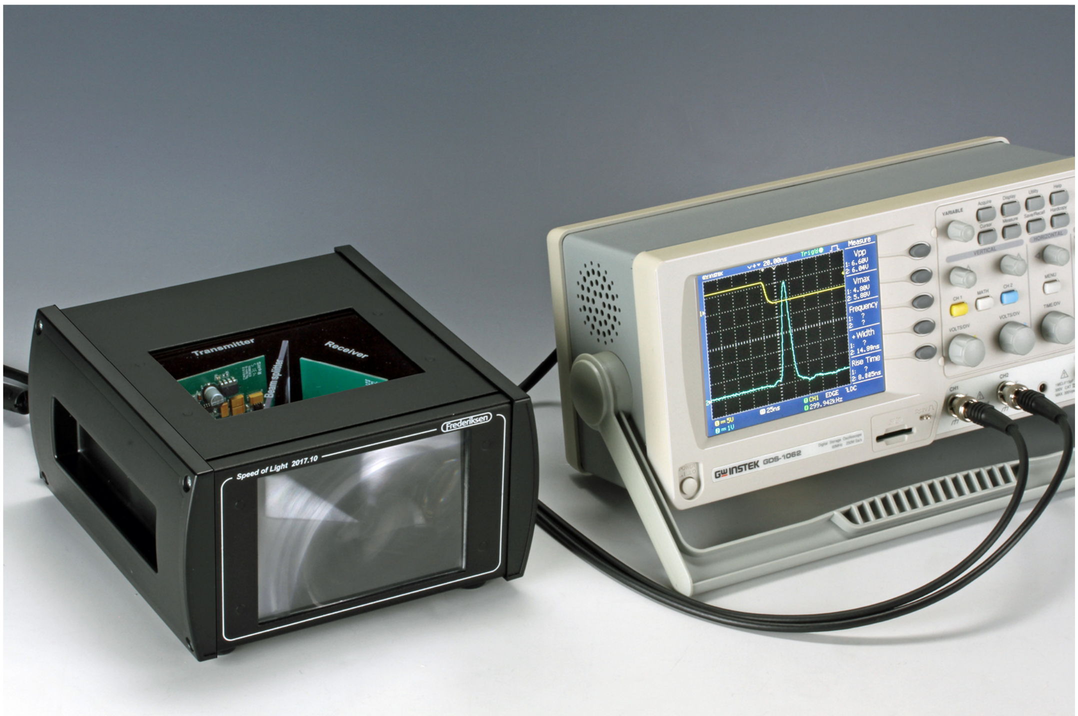
The Speed of Light

Experiment number 133890-EN	*Topic*	Light; kinematics; fundamental constants				
Version 2017-08-25 / HS	*Type*	Student exercise	*Suggested for*	grade 11-12	*p.*	1/4



Setup with an older digital oscilloscope. The reflector is positioned outside the image.

Objective
To measure the speed of light in atmospheric air.

Principle
We measure time of flight and distance travelled by the light – from which the speed can be calculated immediately

The equipment emits very short flashes of light. The light hits a reflector and returns to the apparatus where a sensor converts the flash into an electric pulse. Using an oscilloscope, we measure the delay of the light resulting from its trip back and forth.

Equipment
(Detailed equipment list on p. 4)

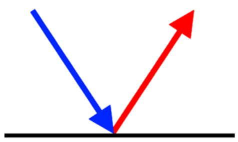
201710 The Speed of Light
The device is provided with mains adapter, cables and reflector.

Digital oscilloscope, e.g. 400150
– or a PC oscilloscope like for instance 400100

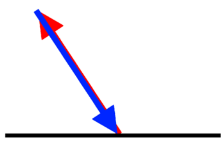
(An analog oscilloscope can possibly also be used – a guide can be downloaded from our web site. Search for item number 201710.)

The re(tro)flector
What in this manual for the sake of simplicity is called a "reflector" has a surface that shows *retroflection* – i.e. it sends incoming light back in the same direction it came from.

This makes it much easier to direct the light back into the apparatus than if e.g. a mirror was used.



