1}{k} = -\frac{1}{\ln b} = -\frac{1}{\ln 0.98202}$$
 s = 55 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 of 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)

Document1 - TI-Nspire™ CAS Teacher Software	tware	Collection Setup
File Edit View Insert Tools Window	ow Help	
Content Documents		Rate (samples/second)
智 • 🔯 💾 🗠 🖊 🐰 🗊 (	💼 💶 Insert • 🤕 🗃 • 🚍 •	Rate (samples/second):
Documents Toolbox	and the destand of the last of the destand	
📉 🥳 🗟 🔹 🛸		Interval (seconds/sample): 0.5
Vernier DataQuest™	*	Duration (seconds): 180
1:Experiment	→ 1:New Experiment 0.976 ∨	Number of points: 361
2:Data	, 2:Start Collection	☑ Use Recommended Sensor Settings
1. Graph	3:Store Data Set	Strip Chart
Analyze	► 5:Extend Collection (60 s) Code	Enable Remote Collection
S:∨iew	6:Replay     6:Replay	
E: Options	7:Collection Mode • 1:Time Based	Devices:
7:Send To	8:Collection Setup	Set Delay (seconds): 0
<u> </u>	9.5et Op Sensors 7 3:Selected Events	
	A:Calibrate + 4:Photogate Timing	OK Cancel
	B:Advanced Setup + 5:Drop Counting	

Figure 5 TI-*n*spire Start screen

Figure 6 Collection Setup





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



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



Figure 2 CBR-2 ultrasonic distance sensor



	run1.time	run1.position	run1.velocity	run1.acceleration	н
٠					=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

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*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-nspire 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



Figure 1 Force Plate Kistler 0285 BA



Figure 2 Gait Analysis with 2 Force Plates (Kistler)



Figure 3 Vernier Force Plate: Newtons 3rd law

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) applications. The glass plate allows simultaneous force measurement and photographic 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 1dforce 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.

## 1<sup>st</sup> 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  $\Delta p$  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

	A run1.time	B run1.force
٠		
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
Α	1 0.	

Figure 5 Measured force to time values pairs

**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

©Sprunghöhe 13.8 cm

h(n,m)

h(249.84)

2 Content Li Neuer - CAI Ready Schest Re Gat View maret Yoon Vielan Help Content Documents	Configure Trigger	Collection Setup
	Select the sensor to use as trigger. (ch1:Force Plate 3500 N	Rate (samples/second):     •       Rate (samples/second):     100       Interval (seconds/sample):     0.01       Duration (seconds/second):     4       Number of points:     401       © Use Recommended Sensor Settings     Strip Chart       © Enable Remote Collection     Devices:       Devices:     TLabCrade =       Set Delay (seconds):     0K

Figure 7 Force Plate : TI-nspire trigger, pretrigger and collection setup

## 2<sup>nd</sup> 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

Height of the Jump:

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

 $\frac{dc01.force1[i+1]+dc01.force1[i]}{2} \cdot (dc01.time[i]-dc01.time[i-1])$ 

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

9.81•*dc01.time* 

2.9.81

Figure 6 Evaluation of a jump from the force plate

0.138419



## 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  $\mu$ F capacitor (Leybold 517 021) and a 9-Volt-battery (figures 1 and 2).



Figure 1 Slowly oscillating Circuit (1 Hertz)



Figure 3 Damped Electric Oscillation

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

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:

$$U_{\rm R} + U_{\rm C} + U_{\rm L} = 0 \rightarrow \underbrace{R \cdot I}_{\rm Ohm} + \underbrace{\frac{Q}{C}}_{\rm Capacitanc\ e\ C} + \underbrace{L \cdot \frac{dI}{dt}}_{\rm Self\ Inductance} = 0 \quad \text{differentiated}: \qquad R \cdot \frac{dI}{dt} + \frac{I}{C} + L \cdot \frac{d^2I}{dt^2} = 0 \text{ or}$$
$$\frac{d^2I}{dt^2} + \frac{R}{L} \cdot \frac{dI}{dt} + \frac{1}{L \cdot C} \cdot I = 0$$

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-nspire CX CAS, handheld or software, Version 4.4 TI-nspire lab cradle or GoLink/EasyLink adapter

