Speed of Light 201710

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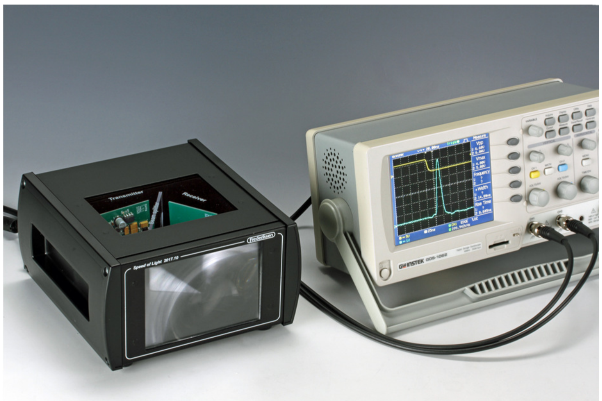
AE 201710



The speed of light in a vacuum *c* is a fundamental constant in physics. In fact so fundamental that it is *defined* in the International System of Units. The length 1 metre can therefore in principle be considered a derived, measured quantity. However, from a pedagogical point of view, it makes good sense to determine the speed of light based on a measured path length and the corresponding time.

Together with an oscilloscope, this device makes it possible to measure the time a short flash of light spends travelling a distance of a few metres. The experiment can thus be performed in a normal classroom.

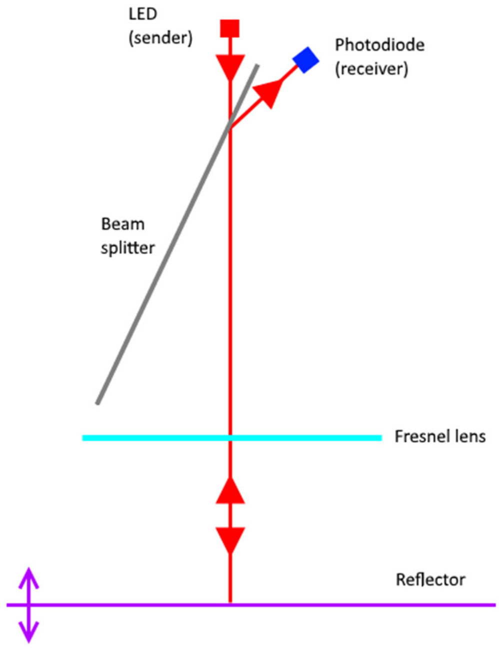
Additional equipment needed

This unit must be used with an oscilloscope. A digital oscilloscope is recommended – like our 400120.

A slower, analogue oscilloscope (like our 400040) can be used for lack of better. A separate guide for using 400040 with this equipment is found at our web site (look for 201710).

Principle

An LED emits very short (10-15 ns) flashes with a repetition frequency around 300 kHz. A Fresnel lens collects the light into a reasonably focused beam. The pulse of light hits a reflector which sends the flash directly back. The Fresnel lens now focuses the light at a photodiode that transforms the flash to an electric signal. As both the LED and the photodiode must be placed in the focal point, a beam splitter is inserted so the photodiode can be moved to the focal point's mirror image (see figure).



The electronic circuit that creates the flashes also transmits an electrical synchronization signal in the form of a sharp, negative slope that is suitable for triggering an oscilloscope. (On a slow oscilloscope, a positive slope is used instead. This occurs approx. 0.75 μs before the negative one.)

The signal received from the photodiode suffers a certain delay when passing through a number of amplifier stages. This delay is **constant** so by comparing the arrival times of two flashes that are reflected immediately in front of the lens resp. some metres away you can determine the time that the flash spends on its trip forwards and backwards.