Reflection



Retroflection

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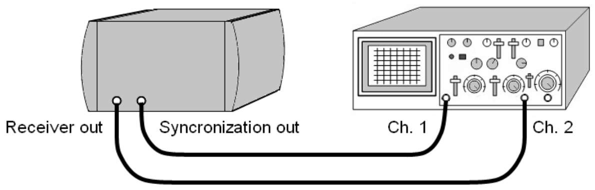
Preparing the oscilloscope

Connect the oscilloscope to the device with the 50 Ω coax cables as shown. Place the reflector immediately in front of the lens while adjusting the oscilloscope.



The following is a short description of the oscilloscope setup – *for a detailed walk-through, see appendix*.

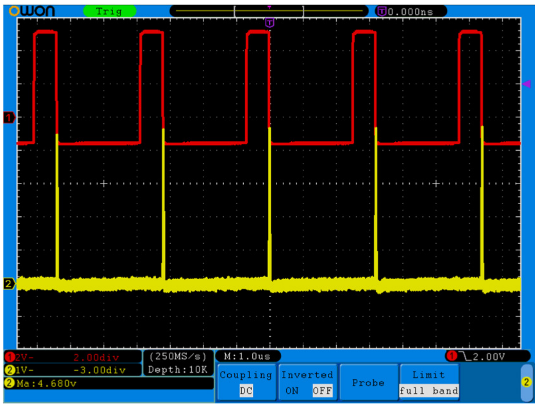
Ch 1: Scale **2 V/div**.
Shift the trace one to two divs upwards.

Ch 2: Scale **1 V/div**.
Shift the trace two to four divs downwards.

Trigger: Source = Ch 1, falling slope, level about **2 V**.

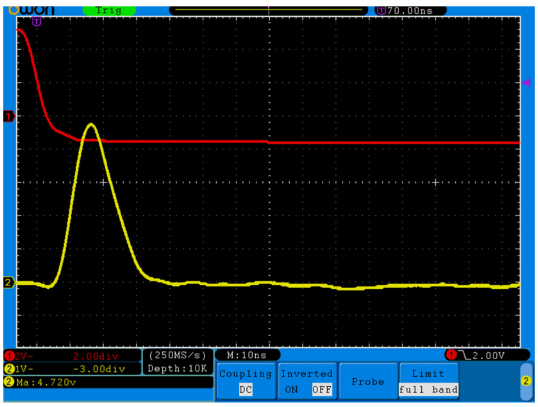
Time-base: t=0 centred on the screen, **1 µs/div**.

Fine tune until the display shows a steady image of the sync pulses in channel 2 – and some sharp "needles" in channel 2:



Next, change the time-base to **10 ns/div.**

Shift t=0 almost completely to the left of the screen. The result should look like this:



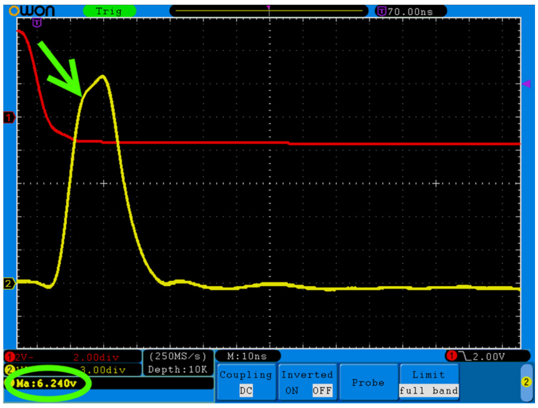
Finally, let the oscilloscope show **the average** of some-thing like 8 or 16 traces.

Procedure

We define the arrival of the light pulse as the time where the rising edge reaches 50 % of the max. value. Thus, it is important to be able to determine the max value fairly correct.

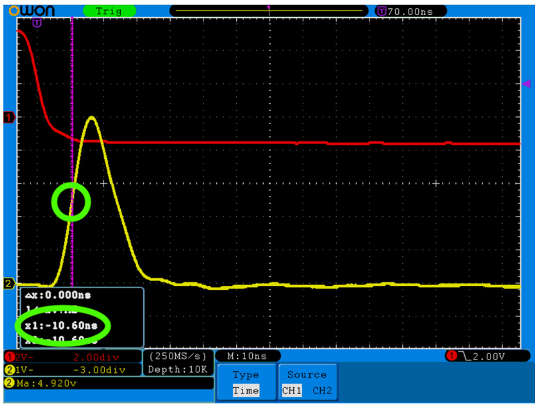
It is possible to have so much light reflected back on the sensor that the circuitry saturates – i.e. cuts the top off the signal. This can be avoided by keeping the top of the pulse below around 5 V.

