Solid Condensed Matter
Lab Report

Light Emitting Diode
"White light"

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25-06-2008

Inhoudsopgaven
(Nederlands, de rest volgt in het engels)

Today LEDs or Light Emitting Diodes are one of the most favorite sorts of light sources. In spite of the fact that these are slightly more expensive than a light bulb, they are less expensive to use. With a very low current they can give relatively high light intensity. Since the every day increasing energy price is becoming a critical issue, the market is dying for a good replacement for the light bulb. LEDs are already used as bicycle lights, but more is needed. It would be ideal if we can replace all our lamps in our houses and on the streets. Since very few people would enjoy diner under red light, a white has to be developed. White light can be made just by merging colours like paint. If you merge the three primary colour LEDs RGB (Red, Blue, Green), you should get white light. Somehow it seems to be not that simple. If you bring the LEDs together the colour will slightly change. Why is this?

If you shine light on a semi-conductor (which LEDs are) some electrons will be excited to a higher energy state and, then fall again while emitting a photon. In other words; if you bring light on to a LED it will emit light without the help of an external current. So if you bring those three LEDs together, the light of each other will enhance the intensity and will corrupt the original intensity ratio.

If we study this enhancement phenomenon we see something unexpected. The intensity of a LED, turned on with a power source ánd with a laser shining on it, is higher than the sum of these two separate (figure 1). This worth while to investigate further.

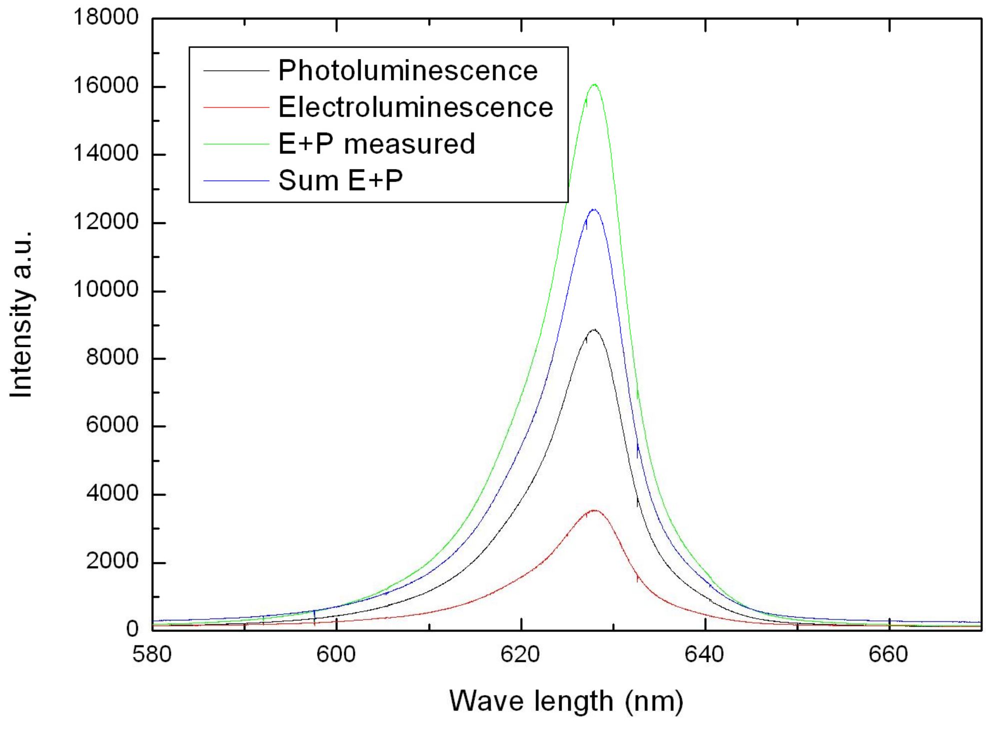
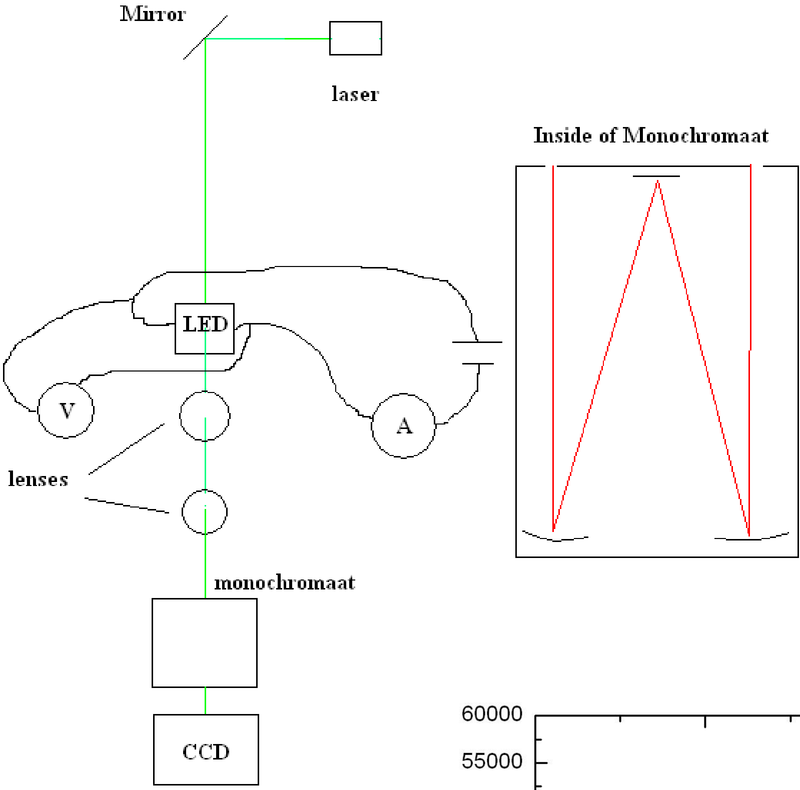


