Graphene Spintronics
Transporting spins within graphene

Monster Puzzle
The ultimate puzzle challenge

Meet the New Board
Read about the next Francken board

# Francken Vrij

## Crystal

20.3 Crystal

# Colophon


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## Editorial

**For twenty years** now this magazine has been published three times each year. Because this is an anniversary edition we have some special articles. You can read an interview with the first editor in chief ever and the middle of this Francken Vrij is a tribute to all editions before this one. This edition, however, will be my last edition as editor in chief. Evelien will take over this position next year and I am sure she will do a very good job (doing mostly stuff she does now anyway). Have fun reading everyone! (Oh, and the 10 beers of last editorial were gone before the Francken Vrij was sent, you proved me wrong)


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# Edition 20.3

# Chairman's Preface

By Jelle Bor

**While writing my** last chairman's preface I sadly noticed that it's the first time in history the theme of the Francken Vrij is 'Crystal', which I find remarkable since it's directly related to the logo of our association. Therefore, I have the honour to give you a beautiful story about crystallography.

Firstly, for those of you who don't already know, a crystal is a solid material arranged in a highly ordered structure. This by itself directly led me to some aspects of T.F.V. 'Professor Francken'. We are a structured community and we're very solid in a figurative sense. We are creating the bonds that bind the students with the overall structure of the Physics part of the university and beyond. Besides this, Materials Science is highly related to Applied Physics and so our logo covers our interests too.

But when we take an even better look, we find a certain structure, namely the so-called face-centred cubic (FCC) structure, which every full-fledged member should know very well (if you didn't, you know now). In my opinion FCC looks like a box, because there is no atom in the centre of the cubic structure, but they're all on the sides like a die. This reflects our creativity and way of thinking which is, so to say, out of the box. Besides this it's a fact that FCC is the most efficient way of packing and it's a good reflection of our way of acting and getting things done, namely in a smart and strategic way.

This may seem as a lot of glorification, but as the president of an association it's one of my jobs; to make up a good story from scratch. Still, I meant every word of it and I really love this association. I've had a great year and I know I can also speak for the rest of my board. I hope that not only the next board, but all the future boards will share the same feeling of pride. Have fun reading this very good magazine!

# News of the Association

**Before my successor will take over my position as secretary, I'll write one final News of the Association. It has been an amazing year with so many epic moments and activities. Luckily, there are still some (although few) left. Below, you can read about some of these moments and what Francken has been up to since the last Francken Vrij.**

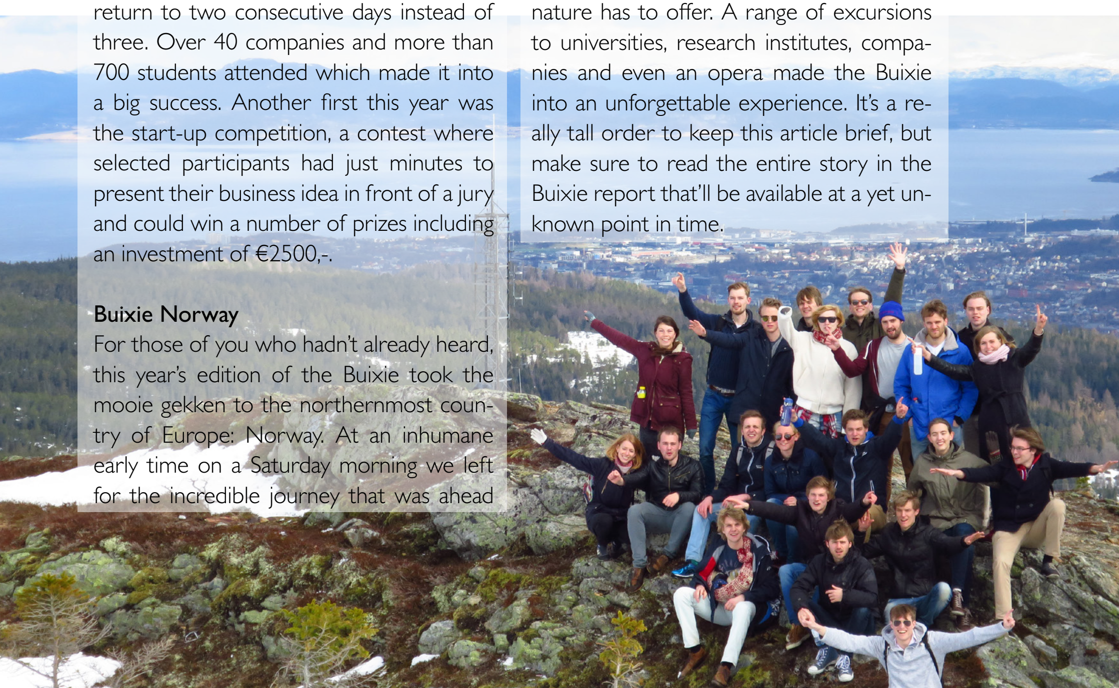
By Max Kamperman

### Beta Business Days

The 2016 edition of the Beta Business Days was the first to be held in Martini Plaza. The increase in area meant that the event would return to two consecutive days instead of three. Over 40 companies and more than 700 students attended which made it into a big success. Another first this year was the start-up competition, a contest where selected participants had just minutes to present their business idea in front of a jury and could win a number of prizes including an investment of €2500,-.

### Buixie Norway

For those of you who hadn't already heard, this year's edition of the Buixie took the mooie gekken to the northernmost country of Europe: Norway. At an inhumane early time on a Saturday morning we left for the incredible journey that was ahead of us. After having spent the first couple of days in Oslo we drove further north to Trondheim, where the amazing roads showed us the extreme beauty Norway's nature has to offer. A range of excursions to universities, research institutes, companies and even an opera made the Buixie into an unforgettable experience. It's a really tall order to keep this article brief, but make sure to read the entire story in the Buixie report that'll be available at a yet unknown point in time.



## ASML excursion

A busload of (Applied) Physics students travelled all the way from Groningen to Veldhoven to visit the inhouse day of ASML for all Physicists in the Netherlands. ASML, being a major player in our field, attracted a lot of interest and had 100 participants. Presentations and a tour showed what it's like to work at ASML and what you can expect to be doing if you're interested in a future there. The afternoon brought a case and final remarks after which drinks closed the day.

## Koningsborrel

This borrel quickly became a success as the Francken room soon became overcrowded. Orange shirts, hats, a suit and numerous accessories accompanied by classic Dutch hit songs and of course the *Wilhelmus* started the celebration of our king's birthday, which would be on the following day. The great atmosphere lasted all night as most left for the city centre to continue partying there.

## Hitchhiking Competition

All participants gathered on Friday April 29 in the centre hall of the train station with high spirits and good faith for the upcoming competition. Firstly the committee revealed the first stop would be just before Hamburg and after arriving there the participants would hear the final destination (Flensburg). It soon became clear that luck wasn't on our side as rain started to pour and the wind froze our hands in a thumbs-up position. After many hours, sometimes with help of public transport and the committee's car, everyone arrived safe and sound. The second day was passed in Hamburg from where we returned to Groningen on Sunday.

## Nedap excursion

On Tuesday May 3 we received a warm welcome in Groenlo for the first ever excursion to Nedap. We started with a presentation and grand tour of the company to introduce us to the research and development of their different business units. After enjoying the lunch, the program continued with a case provided by none other than Francken members Hilbert Dijkstra and Jasper Compaijen. The case, affiliated to the Retail department, allowed us to work with actual Radio Frequency Identification (RFID) gates created by Nedap. Before driving all the way home, the day was closed with some drinks.