The signal amplitude is easily controlled by covering part of the reflector by a sheet of black paper.



The image above shows a pulse that is distorted due to a too strong signal. (Max voltage measured: 6.24 V)

First, determine the time t_0 for the distance s = 0 m: With the reflector immediately in front of the lens and intensity throttled as describe, note the position of the reflected pulse. You can use the cursor functions of the oscilloscope for this.

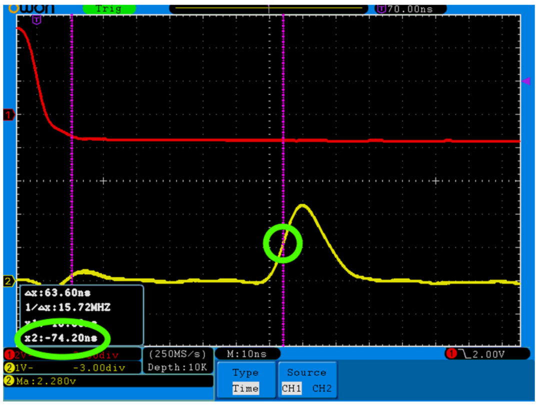


For the rest of the measurements, don't change the time base of the 'scope!

Next, complete a series of measurements with the reflector further away (up to 10 m). To ensure that you hit the reflector, aim only a few cm above the top of the device.

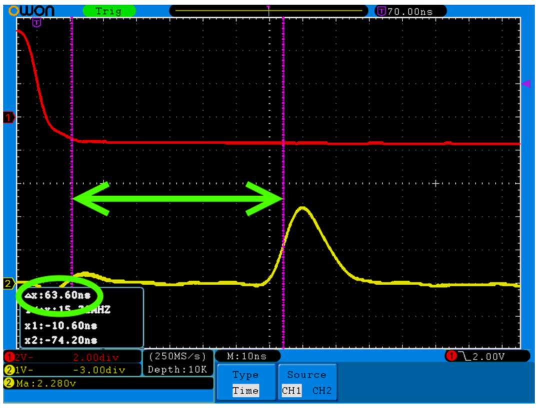
Each time, measure the distance L from the front of the box to the reflector as precisely as possible.

If necessary, adjust the scale of Ch 2 to make the pulse height appropriate.



If you use the cursor function, the time of flight can be read off the screen as the difference between the two arrival times.

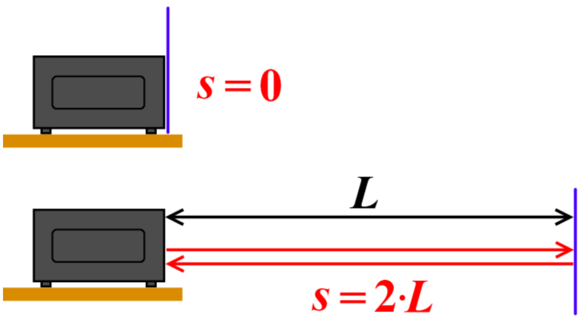
– Otherwise, positions must be read carefully using the time scale of the screen.



Data processing

Unless the cursor functions already has done this for you, all time measurements must be converted to **time of flight** for the light pulses by subtracting t_0 – making time 0 correspond to distance 0.

All distance measurements are converted to **distance travelled** by multiplying them by 2.



The distance travelled is plotted as a function of the time of flight. Use the graph to determine the speed of light in atmospheric air.

The index of refraction of air at room temperature is approx. 1.00028. From this, c (the speed of light in vacuum) can be calculated. Compare the result with the table value. (Specify the deviation as a percentage.)

Discussion and evaluation

The deviation between the measured and the official value of c should be explained by the measurement uncertainty of the equipment used.

Calculate the relative (i.e. as a percentage) uncertainty of a distance measurement of, say, 5 m.

Try similarly to gauge the precision of the time of flight measured with the oscilloscope. For instance, find the relative uncertainty of a time of flight of 50 ns.

Where do we find the largest relative uncertainties?

Can the deviation of the c value be explained by measurement uncertainties – or are there any other important factors that need to be considered?

Teacher's notes

Since 1983, a metre has been defined in terms of the speed of light in vacuum. This makes the speed of light a defined constant and consequently no longer a measurable entity.