Figure 1: Intensity measured[1] for photo luminescence (black) and electro luminescence (red). Blue is what we expect to see (just the sum of E+P) but we measure a significant higher intensity (green).

[1] We measure the intensity (arbitrary units) with a CCD camera, under standard room temperature and pressure. This is for all our measurements unless otherwise is said.

Materiaal en methode
This is the “opstelling” we’re going to use for our experiment. Sometimes a few changes are made, but if we do, we’ll try not to withhold that information for you.
A laser beam is directed on to the LED, with the help of a few mirrors. This LED is also connected to a power source and an Ampère and Voltmeter. The Light Emitted by the Diode will be focused by two lenses and send via a monochromaat into the CCD camera. At the entrance slit, a filter is set to block the laser, so only the light of the diode is beamed into the monochrometer. See figure 2. We perform our experiments with a red LED, that’s why the wavelength of the light in figure 1 is around 630 nanometres. The settings of our measurement equipment can be found in Appendix 1.



Electroluminescence
The first thing we’re going to investigate is how the applied current is related to the intensity. So we don’t have photoluminescence (PL), but only electroluminescence (EL) for now (laser is turned off). This can be seen in figure 3a(below).

Figure 2: Our measurement equipment. Inside the monochromaat, the light will be separated in different wavelengths.