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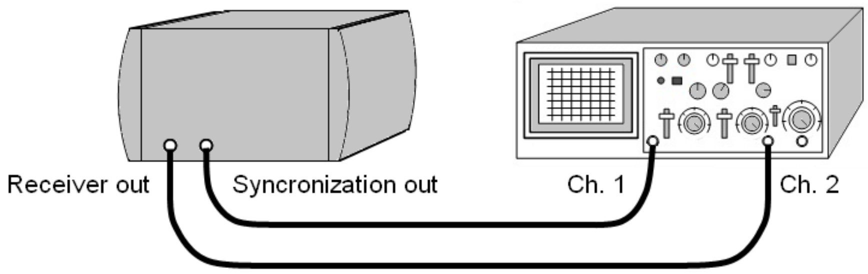


Performing the measurements

The box is powered by the 12 V adapter provided. Even though the individual flashes are rather intense, the average power of the emitted light is so low that it is in no way dangerous for the eyes.

Hook up the oscilloscope as shown using the included 50 Ω coax cables. Place the reflector immediately in front of the lens while adjusting the oscilloscope.

For a quick demonstration, the raw input signal can be used. For a more precise measurement it is recommended to let the digital oscilloscope display a mean value of several pulses. For the images in this manual, 32 measurements were averaged.

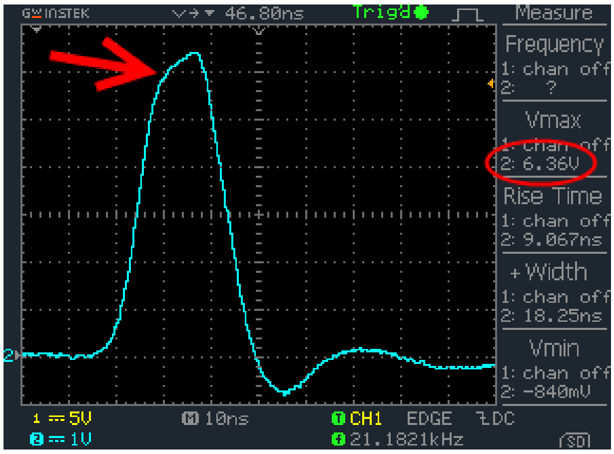
The following set of parameters is a reasonable starting point for the experiments:

Time axis:	10 to 25 ns/division
Ch. 1 (Sync.):	5 V/division
Ch. 2 (Rec.):	0.5 to 1 V/division
Trigger Source:	Ch 1
Trigger Type:	Edge, negative slope

Adjusting the trigger level is perhaps most conveniently done by trying to produce a stationary image of the synchronisation signal with the time axis set at 0.5 µs / division. When successful, the time scale can adjusted as wanted.

It is possible to reflect so much light back to the receiver that the circuit saturates, i.e. cuts the top of the signal. The equipment is not damaged by this, but precise measurements require that the receiver operates with pulses without distortion.

This is ensured when the **peak voltage is kept below 5 V** (4.5 V for a 20 MHz oscilloscope) – either found on the y axis or by directly reading the values given by the oscilloscope's measure functions.



The image above shows a distorted pulse caused by too high amplitude.

The signal strength is most easily adjusted by partly covering the reflector, e.g. by a piece of black cardboard.

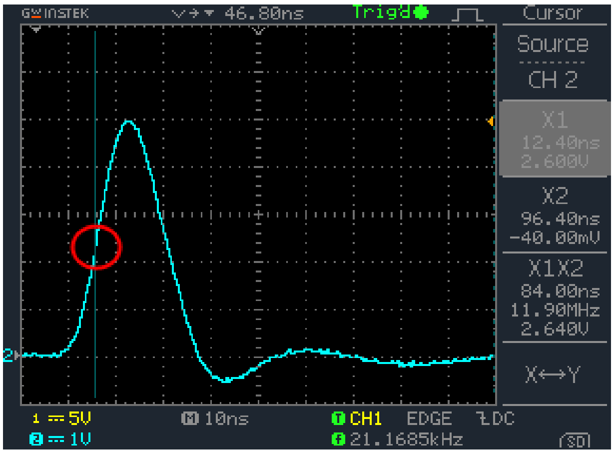
The position of the pulse on the time axis is defined as the instant the positive edge of the pulse crosses **half the peak value**.