# Twenty years ago

## The first *Francken Vrij*

By Emiel Havinga

**In the fall** of 1996, when I, Jasper, was still a cute baby and beer was bought with guldens the so-called *nul-nummer* of the *Francken Vrij* was published. With the current edition we have had twenty years of *Francken Vrij* and I hope we will go on for at least twetny more. Emiel Havinga was the first editor-in-chief of the *Francken Vrij* and for that reason I asked him some questions and he happily answered them. If you ever wondered about the production process of the first *Francken Vrij* or what being a *Francken Vrij* member does with your life, continue reading!

**How did the idea for the first *Francken Vrij* come up? Was it hard to start creating the first edition?**

If memory serves me well, the board at the time came up with the idea for a magazine and approached me with the question if I was interested in kick-starting that project. Since I was becoming more aware of the merits of extracurricular activities on my resume, I answered affirmatively and got to work right away. In close consultation with the board we decided that we wanted to approach this in a very professional and ambitious way, also with our envisaged advertisers in mind. One of the hard goals was to have part of the magazine in full color (probably since the board already pitched that to potential advertisers. At the time, color printers were just entering mainstream, but still rare to come by and certainly not fit for the large edition we had in mind. The other difficulty was in the desktop publishing software. We could certainly not afford a professional software package, and so everything was done in Wordperfect (the first version that supported Windows). Getting all the pages to print on A4 in the right order for an A5 booklet meant that I had to layout all individual half-pages on the floor in the Francken room (interfering with others quietly drinking their beers) and then retrofit the page order in Wordperfect. Next up: finding a printer who could handle color printing on laminated paper, mixed format content (our advertisers did use professional software for their ads), an unachievable deadline and which was still affordable. This proved to be a challenge. But somewhere in the outskirts of Groningen I found one, and to this date I'm still very satisfied with the end result.

**Was it hard to find the first committee for the first *Francken Vrij*?**

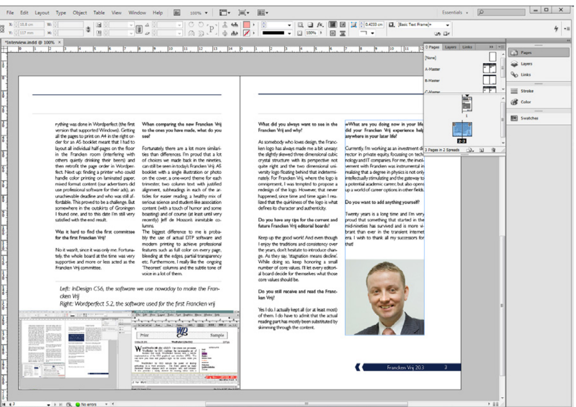
No, it wasn't, since it was only me. Fortunately, the whole board at the time was very supportive and more or less acted as the *Francken Vrij* committee.

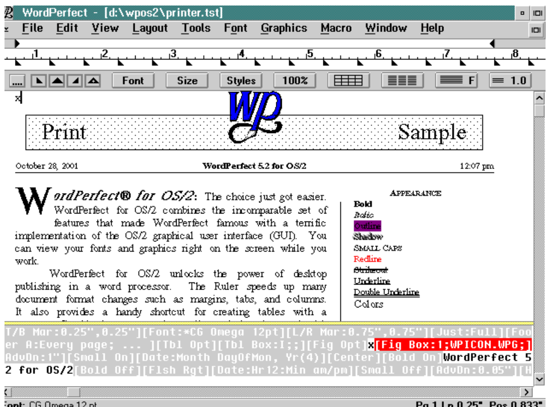
**When comparing the new *Francken Vrij* to the ones you have made, what do you see?**

Fortunately, there are a lot more similarities than differences. I'm proud that a lot of choices we made back in the nineties, can still be seen in today's *Francken Vrij*: A5 booklet with a single illustration or photo on the cover, a one-word theme for each trimester, two column text with justified alignment, subheadings in each of the articles for easier reading, a healthy mix of serious science and student-like association content (with a touch of humor and some boasting) and of course (at least until very recently) Jeff de Hosson's inimitable columns.

The biggest difference to me is probably the use of actual DTP software and modern printing to achieve professional features such as full color on every page, bleeding at the edges, partial transparency etc. Furthermore, I really like the ongoing 'Theoreet' columns and the subtle tone of voice in a lot of them.

*Left: InDesign CS6, the software we use nowaday to make the Francken Vrij*
*Right: Wordperfect 5.2, the software used for the first Francken vrij*





**What did you always want to see in the *Francken Vrij* and why?**

As somebody who loves design, the Francken logo has always made me a bit uneasy: the slightly skewed three dimensional cubic crystal structure with its perspective not quite right and the two dimensional university logo floating behind that indeterminately. For *Francken Vrij*, where the logo is omnipresent, I was tempted to propose a redesign of the logo. However, that never happened, since time and time again I realized that the quirkiness of the logo is what defines its character and authenticity.

**Do you have any tips for the current and future *Francken Vrij* editorial boards?**

Keep up the good work! And even though I enjoy the traditions and consistency over the years, don't hesitate to introduce change. As they say, 'stagnation means decline'. While doing so, keep honoring a small number of core values. I'll let every editorial board decide for themselves what those core values should be.

**Do you still receive and read the *Francken Vrij*?**

Yes I do. I actually kept all (or at least most) of them. I do have to admit that the actual reading part has mostly been substituted by skimming through the content.

**What are you doing now in your life, did your *Francken Vrij* experience help anywhere in your later life?**

Currently, I'm working as an investment director in private equity, focusing on technology and IT companies. For me, the involvement with Francken was instrumental in realizing that a degree in physics is not only intellectually stimulating and the gateway to a potential academic career, but also opens up a world of career options in other fields.

**Do you want to add anything yourself?**

Twenty years is a long time and I'm very proud that something that started in the mid-nineties has survived and is more vibrant than ever in the transient internet era. I wish to thank all my successors for that!

# Meet the New Board:

### Anton Jansen

Dear Francken members, my appointment as candidate-chairman is as big a surprise to me as it probably is to you. I've been a member at Francken for three years now and I've always really liked the people and the atmosphere, although I've never considered becoming an

active member until now (shout-out to Hilbert for convincing me to apply for the board). Anyway, my name is Anton AKA Anton aus Tirol, Anton von Klinkenhoven, Anton von Yolo, Antonius, Antonio, Tonnie, Adton, Raffael van de Kaart, Anton M.C. Jansen, Tampon-ton and a.jan-speed. I'm a third year physics undergrad currently doing my bachelor research, which makes this quite a busy time for me. My interests are physics, problem solving, psychology, entrepreneurship, running and talking a lot (or so I'm told). I'm also a member of Albertus Magnus, although I'm not really active. I still can't jas after three years, and I really want the *vlam-tosti's* to come back. I'm looking forward to (hopefully) becoming chairman and helping create an awesome year for both Francken and myself.