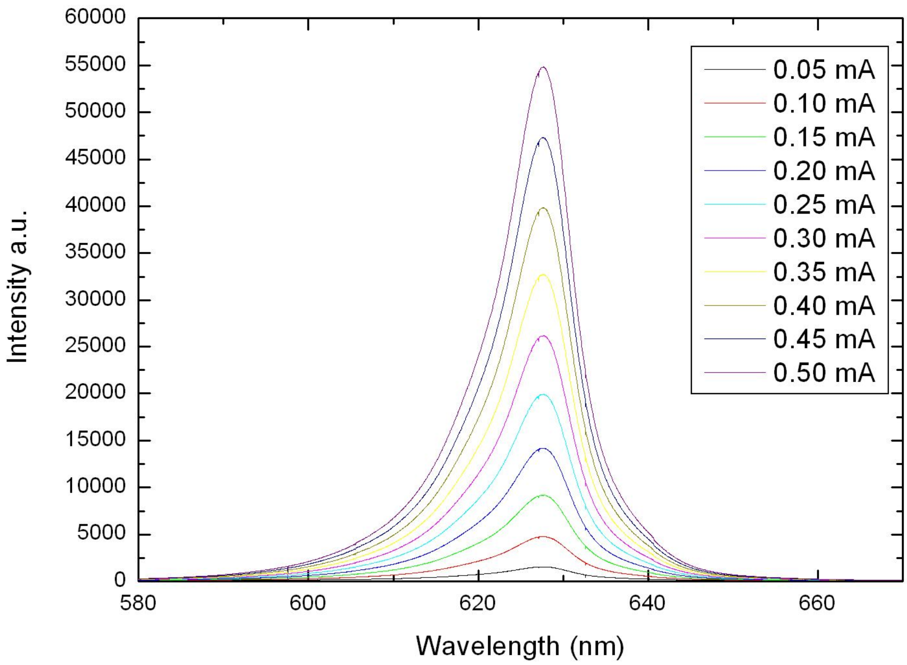


Figure 3a: Measurement of the intensity at different levels of current.

Our assumption is that the intensity increases equally with the current. So let's make a plot to ensure that (figure 3b).

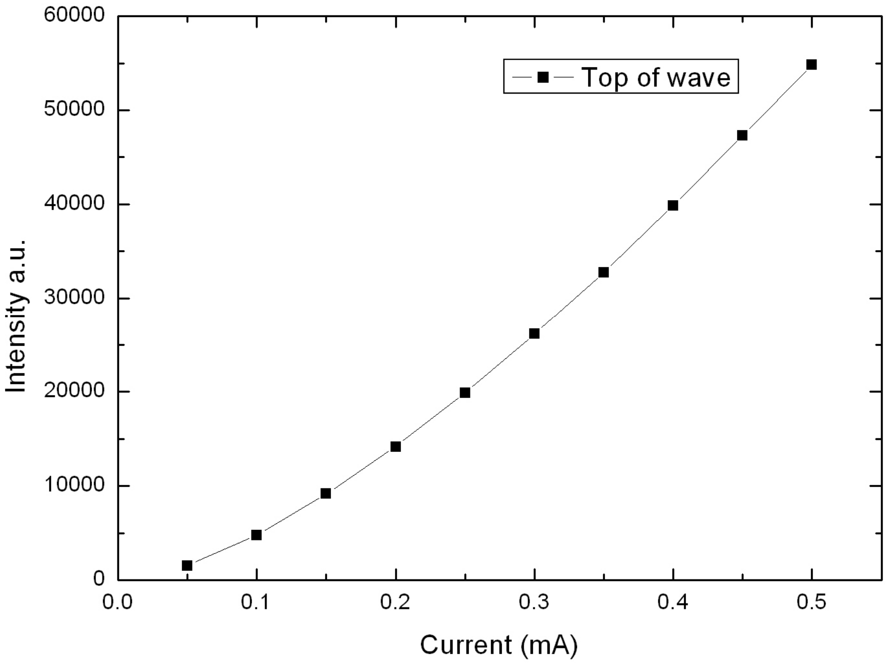
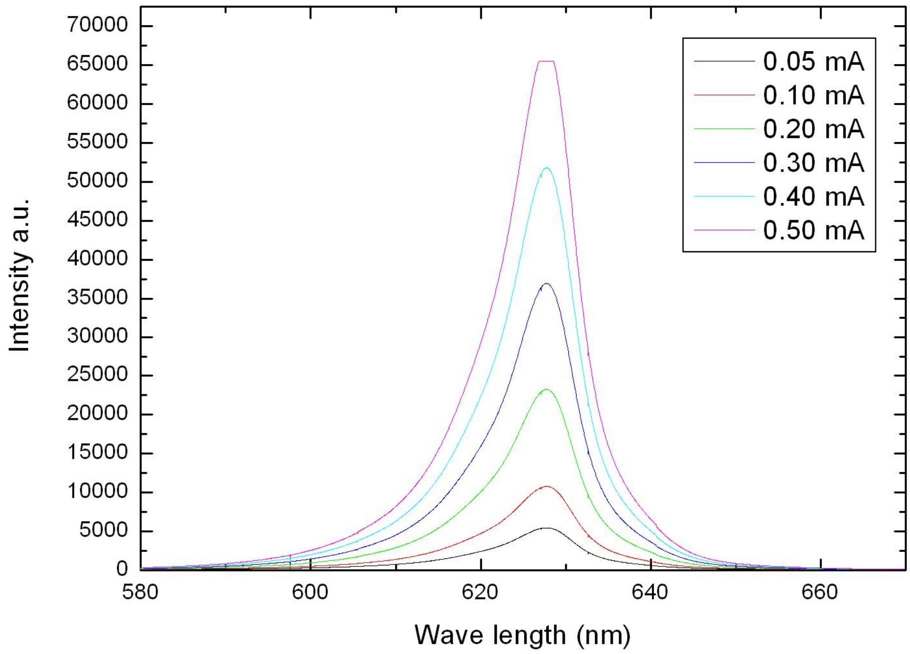