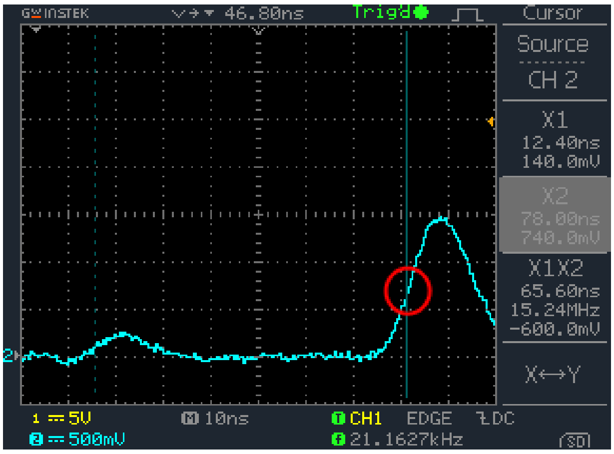
On an analog oscilloscope, this time must be read off the time axis. A digital oscilloscope usually offers a cursor function to help with this.

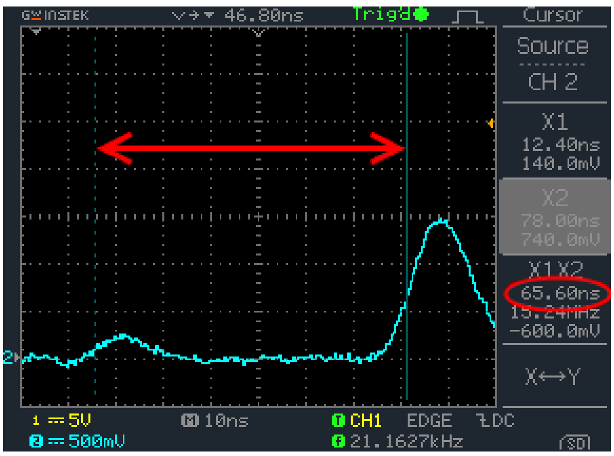
First, the time t_0 corresponding to the distance s = 0 m is determined: With the the reflector immediately in front of the lens and the intensity adjusted as mentioned, the position of the reflected pulse is determined.
From this moment, the time axis must not be changed.

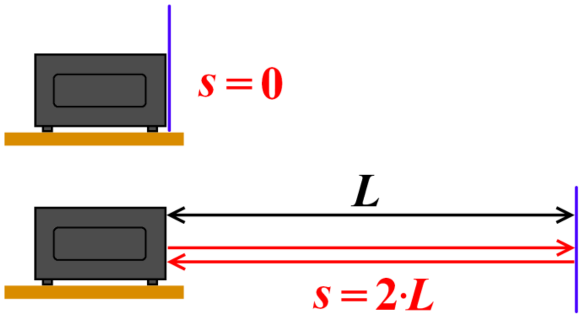
Now, one or more measurements are made with the reflector further away from the box (up to 10 m). The best way to tell if you hit the reflector is by having your eye a few centimetres over the top of the box.

Measure the distance *L* between the front of the box and the reflector as precise as possible.









For each position, determine the arrival times of the reflected flashes.

Each time measurement must now be converted into the **time of flight** of the flash by subtracting t_0 – thus bringing the time 0 to correspond to the distance 0. Again, the cursor tool can make your life easier as can be seen on the screen shots to the left.

Data processing

Each distance measurement is converted into **distance travelled** by multiplying by 2,

Plot the distance travelled as a function of the time of flight and determine the speed of light in atmospheric air by means of the graph.

The index of refraction of air at room temperature is approx. 1.00028. Hence, *c* (the speed of light in vacuum) can be calculated and compared with the table value.

Estimate the size of the experimental uncertainty of the measured value of the speed of light and consider whether it is relevant in this context to distinguish between the velocities in air and in vacuum.