In this lab manual, we take a more pragmatic point of view: We measure distance with a tape measure or similar and corresponding time with an oscilloscope. These two paraphernalia implicitly define the entities "metre" and "second" in our current measurement situation. Hence, the speed of light can of cause be found experimentally from our measurement results.

Concepts used

Speed
Technical terms in connection with the use of the oscilloscope
Uncertainty of measurements

Mathematical skills

Fractions
Percentages

About the equipment

The product manual for 201710 explains the optical design of the apparatus. You literally gain insight into the structure through a window at the top of the enclosure.

Concerning the oscilloscope: See equipment list.

Detailed equipment list

Specifically for the experiment

201710 Speed of Light

Oscilloscope

We recommend the following two oscilloscopes; *their operation is discussed in detail in Appendix 1 and 2 to this lab manual*:

400150 Digital oscilloscope, 60 MHz
400100 PC oscilloscope, 2 channels, 60 MHz (USB)

Just us useful – with virtually identical operation:

400105 PC oscilloscope, 4 channels, 60 MHz (USB)

The following models **are discontinued**, but can also be used:

(400110 Oscilloscope, digital, 25 MHz)
(400120 Oscilloscope, digital, 50 MHz)

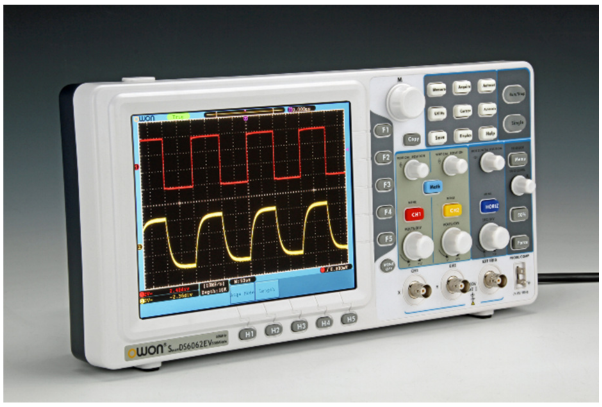
We have delivered many of the following analog oscilloscopes (**now discontinued**). If you simply wish to illustrate the principles in the measurement, this instrument can be used at a pinch. We have written a separate instruction sheet for this oscilloscope – search our web site under item number 201710.

(400040 Oscilloscope GOS 620)

Standard lab equipment

Tape measure, long ruler or similar.

Oscilloscope 400150 setup



400150 Digital oscilloscope, 60 MHz – is an excellent instrument for the experiment “The Speed of Light”.

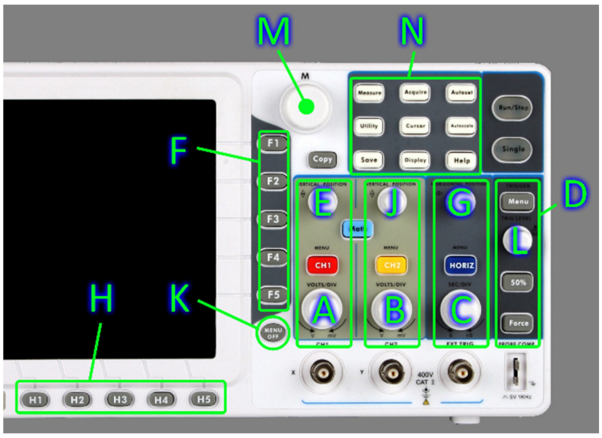
Below is a step by step guide of how the oscilloscope is prepared.

Buttons grouped

The two inputs are controlled by the buttons above them. **A** sets the scale of Ch 1, **E** shifts the trace vertically. Similar for Ch 2 – buttons **B** and **J**.

The next button group controls the time base of the oscilloscope. **C** selects the scale while **G** shifts the zero point right or left.

Buttons in group **D** control the *trigger*. The trigger defines the zero point of the axis relative to the incoming pulses. The trigger level is set by button **L**.



Buttons **F** and **H** are used for selections within menus that appear on the screen. **M** is a dial, also used for selecting options shown on screen.

The buttons in group **N** control major functions – often leading to menus controlled by the **F** and **H** buttons.

Button **K** removes possible menus from the screen.