Figure 3b: Intensity plotted with respect to the current.

As we can see this picture does not really satisfy our assumption. Now two things are possible. Either our measurement is slightly corrupted at low currents, and the reason for this curved line is due the lack of more precise data, or it really is a wide hyperbolic function. We can only know for sure if we do much more measurements, but that is not necessary for now. Since we want to figure out the effect of electroluminescence combined with photoluminescence – which also takes place at high currents, where the function is more linear – this data is sufficient. Let's make a short recap. If a higher current is applied, there are more electrons in the conduction band which means there is a higher probability for an electron to combine with a hole. This leads to a higher intensity just as we can see in figure 3b.

Electroluminescence plus Photoluminescence

Now we have seen that single electroluminescence acts the way we think it does, we will apply a laser. The laser is set at power of 200mW. This is not the real power beamed on to the LED, because there're polarisation filters in place to reduce power. This is because a direct hit with the laser will make the LED emit light too intense for our CCD camera, which will give an overloaded signal. Figure 4a is our measurement and figure 4b again the intensity with respect to the applied current. However this time we didn't take the top intensity but the integral over the whole spectrum. We expect it to be a more reliable plot this time. (We regret that we didn't do it the first time (figure 3b), but we simply didn't know how to do it.)



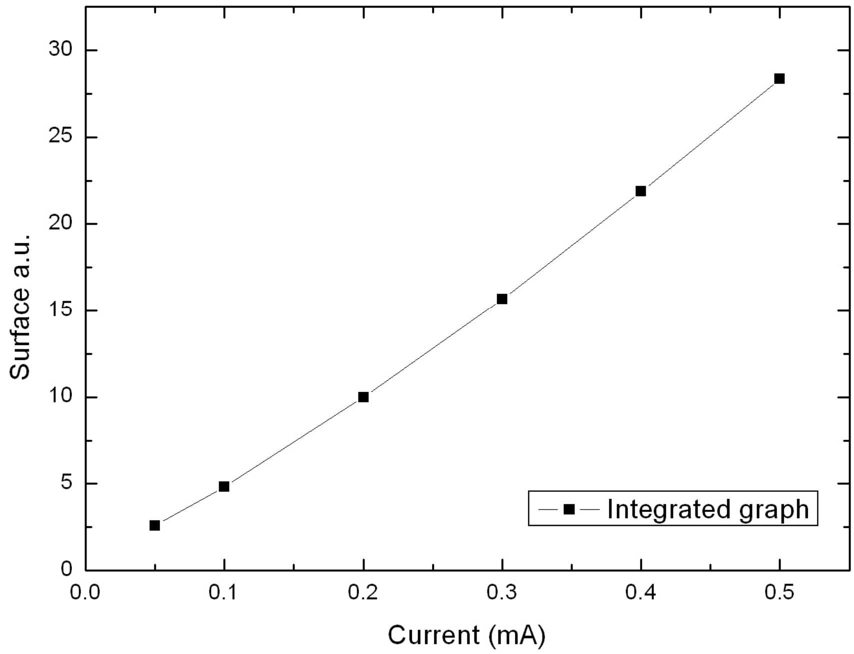


Figure 4a: Measured light spectrum with both EL and PL. At 0.50 mA the curve shows a flat top. This means that intensity is too high and the CCD is overloaded. Figure 4b: The sum of the spectrum's surface. Intensity is more or less linear with the current, just like we saw in figure 3b, but this time with laser on.

What can we see in those figures? It seems that if EL and PL are combined the EL part acts just the way it would if no laser is applied. In this stadium we can conclude that the applied current has nothing to do with the enhancement phenomenon. But let's not rush, because there definitely is something extraordinary about the current.

Probably I've to describe first how we performed our last measurement. We did this by applying a voltage so the current is at the level we want (0.05, 0.1, 0.2 etc.). These are the currents we showed in the figure. But after we applied the laser, the current drops slightly. So the current we measure while taking the spectrum is lower than we suggest in the figure. How does this happen? I'm afraid we can't tell you just yet. However, what we can do is tell a bit more about the effect. It seems that the higher the current is, the less it drops with a laser applied. We can see this in figure 5.

Applied current	Measured current
0,05	0,019
0,1	0,081
0,2	0,189
0,3	0,292
0,4	0,395
0,5	0,496

Figure 5a.

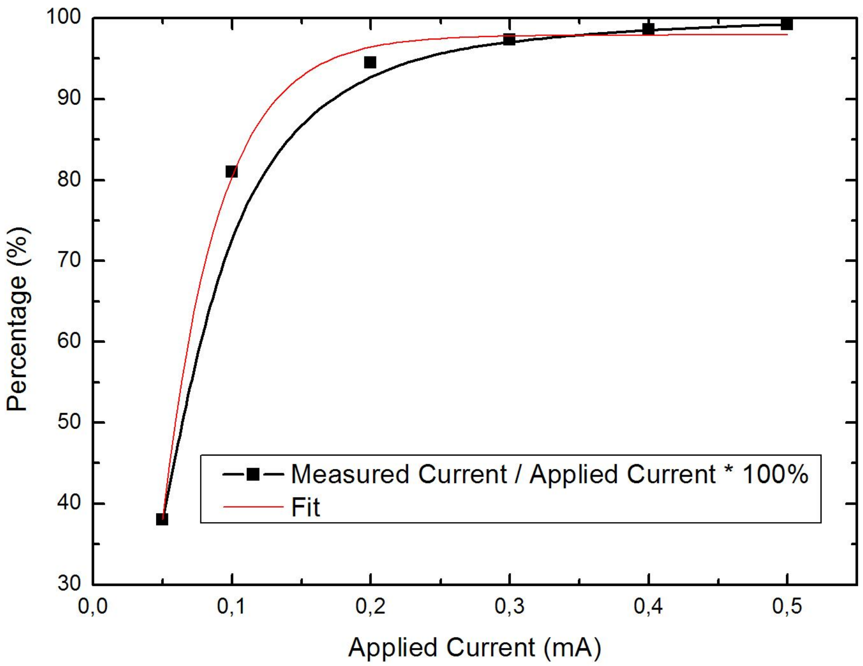


Figure 5b.

