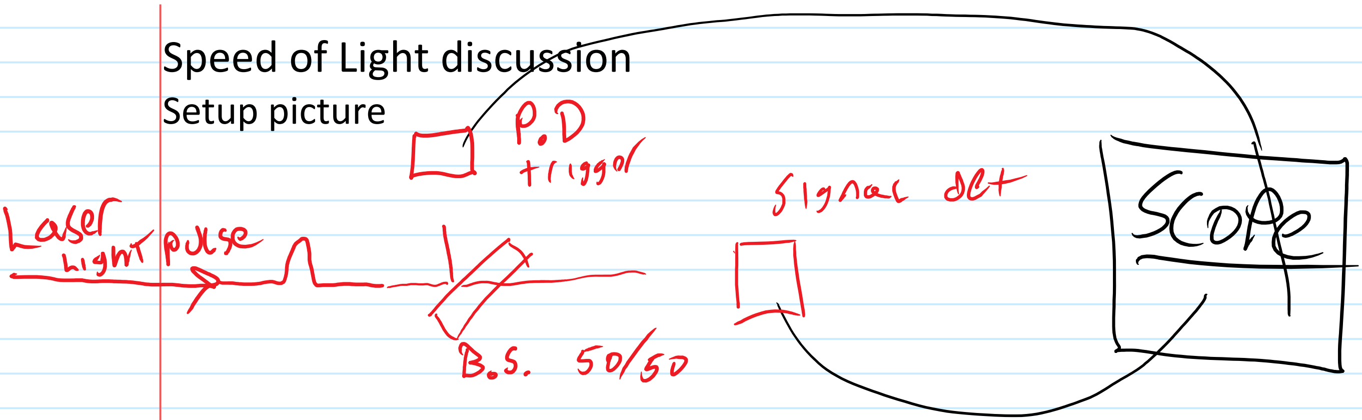
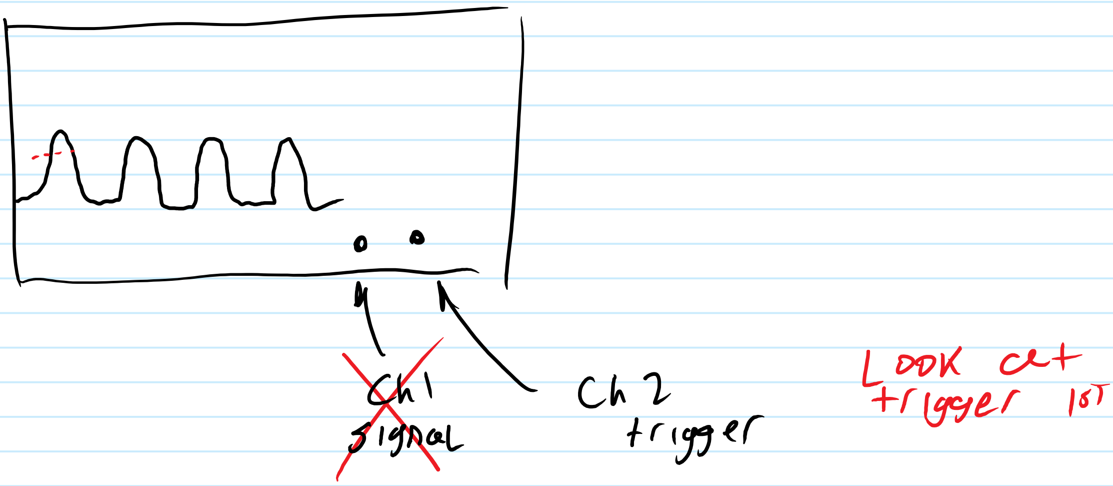
Speed of Light discussion

Setup picture



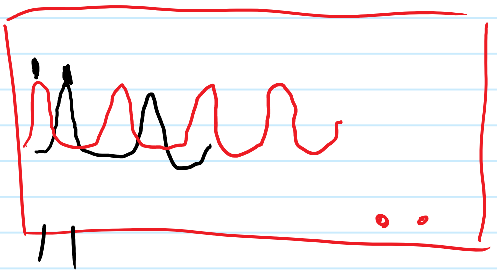
why does the Continuous Wave Laser make pulses that are about 1.00ns wide and 3.00ns apart---roughly (you measure)---NO REALLY---YOU MEASURE. ? Discuss why later---THIS IS NOT A PULSED LASER---(BUT IT MAKES PULSES).