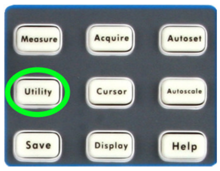
Setting up – step by step

Mount the cables as described in the lab manual. Turn on the “Speed of Light” box and the oscilloscope. Place the reflector immediately in front of the lens.

1 –Resetting to factory settings

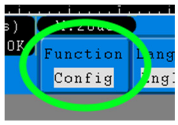
Group **N:** Press *Utility*.

(This opens a range of choices for the **H** buttons.)



Group **H**: Press **H1** for *Function*.

(This opens a menu on the left side of the screen.)

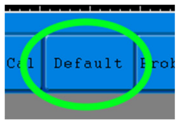


Turn the dial **M** to select menu item *Adjust*.

(This opens a range of new choices for the **H** buttons.)

Group **H**: Press **H3** for *Default*.

After emitting clicking sounds for a short while, the oscilloscope is brought to a well-defined state.

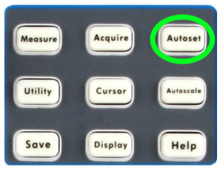


(The screen shows only noise at this point – the traces are smeared all over the area.)

2 – Automatic settings

Group **N:** Press *Autoset*.

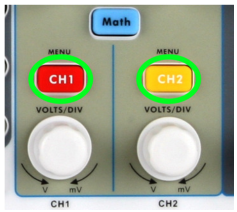
The screen now starts to *re-semble* the image on p. 2 in the lab manual.



3 – Input setup

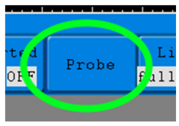
Press the red button **CH1**.

(This opens a range of choices for the **H** buttons.)



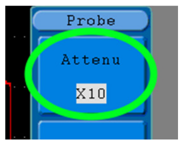
Group **H**: Press **H3** for *Probe*.

(This opens a range of choices for the **F** buttons.)

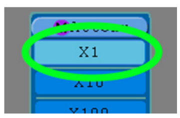


Group **F**: Press **F1** for *Attenuation*

(This opens a menu at the left side of the screen.)

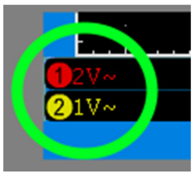


Turn the dial **M** to select *X1*



Repeat this procedure for Ch 2 (starting with yellow button **CH2**).

Adjust the scale for Ch 1 and 2 with the buttons **A** and **B**. The setting is shown at the bottom to the far left of the screen.
Select ”2V” resp. ”1V” (– implicit ”per div”).

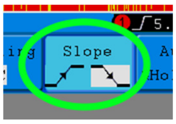


4 – Trigger setup

In group **D,** press the *Menu* button.

(This opens a range of choices for the **H** buttons.)

Press **H4** once to change the *Slope* from rising to falling.

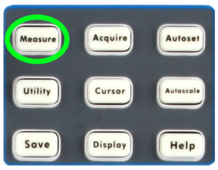


In group **D,** press the *50%* button.

5 – Measuring signal level

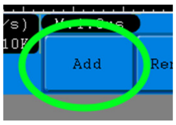
Group **N**: Press *Measure*.

(This opens a range of choices for the **H** buttons.)

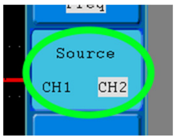


Group **H**: Press **H1** for *Add*.

(This opens a range of choices for the **F** buttons.)



Group **F**: Press **F2** once to measure at Ch 2.



Press **F1** for *Type*.

(This opens a menu at the left side of the screen.)

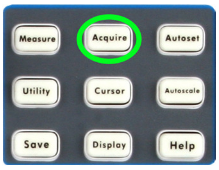
Use dial **M** to select menu item *Max* <u>and finish with **F4**</u> for *Add*.

Max. signal can now be read at the bottom of the screen to the far left.

6 – Averaging

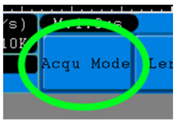
Group **N**: Press *Acquire*.

(This opens a range of choices for the **H** buttons.)



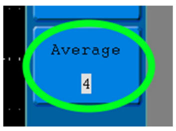
Group **H**: Press **H1,** *Acqu Mode*.

(This opens a range of choices for the **F** buttons.)

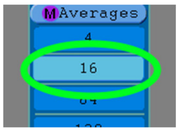


Group **F**: Press **F3** for *Average*.