Figure 5a: This table shows us the applied current (mA) before the laser is applied and the measured current (mA) with the laser on. Figure 5b: The relative amount the current drops is much higher at low currents. At a current of 0.05 mA the measured current is below 40%, while at 0.5 mA it's almost 100%.

It seems figure 5b is hyperbolic function with an asymptote at 100%. Not totally unexpected since it would be puzzling if the current first reduces with a laser and at a sudden point it would increase. Of course we have to be broad and open minded as scientists but I think this is safe to say this was to be expected. This effect is in my opinion not even that strange. If we just get out our dark lab with scattering lasers all around you get some fresh air and think straight. If a higher current is applied there mostly is a higher voltage. This produces warmth which results in a semi-conductor in a lower resistivity due the Fermi-Dirac distribution. So if we have higher current, it's easier for the electrons to drift. Maybe this is a circular argument, so I'll just move on.

The current of Photoluminescence

Now it's time to look to the effects of single photoluminescence. So no external voltage is applied. We just saw that the current acts strange if a laser is turned on, so let's take a look at the current when we use photoluminescence. If we turn on the laser we see the current is in the opposite direction of the applied current. This might be an explanation why the external current is reduced after laser is turned on. Figure 6 shows us the backward current potted with respect to the laser power. Maybe I've to remind you that the laser power is arbitrary, because of the polarisation filters.

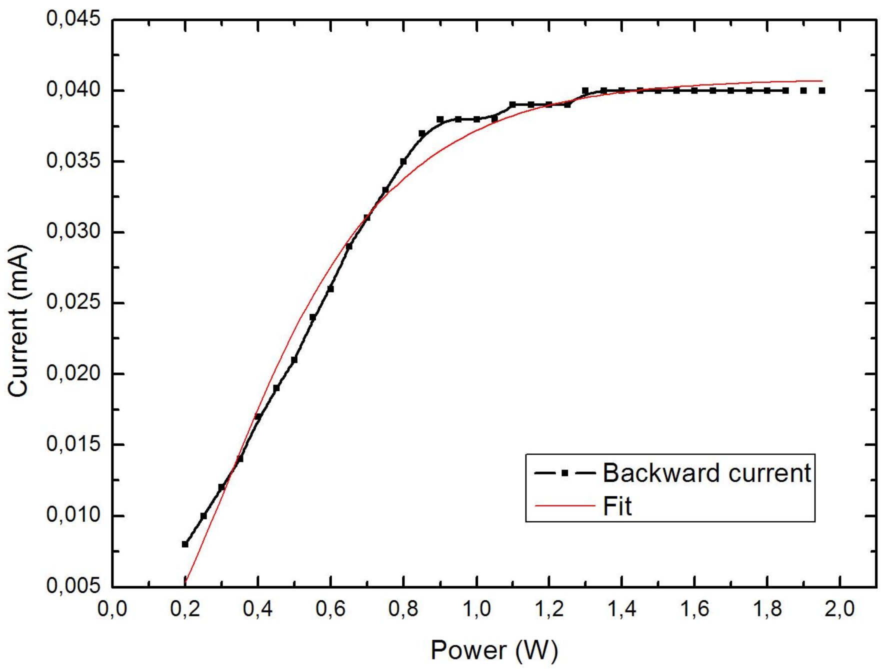


Figure 6: Diagram of current with respect to the laser power (arbitrary). The fit is a hyperbolic function with an asymptote around 0.04 mA.

Again our data seems to be a hyperbolic function. This is quite interesting, because there is no obvious reason why this occurs. Our theory is as follows: The current exists because of the electrons which get excited by the light to the conduction band. If you shine more light on de diode, more electrons will excite, but at the same time more holes will be available for recombining. At a certain point the force of the holes attracting the excitons will somehow be equal to the force produced by the energy of the light to get the electrons in a higher energy level. It might be better to say, that at that point the probability to excite electrons is equal to the probability to combine with a hole. If this is a correct thought, it would explain the behaviour of the curve.

What have we found?