### Willeke Mulder

*"Because there is a law such as gravity, the universe can and will create itself from nothing."* A quote from Stephen Hawking, which is the perfect description of the feeling I am experiencing as the candidate secretary and -commissioner of education. Being an astronomer and freshman, or in correct Dutch language, *Sjaars*, of the MSc Astronomy Instrumentation and Informatics, I know, or at least should know, a lot about the laws of gravity. As a candidate of the 32nd board of Francken you learn to say: *"Ik kan ook niets."* But I know for sure that the coming year will be filled with the application of the laws of gravity, in order to create wonderful experiences for not only myself, but also for all Franken members. I would like to end with another quote, which will guide me in the coming year. *"The past, like the future, is indefinite and exists only as a spectrum of possibilities."*

# ‘Buitengewoon’

**David Koning**

Hi! I’m proud to hopefully introduce you to the first black board member of our beloved study association T.F.V. ‘Professor Francken’. My real name is David, but I am also known as ‘*zwart*’ or ‘*schwarz*’ (which are the Dutch and German word for ‘black’, respectively). These words are my nicknames during one of my favorite games called thirties, which you have probably seen me playing at some activity or at a random ‘*maandagdertigdag*’. Almost four years I’ve been hanging around at my second home Francken and I’ve been part of several committees of the association. However, I never expected to become a board member going into my fifth year as a student at the RUG, but here I am, candidate treasurer, and I’m very much looking forward to it! Furthermore, you may like to know that I am a master student Mathematics, living in the most prominent ‘*Franckenhuisje 2*’, I’m a real fanatic tennis and Formula 1 watcher and every now and then I like to *eat beer*.

**Anne in ‘t Veld**

Dear Franckenmembers, hereby I present to you a piece of introducing text about me. My name is Anne in ’t Veld and I’m the candidate commissioner of external affairs and candidate vice-president of T.F.V. ‘Professor Francken’. I was born in Rotterdam, grew up in Raalte and am now a third year Physics student in Groningen. Next to studying, I fill my time with listening to music, making music, dancing and chilling or partying at Francken or Mayday. From my first year I have been an active member of T.F.V. ‘Professor Francken’ and since that time I have been active in a lot of different committees. After a lot of doubting and changing my mind, I finally decided to apply for the 32nd board of our association. Now that I’m in the candidate board, I am very excited and looking forward to spending a lot of time with Francken members, organizing awesome events and excursions for them and collecting money to spend on Beers (and other things). Hopefully, together with the rest of my candidate board, we will be accepted as the new board and let a lot of positive developments happen.

# Graphene Spintronics

*Graphene is often described as wonder material for the 21st century with potential to revolutionize many areas of application. Despite being atomically thin, graphene is more conductive than copper, hundred times harder than steel while being six times lighter and extremely flexible. While graphene has huge potential for macroscopic applications, it can provide even greater impact on the field of spintronics, which we investigate at the Zernike Institute for Advanced Materials.*

By Christian Leutenantsmeyer, MSc

**Graphene describes the** two dimensional form of graphite, structured carbon atoms which are aligned in a hexagonal crystal lattice. The existence of graphene was theoretically predicted in the mid-20th century when it was not clear if such two dimensional material could be stable in ambient conditions. Experimentally, thin carbon flakes attracted first attention from the 1950s onwards. The first studies investigated the structure of graphene with transmission electron microscopy and proved the existence of a single atomic layer of carbon atoms. Intense research was triggered from 2004 onwards where Geim and Novoselov exfoliated graphene from graphite crystals by using scotch tape. Due to the relatively weak interaction between the different graphene sheets in a graphite crystal, the large areas of the single layers can be separated with reasonable effort. The first electric characterization of graphene revealed the exceptional charge transport properties and attracted a lot of interest in graphene research[1]. Both were awarded the Nobel prize in 2010 'for groundbreaking experiments regarding the two-dimensional material graphene'.

1: K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, I. V. Grigorieva, and A. A. Firsov, "Electric field effect in atomically thin carbon films.," Science (80-. )., vol. 306, no. 5696, pp. 666–9, Oct. 2004

Despite the focus of the first studies was on the physical properties of graphene it quickly attracted the attention for further applications. For example, the flexible mechanical properties of graphene would allow to create flexible displays or electronics.[2] Highly efficient water filters are being developed by introducing custom size nanopores into graphene, which could help to provide clean water in Third World countries.[3] While most potential applications are still under development, several small companies started to produce graphene and related products indicating that graphene is close to commercialization and entering the consumer market. Recently, a tennis racket was presented, which uses the lightness combined with the hardness of graphene to optimize the weight distribution. As a result, the manufacturer promises a "faster swing and more power" by using the new racket.[4]

At the Physics of Nanodevices group, we are more interested in the elementary physical properties of graphene and related

2: http://www.graphene-info.com/smartphone-bendable-graphene-based-touch-screen-unveiled-chinese-tech-fair
3: http://www.graphenea.com/blogs/graphene-news/7714771-water-purification-with-graphene-sheets-surprising-yet-commercially-feasible
4: http://www.head.com/en/sports/tennis/technology/graphene-xt/

two dimensional materials. While the first study of graphene focused on the transport properties of graphene for charge carriers, graphene offers even greater potential in the field of spintronics.

The word spintronics combines the spin property with a potential electronic application. All electrons possess besides their charge also the property of spin, which can be seen as a quantum mechanical equivalent to an angular momentum. An electron can have the spin property pointing either upwards ('spin up') or downwards ('spin down'). Similar to a conventional charge current a spin current consists out of one spin species where only the spin is transported. The use of pure spin currents brings several advantages compared to charge currents. While flowing charge currents always create heating in the wire, spin currents do not. The excess heat generated by the charge currents in integrated circuits has become a bottle neck for their further development and limited the downscaling of the circuits. Here, spintronics promises potential for faster devices, higher data storage capacities and lower power consumption.

*...graphene is at the verge to enter the commercialization*

However, the distance that spin currents can travel without losing their alignment is limited. For many materials used in the semiconductor industry this length scale is in the nanometer range, which is too short to allow the realization of logic devices. This limitation originates from the spin orbit coupling, which describes an interaction between the spin of an atoms electron with the orbital angular momentum. The strength of the interaction strongly depends on the nuclear charge of the atoms core, which is rather large in the conventional materials used in the semiconductor industry and therefore the interaction is strong. This is where graphene becomes an appealing material to transport spins. Originating from the carbon atoms with a relatively small nuclear charge, graphene is predicted to have a negligible spin orbit coupling and therefore the ability to transport spins over millimeter distance. However, only several tens of micrometers are realized yet. Given the theoretical predictions for long distance spin transport, we are not only seeking methods to further extent the spin transport length but also to tune the intrinsic properties of graphene.

Triggered by graphene research, interest was also drawn to other two-dimensional materials, which are also studied in Groningen in the Physics of Nanodevices group. The goal of the research is to have a set of monolayer materials with different properties to combine those to tailor devices with various functionalities (Fig 1.). A prominent example is hexagonal boron nitride, an in-

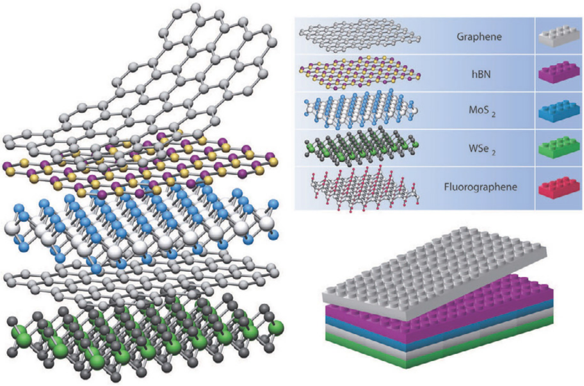



*Figure 1: Comparable to Lego blocks, research on two dimensional materials aims on creating devices by combining the building blocks to tailor the properties of the devices.*

*Image taken from A.K. Geim, I.V. Grigorieva, Nature 499, 7459 (2013)*

sulating material, which consists of boron and nitrogen atoms aligned in the same structure as graphene. This material is now widely used to create very clean encapsulated graphene devices, which allows the graphene to be free of contaminations arising from different processing steps, which limits the spin transport length.