When the trigger signal reaches a level we set (voltage) then this tells the oscilloscope "start" acquiring data. We set it to acquire for 20.0ns----keep and hold, wait till ready (could be microseconds later) ----then take next pulse that triggers. If the signal is identical, it will overlay. If not---we see jitter and noise on entire pattern. So we average 512 pulses, and it really cleans up. WE THEN NEVER MOVE TRIGGER PHOTODIODE---.

The signal hits a different detector, and the same pulse gets to the scope at a different time, down a different cable, ...so what. There is a fixed time difference.

When we switch to the "Signal" photo-diode detector---we get a pattern that may look nearly the same---different amplitude, peaks may start at slightly different TIME on the oscilloscope (V vs t) screen. BUT



Δt = delay due to moving signal detector on the table!

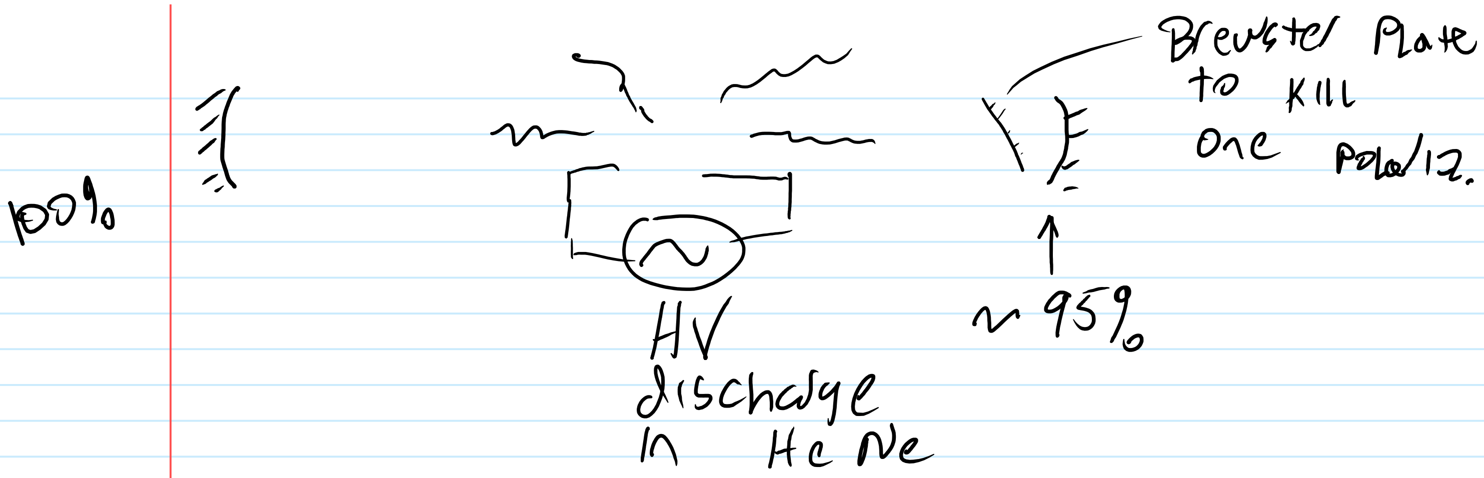
We are going to move the signal detector, which delays the pulses in time from reaching the detector.

That is the experiment. We move Δx and measure Δt. We will do this for many positions, but we have the speed of light now.

To do this we need to get many things correct.
Fast oscilloscope, fast detector, and fast transient (those pulses).

Fast averaging oscilloscopes are $$$ but doable. Fast detectors, also can do. We need to set things up properly (carefully). But where do those pulses come from?

The answer---~25 years ago, I got lucky. I was trying other ways to modulate (introduce a transient in the laser light). It was difficult--since fast pulsing of LED's was not a common thing back then. I used....other....but found that the laser itself made pulses that were just right.



The laser cavity tube length is about 0.486meters for the 1135p laser (you look it up). The wavelength of the laser is set by an energy transition in the HeNe gas--- 632.8 nm.

The frequency is f=4.74E14 Hz.

Just like standing waves on a string, the longitudinal modes are set by

$$f_n = n \frac{c}{2L}$$

$$n = 1.536 \times 10^6$$

And c/2L=308.6MHz (the mode spacing)---we don't round as much as the manufacturer).