What did we see those three days in the lab playing with light?

- In the first place we found the enhancement phenomenon (figure 1). This is fact the reason for our research. So what we saw is that the intensity of the LED produced by Electroluminescence and Photoluminescence is substantial larger than the sum of these two, measured one at a time.
- Secondly we found that the intensity increases equally to the current. With single EL but with EL and PL as well.
- If we look to the current, it changes when we turn the laser on. It seems that the effect is less at larger currents.
- If we only use the laser, there seems to be a backward current. This does not increase equally to the power of the laser, but looks like a hyperbolic function with an asymptote around 0.04 mA.

What can be done?

Our time in the lab has exceeded, but if we had the time there are a few more things we would like to see. We think it might be interesting to study the effects of the voltage when applying different levels of the laser. Maybe then you can say something about the resistivity. The monitoring of the temperature of the sample can also play its part.
What I really would love to do is to connect the current effects to the intensity. Okay, we have seen that the intensity increases equally to the current. But did not see how the hyperbolic increase of backward current produced by the laser takes effect on the intensity. That would be the next step to investigate the enhancement phenomenon. Eventually all those experiments should be done with different colours of laser and different colours of LEDs.

Conclusion
What we want to know eventually is how, what we call the enhancement phenomenon, works. We have to disappoint you, because we don't know it yet. A few speculations are already said in this report and I'll recapitulate it into one short hypothesis:

"For our first hypothesis we take a look at the Fermi-Dirac Distribution. When we shine both the laser on the LED and run a current through it, the LED should be warmer then when you do those separately. Because of this more electrons will be kicked to a higher energy level. This means that an electron will fall into a hole more often. Because of this more photons will be emitted."

A second hypothesis, a very farfetched but creative one is:

"If you drink two beer in a short time, your body takes more time to get rid of the alcohol then if you drink first one beer until the alcohol is processed and then take a second one (figure 7). Maybe we can apply this somehow to our case. A few modifications has to be made to the theory ☺."

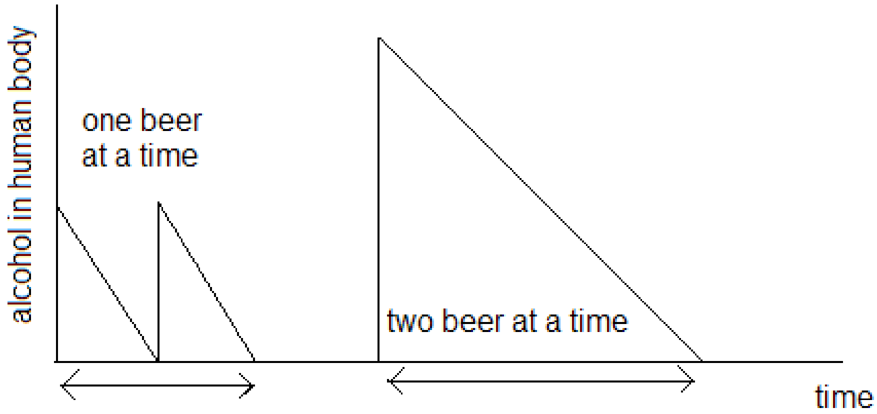


Figure 7: The Δt of two beers separate is smaller than the Δt of two beers at a time.

Thanks to:
We willen graag in het bijzonder de volgende mensen bedanken:
Onze lab begeleider die ons geholpen heeft met de experimenten, onze leraren Gecondenseerde Materie, en Turton.

Further readings:
The Physics of Solids – Richard Turton
Information about LEDs at open source Wikipedia.

Appendix 1

Instellingen Meetapparatuur

Spectrum:	570 – 670 nm
Slit opening:	0.05 mm
Integration time:	0.2 s
Accumulation:	15 times
Grating nr:	1
Position CCD:	628 nm

Intstellingen LASER en LED

Tenzij anders aangegeven

Laser power:	200 mW
Aangebracht voltage:	1.6V