To complete the building blocks of two dimensional materials, it is desired to also have a two dimensional crystal that is a magnet. To create one, we have tuned graphene into its magnetic state by using the proximity effect. Bringing two materials in direct contact can create a novel state at the interface and transfer one property into a material that does not exhibit this property intrinsically. Since the proximity effect decays strongly with the distance to the interface, a two dimensional material like graphene is the ideal material to study such effect since the whole volume of the material is affected with a homogeneous proximity effect. To make graphene magnetic we have placed it in direct vicinity of a special ferromagnet and studied the properties. Since most ferromagnets are also conductive, an electrical characterization of the graphene flake would not be possible since the circuits are shorted through the ferromagnet. Luckily, there are a few artificial materials, which are magnetic but also insulating. We chose Yttrium-Iron-Garnet (YIG), deposited graphene on the surface, injected spins into the flake and detected the spins after passing the graphene. By controlling the magnetization of the YIG, which determined the magnetization of the graphene via the proximity effect we could prove that the graphene has actually become magnetic – even at room temperature – but also that the magnetism in the graphene can control the direction of the spins highly efficient. This effect is of great interest for the realization of the spin transistor, the spintronic equivalent of the transistor.[5] In conventional transistors, two states are obtained by modulating the resistance of the electron channel. This results into a high and a low resistance for the electrons. The spin-transistor uses the spin (up/down), which brings all advantages of spin currents over charge currents to these devices. However, the realization of the spin transistor still lacks an efficient method to manipulate the spins in the transport channel. At this point, the efficient modulation of spins by using magnetic graphene becomes an attractive candidate for the realization of the spin transistor and might trigger the development of the next generation of spintronics based chips that can lead the future development of high performance devices. [6]

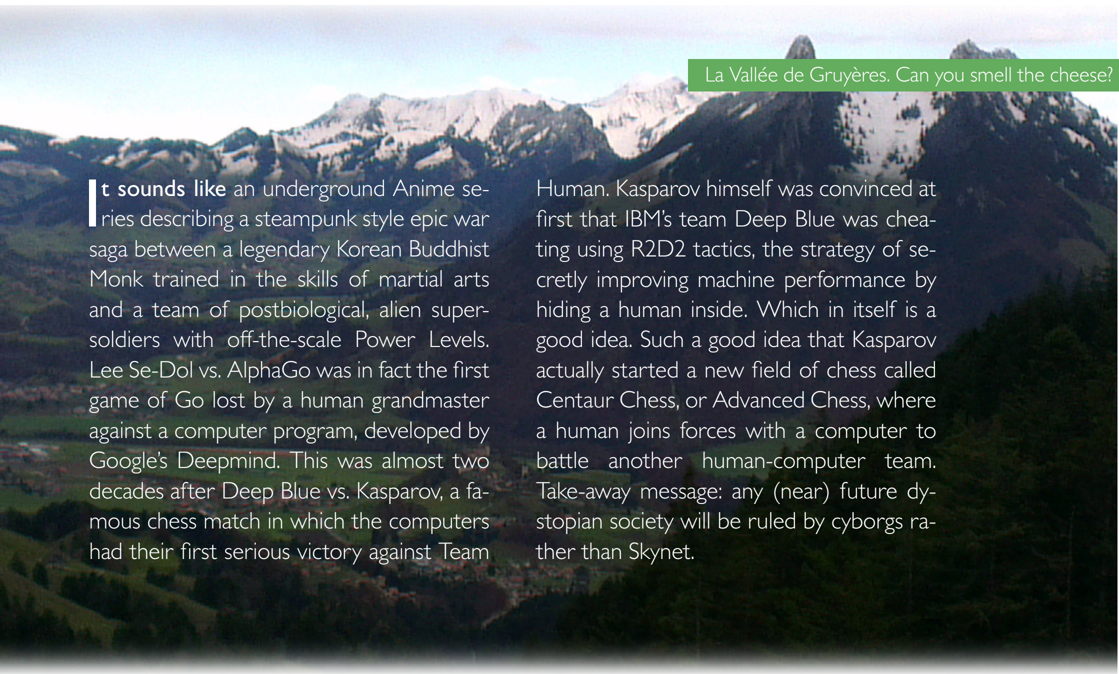
5: S. Datta and B. Das, "Electronic analog of the electro-optic modulator," Appl. Phys. Lett., vol. 56, no. 7, p. 665, 1990.

Over the last years, graphene research has attracted much attention and has proven great potential for a broad range of biological to physical applications. As of today, graphene is at the verge to enter the commercialization. Nevertheless, graphene is still an attractive material for investigating novel spin transport phenomena with respect to the applicability in the information technology. Therefore, even fundamental studies of graphene and their related two dimensional materials as is done in the Physics of Nanodevices group can become very relevant for the future development of graphene based nanostructures.

6: General article about the perspectives of graphene spintronics: W. Han, R. K. Kawakami, M. Gmitra, and J. Fabian, "Graphene spintronics.," Nat. Nanotechnol., vol. 9, no. 10, pp. 794–807, Oct. 2014.

# Inventing in the Swiss Alps

By Jasper van den Berg

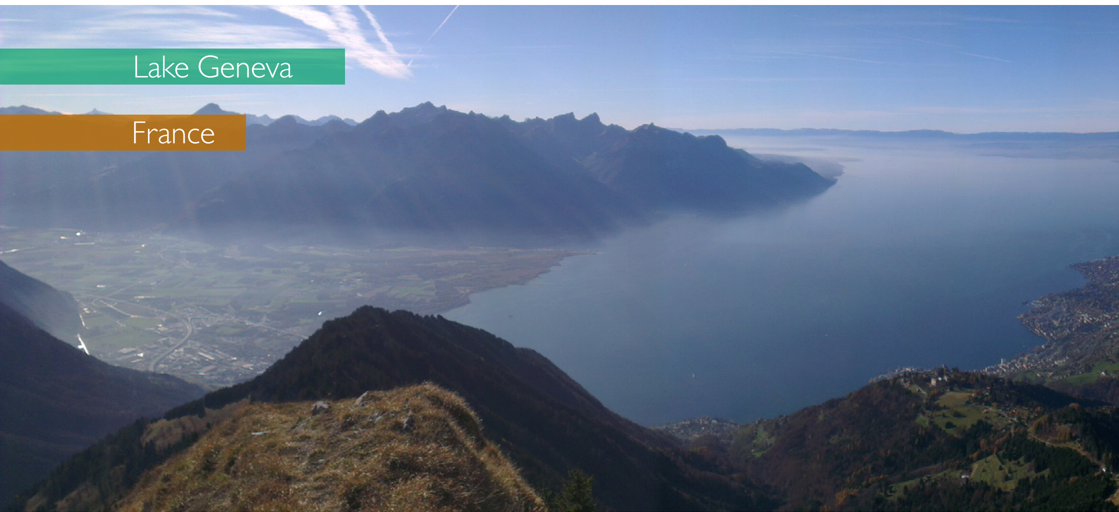


La Vallée de Gruyères. Can you smell the cheese?

**It sounds like** an underground Anime series describing a steampunk style epic war saga between a legendary Korean Buddhist Monk trained in the skills of martial arts and a team of postbiological, alien supersoldiers with off-the-scale Power Levels. Lee Se-Dol vs. AlphaGo was in fact the first game of Go lost by a human grandmaster against a computer program, developed by Google's Deepmind. This was almost two decades after Deep Blue vs. Kasparov, a famous chess match in which the computers had their first serious victory against Team Human. Kasparov himself was convinced at first that IBM's team Deep Blue was cheating using R2D2 tactics, the strategy of secretly improving machine performance by hiding a human inside. Which in itself is a good idea. Such a good idea that Kasparov actually started a new field of chess called Centaur Chess, or Advanced Chess, where a human joins forces with a computer to battle another human-computer team. Take-away message: any (near) future dystopian society will be ruled by cyborgs rather than Skynet.