(This opens a menu at the left side of the screen.)



Turn dial **M** to select menu item *16*



Turn off the menus with button **K.**

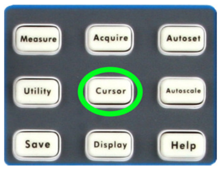
Now the oscilloscope is ready for setting the time base to 10 ns/div (button **C**) and to shift the zero point (button **G**) – as indicated on p. 2 in the lab manual.

Using the cursor functions

It can be convenient to mark the position of the pulses with vertical lines on the screen. At the same time, the oscilloscope automatically calculates their distance.

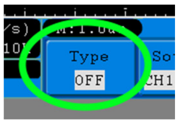
Group **N:** Press *Cursor.*

(This opens a range of choices for the **H** buttons.)

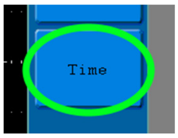


Group **H**: Press **H1** for *Type*.

(This opens a range of choices for the **F** buttons.)

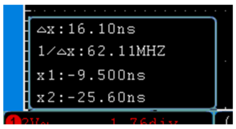


Group **F**: Press **F3** for *Time*.



Cursor positions are controlled by buttons **E** and **J**.

The positions and the distance between them are shown in a small frame on the screen.



Note: As long as *Cursor* is the last major function selected (button in group **N**), the **E** and **J** buttons control the cursors.

If you wish to use the buttons to shift the traces vertically, press e.g. *Measure* to reinstate their normal function.

Press *Cursor* again to control the cursors – no further action is needed when the above mentioned settings have been completed once.

Final remarks

The oscilloscope is one of the most universally applic-able electrical measuring instruments available.

The settings depend entirely on the given context and the setup procedure discussed above cannot be used in all sorts of other contexts.

Oscilloscope 400100 setup

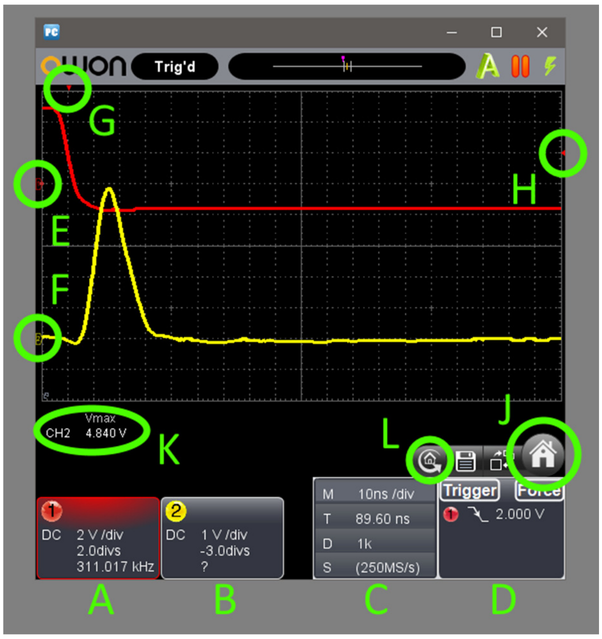
400100 PC oscilloscope, 2 channels, 60 MHz, USB – is an excellent instrument for the experiment “The Speed of Light”.

Below is a step by step guide of how the oscilloscope is prepared.

Note: It is assumed that software – including USB driver – has been installed correctly in advance.

The screen

Before the detailed walk-through, we present the most important features of the program window.



A and **B** shows the settings for Ch 1 and 2.

You can select the scale (x V/div) from a menu by clicking the text.

The line below the scale indicates the amount the traces has been shifted vertically. This is most easily adjusted by using the mouse to pull the red and yellow triangles **E** resp. **F**.

C covers settings for the time base. Primarily, we need to change the scale in the upper line. Click and select from the menu.

During the lab we will need to shift the zero point for the time axis – easiest done by pulling triangle **G** with the mouse.

D controls the *trigger*. The trigger defines the zero point of the axis relative to the incoming pulses.

The symbol to the left in frame **D** (start value ❶), indicates the *source* of the trigger – let it stay at Ch 1.

Next symbol allows you to select rising or falling edge – click to change.

The trigger *level* can be set by pulling the triangle **H** with the mouse.

Button **J** opens a detailed menu with several tabs – we look at some of those below.