Document1 - TI-Nspire** CAS Teacher Software      File Edit View Insert Tools Window Help	Configure Trigger
Content Documents	
🎦 • 🔯 💾 🖙 제 💥 🗐 🌔 🖳 Insert • 🎯 🔯 • 🗮 •	Select the sensor to use as trigger.
Documents Toolbox         ★ • ▲ • ∠ • ▲ • ▼ 0 ▼ A• A• B I U           ※ ● 日 ■ ▲         ★ • ▲ • ∠ • ▲ • ▼ 0 ▼ A• A• B I U	ch1:Voltage (+/-10 V)
Vernier DataQuest™ *	Select the type of trigger to use.
1:New Experiment U.984 V	Decreasing through threshold
3:Store Data Set	Enter the triager threshold in units of the selected sensor.
4. Neep Current Reading S:Extend Collection (60 s) <b>ode</b>	
6:Replay , me Based ch1 Potential	0
Collection Mode     Samples/s	Enter the percentage of points to keep prior to the trigger event.
→ 7:Send To 9:Set Up Sensors s	10
A:Calibrate >	
B'Advanced Setup 1:Triggering 1:Set Up 2:Configure Sensor P ::Ecobled	OK Cancel
• 3.Disabled	
	Collection Setup
Document1 - TI-Nspire™ CAS Teacher Software     Soft	Rate (samples/second)
Content Documents	Rate (samples/second): 100
🎱 • 🔯 💾 🗠 🎮 🐰 🗊 💼 🖬 Insert • 🌚 🗃 • 🚍 •	Interval (seconds/sample): 0.01
	Duration (seconds): 4
Vernier DataQuest <sup>en</sup> *	Number of points: 401
1.New Experiment ○ 0.983 ∨	☑ Use Recommended Sensor Settings
2:Start Collection	Strip Chart
3:Store Data Set	
4. Kep Current Reading	Enable Remote Collection
The Based ch1 Potential	Devices: TILabCradle
Collection Mode     I:Time Based	
7:Send To	Set Delay (seconds): U
A:Calibrate + 4:Photogate Timing	OK Cancel
B:Advanced Setup	

Figure 4 Voltage Probe : TI-nspire trigger, pretrigger and collection setup

Alternative : We work here with a 15 Henry inductor (Digikey) and a (unpolarized!)  $2.2\mu$ F 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

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

We get

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

for the left part of the signal and

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

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 cm<sup>2</sup>)

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

If we suppose that the distance between minimum and maximum value of the induction signal corresponds to the length of the bar magnet ( $\Delta s = 17 \text{ cm}$ ) 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)



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	Enter the trigger threshold in units of the selected sensor.
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	B:Advanced Setup +	5:Drop Counting			

Figure 4 Voltage Probe : TI-nspire 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).













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:

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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-nspire 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.



=> 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 measurement 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 :

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Figure 4 Voltage Probe : TI-nspire 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

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)

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 4<sup>th</sup> power of the absolute temperature

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

$$\rightarrow U \cdot I = \sigma \cdot S \cdot \frac{U^{4}}{c_{1}^{4} \cdot I^{4}}$$
  

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



## 

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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)

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



## 



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  $\Delta t$  between two peaks is measured. The velocity of sound can now be calculated by  $c = \Delta \ell / \Delta t$  (Figure



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<sup>3</sup> – Physik, Schülerexperimente im Physikunterricht mit digitaler Messwerterfassung, T<sup>3</sup> – Deutschland (2013), p.36 -41



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## Measuring proceedure

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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  $(13.0\pm0.9)$  mm

A dicke	<sup>B</sup> rate	⊂ lograte	D	<sup>∈</sup> 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(fI(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



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)



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## **Measuring Procedure**



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







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<sup>2</sup> and b = -1.63 cm

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Figur 3 manual Measurement with "Vernier DataQuest"



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

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5:Table	Program Editor +	<b>†⊺</b> ↓ <u>9</u> :Settings	, in the sequence ,	€Geometry	5:Zoom - Standard	
	2 Script Editor		8:Diff Eq	t¶, g:Settings ►	6:Zoom – Quadrant 1	

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  $a = 3.93 \cdot 10^5 \text{ lux} \cdot \text{cm}^2$ 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



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



### wählbare Apertur-Spalt-Laser 635nm / 532 nm hochempfindlicher blenden 0.1 - 1.5 mm Lichtsensor Spaltblenden manuell bedienter Halterung Stromversor-Schlitten mit digitaler gung Laser Positionsmessung Weg 150 mm Vernier Auflösung 0.04 mm Fahrbahn

Figure 1 Vernier «Diffraction Apparatus» DAK

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

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: Logger Pr



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 :

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

The central function for the local distribution of the 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 of the distance of the two slits. https://de.wikipedia.org/wiki/Doppelspaltexperiment





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

- $I_0$  intesiy of the central peak
- k wavenumber  $2 \cdot \pi / \lambda$
- central distance of the two slits
- width of the two single slits

lambda:=6.35E-7 © 635 Nanometer	6.35E-7					
©Wellenzahl k						
$k = \frac{2 \cdot \pi}{lambda}$ © Wellenzahl 9.89478E6 $\cdot \frac{1}{Meter}$	9.89478e6					
©Spaltabstand a						
a:=2.5E-4 © Spaltabstand 0.25 mm	0.00025					
©Spaltbreite b (der beiden Einzelspalte)	©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					
$fI(\mathbf{x}) := \left  \frac{\sin\left(\frac{k}{2} \cdot b \cdot \sin\left(\tan^{-1}\left(\frac{x}{d}\right)\right)\right)}{\frac{k}{2} \cdot b \cdot \sin\left(\tan^{-1}\left(\frac{x}{d}\right)\right)} \cdot \cos\left(\frac{k}{2} \cdot a \cdot \sin\left(\tan^{-1}\left(\frac{x}{d}\right)\right)\right) \right ^2$	Done					

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



## L



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