Anyway, this story is about me living in Switzerland, the land where every mountain peak smells of molten cheese and where people go out to vote more often than they ride their bikes to work. I live in Lausanne, a medium-sized, French speaking city on the Swiss shore of Lake Geneva. Close by are the Alps, so that puts me in an excellent position for all sorts of outdoor activities that involve great heights, with the closest pistes an hour and a half away by public transport. Also close is the Jura, an older and somewhat lower mountain range that nonetheless has many places to explore with views, gorges, caves and even an underground glacier. Lausanne itself is a bit smaller than Groningen, and has similar percentage of student inhabitants and a slightly lower bar-to-student ratio. The city might be well-known to you because of the headquarters of the International Olympic Committee, or because of the nuclear deal with Iran which was sealed here. Lausanne has two universities: l'Unversité de Lausanne (UNIL) and l'École Polytechnique Fédérale de Lausanne (EPFL), a quite well-known polytechnic university. There is a great atmosphere here and there are many nationalities to be found due to the EPFL's strong international focus. On and near the campus, English is used as often as French, which is not very common in this area - though to be fair, there are a lot of big multi-nationals that have their European headquarters located in what is called the greater Geneva-Bern area.

Wait, did I introduce myself? I was Treasurer of Francken in 2006-2007 and was spotted in the Francken room a few times during the last years taking breaks from my PhD research at the Physics of Nanodevices group. Yes, I know, I still have to defend my thesis, but I already wrote my booklet and the date of my defense is set, so let's not dwell on things, shall we? Marieke - my awesome girlfriend - found a PhD position here at the UNIL to study sleep behavior and circadian rhythms of mice, and that was reason enough for me to move to Lausanne as well. Right before this piece was written, the Swiss decided to vote against a univer-



sal income for all citizens. I knew that something like that would happen all along, so when I moved here I decided to find a job. The moving process was done very gradually, so I could spend increasingly longer time periods writing my thesis whilst viewing the French Alps, and at the same time start hunting for new career opportunities. Did this speed up things? No. I would have finished faster writing in Groningen and I would have found a job sooner with all

*Did this speed up things? No.*

my time and attention allocated to the job application process. But it was fun to randomly disappear abroad and then suddenly turn up at work or at a birthday party in the Netherlands and hand out Swiss chocolate to unsuspecting friends and colleagues.

My job hunt payed off in the end and I found a position at a company called Iprova, located on the EPFL Innovation Park, a place full of startups and technology spin offs from the EPFL. Here, I have the unusual but exciting position of Invention Developer. My task is to create patentable inventions on behalf of our customers, which are large technology and industrial companies in North America, Europe and Japan – two of our Dutch public costumers are Philips and KPN. These customers work with us because we have quite a unique approach to the invention process. Our approach brings together a few essential things. First of all, there is the in-house knowledge and understanding of what are the Essential Ingredients that make up a patentable and commercially relevant invention. Secondly, there are the invention developers (like me), that put together these Essential Ingredients into a working invention – on paper, we don't have a lab to build prototypes, so a typical invention fits on a PowerPoint slide. And thirdly - now comes the surprising link to the seemingly random introduction – we make these inventions as a human-computer team. Our company has developed unique software that helps the

invention developer find the Essential Ingredients quickly and effectively. As a result, and using some additional manual steps, we are able to create diverse and disruptive inventions in a broad range of fields.

How does that work exactly? Well, that is a secret. What I can tell is that our software is able to sense technological, market and social changes as they happen around the world. Our data driven approach increases the speed at which we deliver inventions, and also allows us to asses their quality. Two important metrics for quality are novelty (how new is the invention) and disruptiveness (is the invention touching several domains). This method allows us to create many inventions per week, all with a high likelihood of having significant commercial value and covering broad patent claims. Sounds exciting? Well, we are currently recruiting, so if you are interested in all of this and in moving to Switzerland or to the UK, check out our website, iprova.com.
After shamelessly turning a story about cultural exploration and personal growth of a Francken member into an advertorial, and realizing that the following doesn't sound funny in the original language at all, I am going to rest my case.

*Jabs choco, still the picture you see when you streep Chocomel*

# An inside view: Nanostructured Materials and Interfaces

By Dr. Ir. Bart J. Kooi

**Most atoms, when** brought together in the solid state, want to form crystals. From all the elements in the periodic table, which at room temperature form pure solid substances, only one, selenium can be produced easily in a non-crystalline, i.e. amorphous, state with modest cooling rates (e.g. 10-100 K/s). To produce metals in a glass state, alloys are required and cooling rates of the order of a million Kelvin per second. Selenium belongs to the class of chalcogenides, which are substances based on S, Se and Te. Chalcogenide materials exhibit a large variety of intriguing properties and associated applications, such as highest reported figures of merit in the field of thermoelectric materials and unique optoelectronic properties in phase-change materials that have been exploited in e.g. rewritable DVD technology. Thermoelectric materials are highly interesting, because they can produce electrical power from a temperature difference and thus can harvest energy from waste heat. Phase-change materials are excellently suited for digital memory applications, because they can be switched rapidly and reversibly between their amorphous and crystalline phases, having large differences in optical reflectivity or electrical resistance, but at the same time both phases are remarkably stable at room temperature.

Around 2001, I started with research on phase-change materials where I studied the crystallization of amorphous films with

heating inside a transmission electron microscope (TEM); see an example image in Fig. 1. At that time I had no idea that phase-change materials and chalcogenides would still be a booming research field in 2016. Although the rewritable optical disk technology (e.g. Blu-Ray Disks) will be dying soon, fortunately new completely electrical solid state memories, such as the 3D XPoint technology recently announced by Intel, keep phase-change memory technology highly alive. Moreover, in 2009 the totally new phenomenon of topological insulating behaviour was discovered in for instance Bi2Se3 and Sb2Te3. Crystals of these materials are very special, because they have a band gap (are insulating) in the bulk, but form conductive states at the surface with a very similar surface band structure (Dirac cones), as holds for the famous (Nobel prize related) graphene. In 2010 transition metals di-chalcogenides also made their striking appearance, because they have various favourable properties, e.g. opposite to graphene, these 2-dimensional materials have a direct bandgap, which makes them more interesting for applications than graphene.