The area **K** can be used for showing a range of measured values (we will need the max. value of Ch 2).

Button **L** brings the oscilloscope back to factory settings. It is not often used in daily work.

Setting up – step by step

Mount the cables as described in the lab manual. Turn on the “Speed of Light” box and the oscilloscope. Place the reflector immediately in front of the lens.

Start by clicking button **L** and confirm that you wish to reinstate the factory settings.

The menu window appears – if not, click button **J**.

First tab, *Trigger*

The first three lines should already be OK

Select *Falling* edge.

Tick the box *Auto set Trigger Level 50 %.*

Second tab, *Channel*

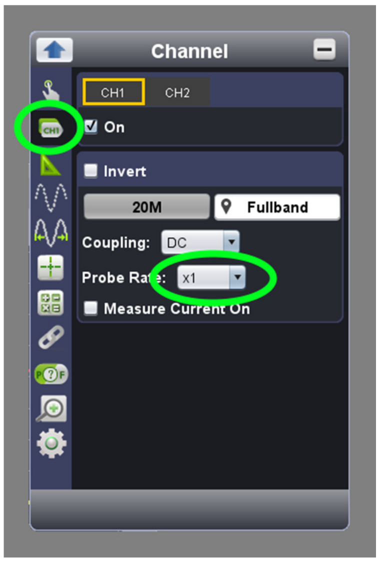
Set up *CH1* first

Again, the first three lines are OK.

Both *AC* and *DC Coupling* can be used.

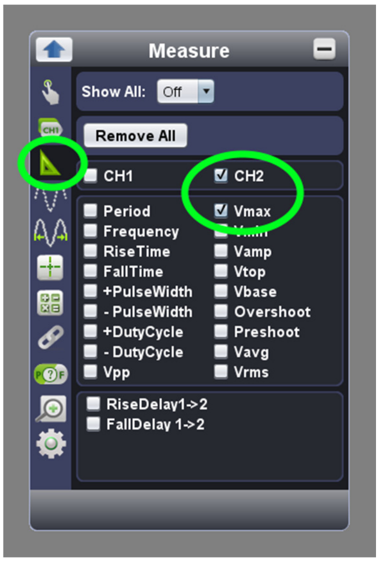
Probe Rate must be set to *x1*, as we don’t use probes but normal cables.

Change to *CH2* (in the topmost line) and repeat this procedure.



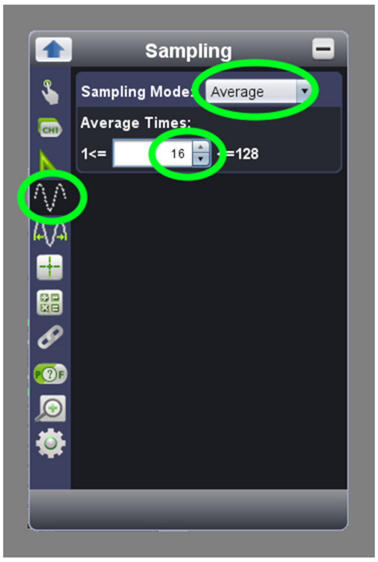
Third tab, *Measure*

We only need to measure the max. signal voltage at Ch 2.



Fourth tab, *Sampling*

Change *Sampling mode* to *Average* and select to average 8 to 16 traces.

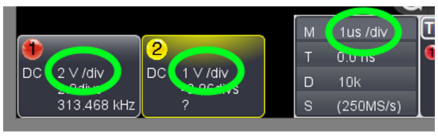


Main window

Change Ch 1 scale to *2 V/div* (upper line in frame **A)**.

Likewise for Ch 2: Select *1 V/div* (frame **B**).

Select the time scale: *1 us/div* (frame **C)**.



This should make the screen resemble the image on page 2 in the lab manual.

Using the cursor functions

It can be convenient to mark the position of the pulses with vertical lines on the screen. At the same time, the oscilloscope automatically calculates their distance.

The cursors are activated on the fifth tab of the menu, *Mark Cursor*.

Tick the *Time* box and two vertical white lines appear on the screen.

They are positioned by pulling them with the mouse.

Final remarks

The oscilloscope is one of the most universally applicable electrical measuring instruments available.

The settings depend entirely on the given context and the setup procedure discussed above cannot be used in all sorts of other contexts.