OK--so what makes pulses?

The LASER actually (for a long tube with close mode spacing) is able to "lase" on modes n+1, n+2, n-1, n-2, etc.....several modes can lase at once.

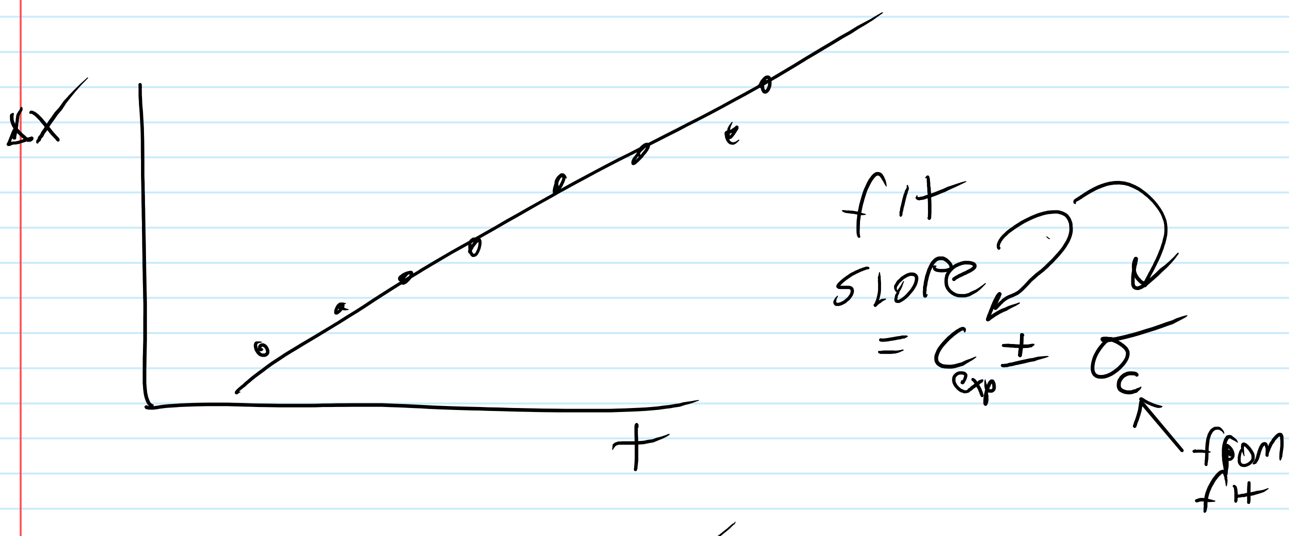
As we saw in Modern with different frequencies--when we have any two frequencies, a beat forms. The beat frequency is the difference. So we get pulses formed by the beating of several modes. The beat frequency is the mode spacing-----and 1/308.6MHz=3.24 ns.

Again---you will run these numbers more precisely, and you will measure the time between peaks to determine the mode spacing and see how things compare.

There are some slight deviations from the longitudinal mode frequencies that we get---due to coupling with transverse modes (geometry stuff). It is small, but remember that in optics the best precisions reached to date are measurements down to about 1 part in 10^{23}……..with the right funding and equipment (some know how helps too).

The key to our accidental fortune is the accidental mode mixing. We have enough modes mixing to always see the fundamental mode dominate the spectra (making those pulses equally spaced). We do see some drift and change in pattern since the laser gain curve moves (thermally). The key is having a long enough laser cavity to encompass many modes! Which we do. Got lucky!!!!

You have a sample set of data in HW to analyze as an exercise in uncertainty analysis.



Now find a rough experimental uncertainty by considering max and min slope using endpoints only.

Then reduce by $1/\sqrt{N}$

That second method gives a rough way to bring in the estimated experimental uncertainty in your measurements. Then to reduce uncertainty since we have N measurements. This is realistic and reasonable.

You will compare the uncertainty to the one found using the fitting routine of your choosing (I use ORIGIN).   The linear fit uses only statistics to determine uncertainty.

If you have no systematic effects to deal with, then the two methods should agree reasonably well (factor of 2 or so). That agreement depends on making a good estimate of the experimental measurement uncertainties in position and time.

Note--we can always do extensive testing of our measurements of positions and times (thousands of them) to beat back the statistics and get real standard deviations of measured quantities (uncertainties).