Although phase-change memories in general have very desirable properties, the relatively high current and power, needed to switch from the crystalline to the amorphous phase via the liquid phase, is still considered a major drawback. Therefore, a breakthrough in the field was achieved when it was shown in 2011 that chalcogenide superlattices (CSL) of alternating (1 nm) GeTe and (4 nm) Sb2Te3 could be switched with nearly an order of magnitude lower power. In a European consortium we also started to work on these CSL, where they were grown by molecular beam epitaxy (MBE) in Berlin and physical vapour deposition (sputtering) in Aachen. In Groningen we obtained the task to do TEM analysis of these CSL. A TEM image of a detail of a

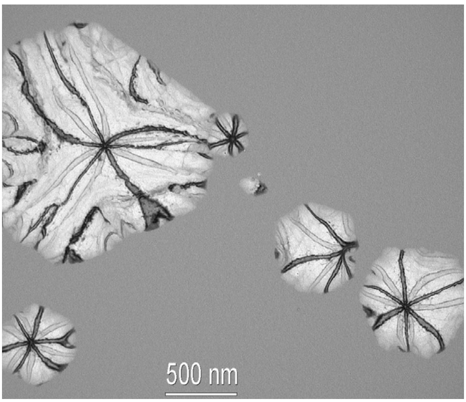



*Figure 3: TEM image of crystals that have been grown in a 40 nm thick amorphous GeSb15Te4 film by in-situ heating (10 min., 155 °C) in a TEM*

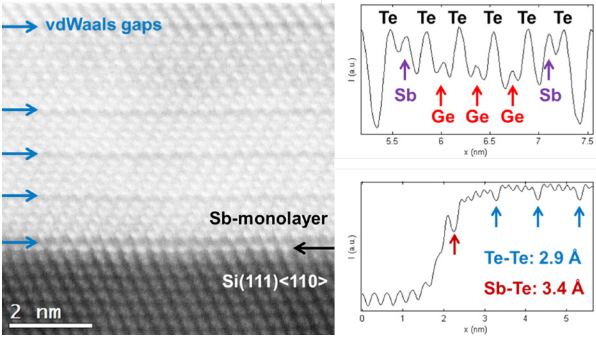
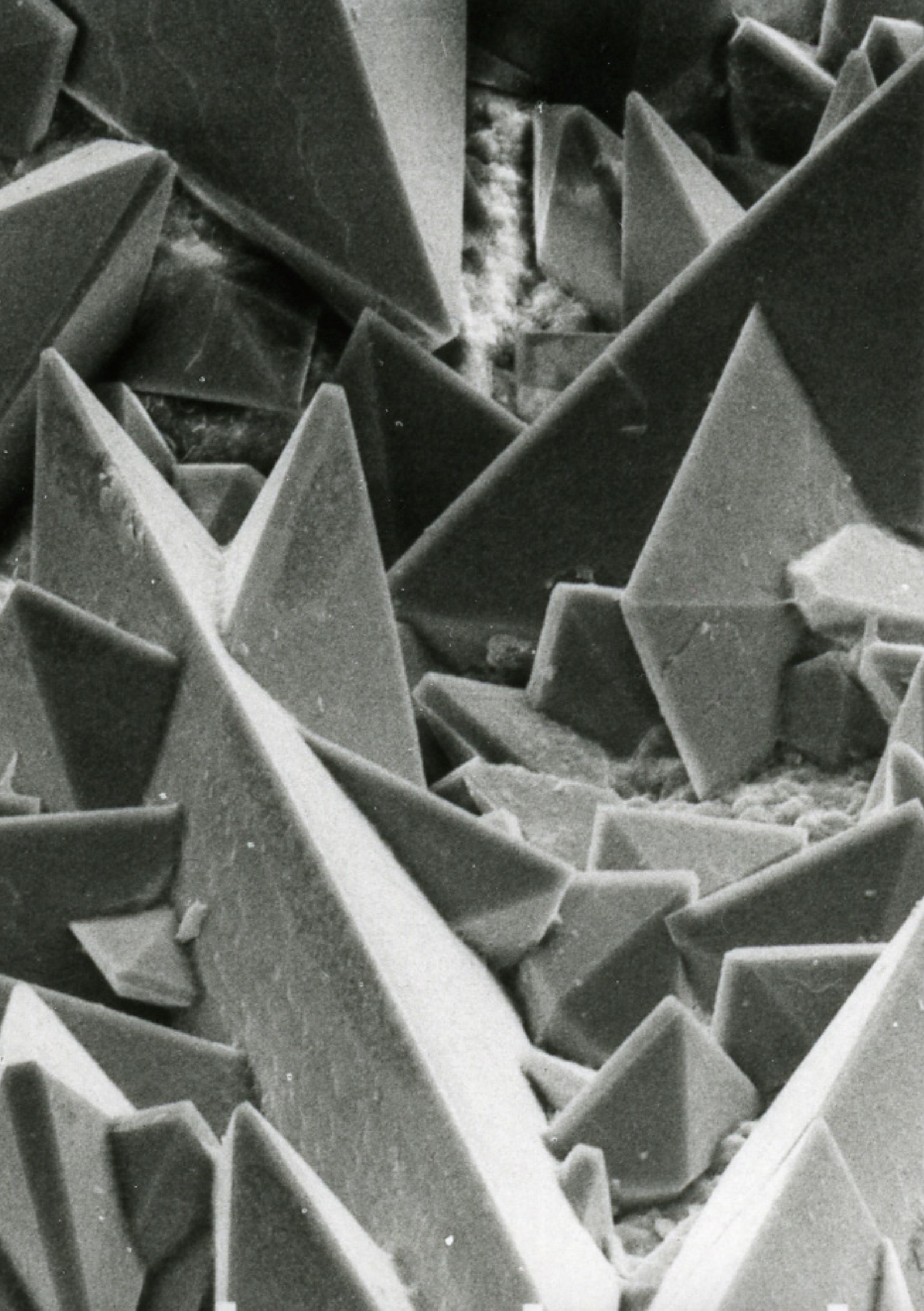



*Figure 2. TEM image showing atomic resolution Z-contrast of the interface region in a cross-section sample of a GeTe-Sb2Te3 superlattice grown by molecular beam epitaxy on Si(111)*

cross-section of such a CSL grown by MBE is shown in Fig. 2 below. This image actually shows atomic resolution Z-contrast, which means that the substrate which contains the lightest Si atoms appears most dark and the Sb and Te are most bright and the Ge atoms have intermediate brightness. The relatively dark horizontal lines in the bright film are van-der-Waals gaps implying that we in principle grow stacks of 2D materials. In order to grow the films with high quality on Si(111) it turned out important to passivate the Si surface with a monolayer of Sb and to create so-called van-der-Waals epitaxy between substrate and film. Otherwise, with a normal chemical bonding type of epitaxy, more than 10% lattice mismatch between Si substrate and the bottom Sb2Te3 layers would result in a highly defected (not a single crystal like) film. Due to the atomic resolution Z-contrast, such images also allow a line scan type analysis, where some examples are shown in Fig. 2 on the right.

Figure 2. TEM image showing atomic resolution Z-contrast of the interface region in a cross-section sample of a GeTe-Sb2Te3 superlattice grown by molecular beam epitaxy on Si(111).

Based on a detailed analysis, we were able to demonstrate that the switching mechanisms proposed in literature for the CSL could not hold. Still, when the CSL we analysed were incorporated in a nanoscale memory structure they showed the same clearly improved switching characteristics as shown for the first time in 2011. We published this in the journal Nanoscale in 2015 and currently we are finalizing two other manuscripts. So, we confirmed the positive switching characteristics, but we still do not know how the switching actually occurs. Therefore, more research is needed in the next years to find out 1) what the switching mechanism actually is and 2) whether this CSL can be incorporated in a robust memory technology that can become a commercial product.



# Francken Vrij
# Through the Years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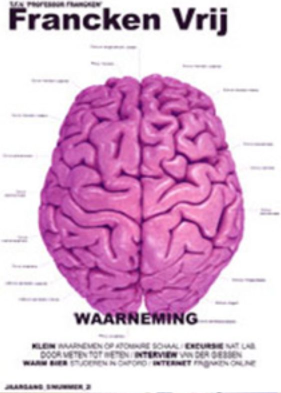
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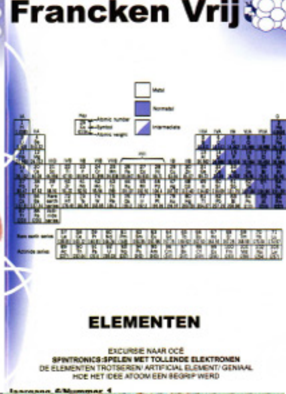
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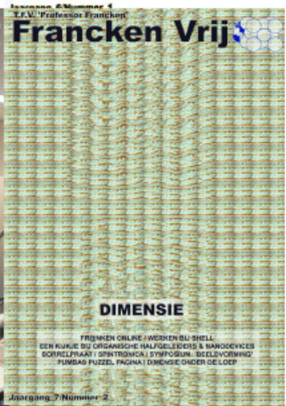
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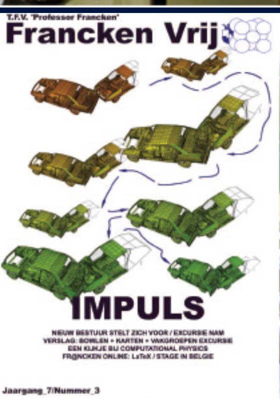
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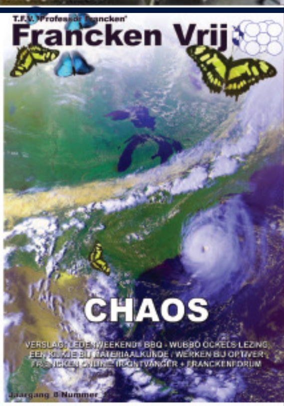
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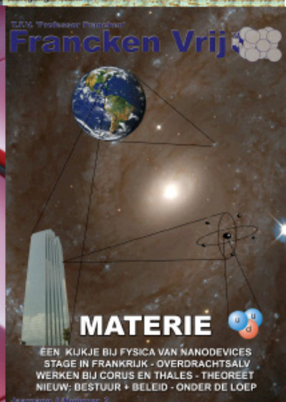
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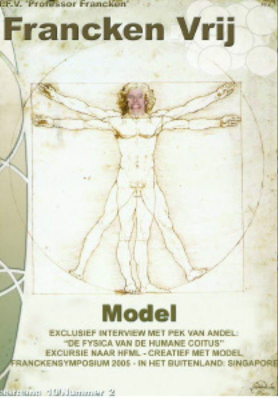
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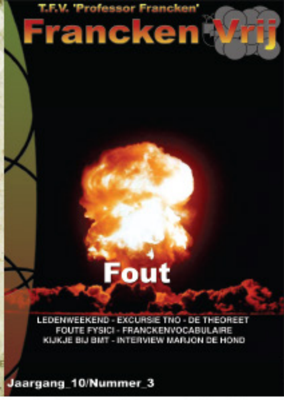
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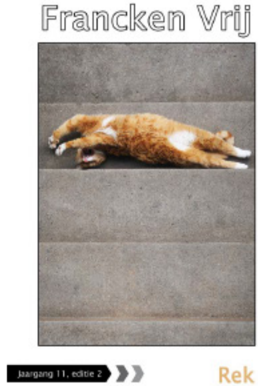
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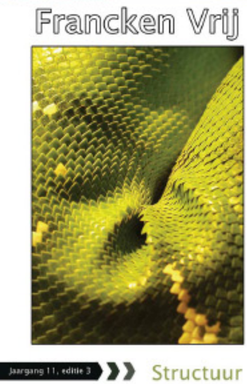
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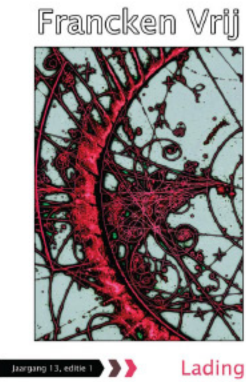
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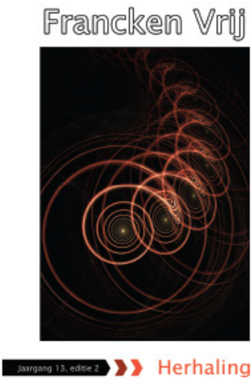
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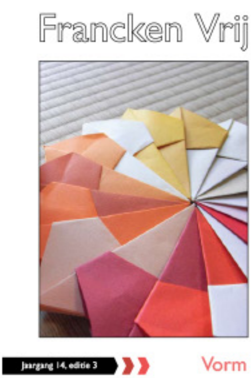
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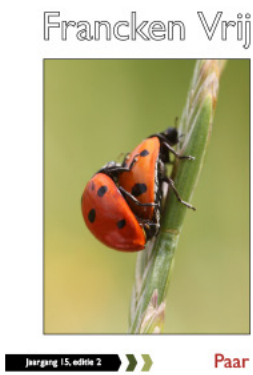
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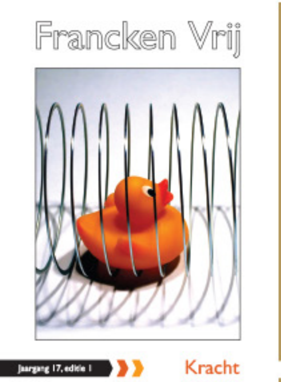
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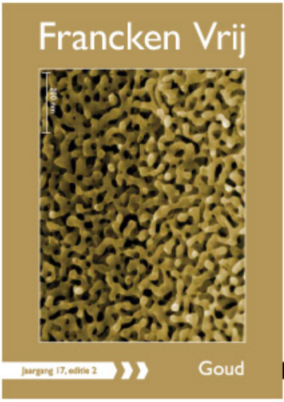
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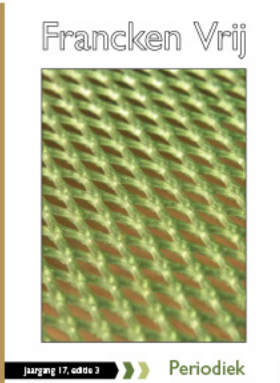
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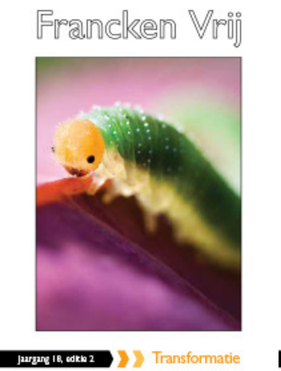
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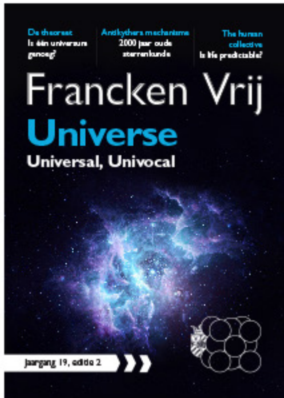
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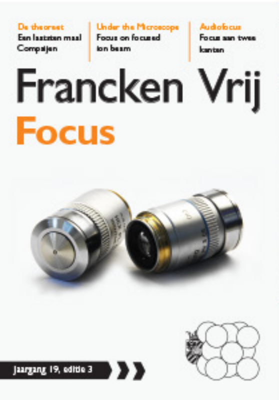
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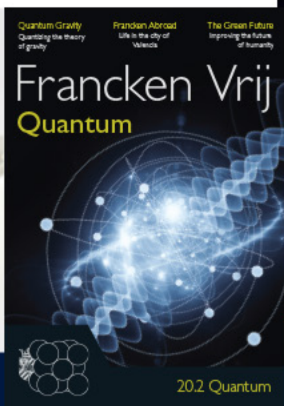
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20.3 Crystal

# Topological Defects

By Remko Klein

**As I'm sure** you've already read in the editorial or some other piece, this edition of the Francken Vrij marks the end of it's twentieth year of existence. This basically means that the Francken Vrij is now older than the newest generation of Franckenleden and I guess it won't take too long before it will outdate all student members. (Although, there are of course some members that will delay this moment, as their rate of acquiring ECTS seems to be inversely related to the rate with which they can adt beer...)

**Francken Vrij**

**Theoretisch gebrabbel....**

**Ik ben eigenlijk een theoreet en toch een lid van T.F.V. Prof. Francken en ik lees dus ook de Francken Vrij. Waarom ik als theoreet toch lid van Francken ben wordt met dit schrijven niet verduidelijkt; ik wilde slechts wat uitleggen. In de vorige editie van dit mooie blaadje las ik namelijk enkele dingen waarvan ik vond, dat ik er op moest reageren. Het betreft de stukjes van Friso Jedema en meneer de Hosson waarop ik een kleine reactie wilde maken.**

een heleboel berekeningen aan elementaire deeltjes gedaan kan worden. De snarentheorie probeert via een andere weg volgens mij voornamelijk drie problemen aan te pakken. De belangrijkste is het oplossen van de technische problemen van de quantumveldentheorie (de zogenaamde oneindigheden). Het tweede behelst het verklaren van het bestaan van de elementaire deeltjes vanuit een meer elementair oogpunt. En het derde aan te pakken probleem is een andere technische aangelegenheid;

** His reaction in edition 6.2 of the Francken Vrij, which can be found on the Francken website.*

Now, as far as I can tell by going through the Francken Vrij database, De Theoreet is only about five years younger. It all seems to have begun when the pioneer Dennis Westra, a lone theorist amongst technicians, decided to correct some of the statements made about aspects of fundamental physics in several pieces (written by technicians) in a preceding edition of the Francken Vrij.* Apparantly well received, he continued to write pieces on theoretical physics, and thus De Theoreet was born. Many theorist

have succeeded him since and, being one of these theorists, I of course hope that the tradition will remain intact for as long as the Francken Vrij exists.
Anyway, let's slowly gravitate towards the actual topic of this edition. According to the editorial board the term for a twentieth anniversary is crystal and so crystal it is. Sadly, being a cosmologist (oke fine, a cosmologist in training), I know little to nothing about crystals. Luckily however, there is a phenomenon one encounters while considering the formation of crystalline structures that has a counterpart in cosmology, namely the emergence of topological defects. Before going on to cosmology though, let's recap the basics of crystals and topological defects.

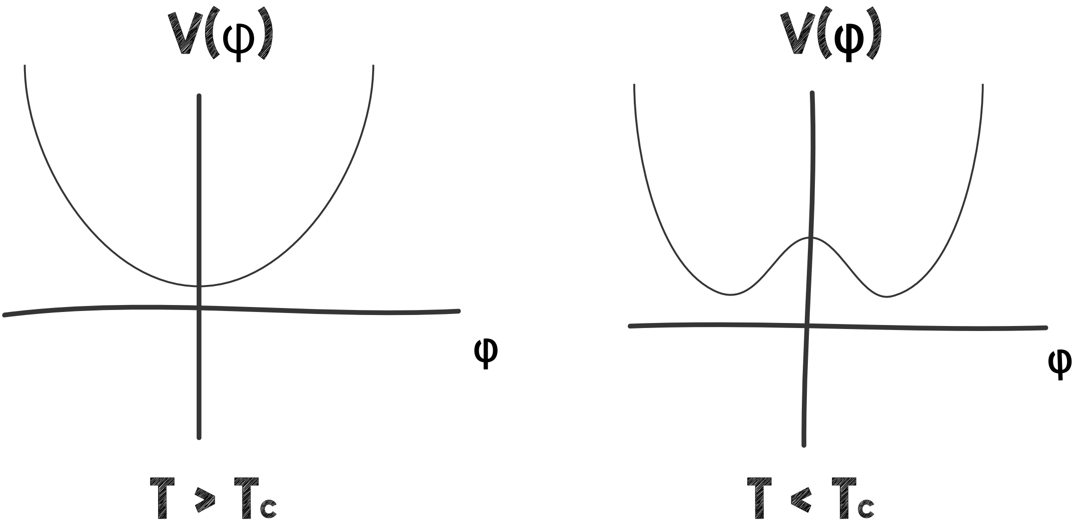
**Crystals and topological defects**

As you know, an ideal crystal is a solid (ignore liquid crystals for the moment) whose basic constituents, like atoms, molecules or ions, are configured into a highly ordered periodic structure, called a lattice. Examples of perfect crystals would be snowflakes and table salt. Of course, in nature ideal crystals are rare and usually impurities form for one reason or another.
The main topic of this piece is a particular type of impurities that can emerge during the formation of a crystal. To this end let's consider some would-be crystal that, at a certain temperature, is in the liquid phase. In this phase the molecules are approximately moving randomly, and there is no structure amongst the molecules. This changes if one cools the liquid down to some critical temperature such that it will undergo a phase transition and solidify. This solidification is of course not an instantaneous and coordinated process. Rather, different parts of the liquid will solidify at slightly diffferent times and independently growing parts of lattice structures will form within the liquid, until finally the entire liquid has solidified.
The key point is that although the lattice structures of these independent parts are the same, they are in general differently oriented. As these growing lattice structures reach eachother they will thus not interconnect and form one large lattice structure, but rather boundaries will form that seperate the different parts. These boundaries are what we call topological defects. They come about in all kinds of varieties, basically depending on their dimensions. I.e. one can have pointlike, line and surface defects depending on the particularities of the mismatch between the structures.
The underlying process at work in the formation of topological defects is spontaneous symmetry breaking. To see this consider again the liquid. It has a lot of (approximate) symmetry: it is the same randomness everywhere and is hence invariant under rotations, translations and reflections. Now, as the temperature drops and the liquid solidifies the crystalline structure emerges and part of the original symmetries are spontaneously broken in the process. For example only translations in certain directions or ro-

tations over fixed angles (depending on the actual lattice structure of course) are still symmetries.
The principle and implications of spontaneous symmetry breaking can be applied (and are actually paramount) to practically all fields of physics. In particular one can apply this to a theory of elementary particles and their interactions, which is precisely what we will do next.

**The universe and topological defects**
Our theories of elementary particles are characterized by symmetries that dictate how the different particles can interact. Now, these symmetries, and hence interactions, can change depending on the temperature. In fact, phase transitions can occur that radically change the behaviour of the particles. In practice the interactions and their transitions are very complicated, but to illustrate what can happen let's consider a simplified setting. Say we have just one particular particle which can be described via a scalar field, $\Phi$, which is basically a function defined all over space-time. Ripples within this scalar field then correspond to the actual particle, just like ripples in the electro-magnetic field correspond to photons. (This is quantum field theory in a nutshell.)
What is important for how such particles will interact amongst each other, is the background value of the scalar field, also called the vacuum expectation value. What this background value is, is determined by a potential function for the scalar field, $\Phi$. The value of the field will be such that it minimizes the value of the potential, i.e. it will sit at a minimum.
Now, the shape of the potential can take on very different forms depending on the temperature. Consider Figure 1 depicting a potential at different temperatures. At temperatures above some critical temperature, Tc, it has a single minimum at the

*Figure 1. The potential $\Phi$ at different temperatures.*



origin where the field value will sit. In this case reflection with respect to the y-axis is a symmetry of the theory as this leaves the minimum, and therefor the field value and the interactions, invariant. At temperatures below Tc however, two distinct minima will emerge. As the temperature drops, the field value will thus move from the original minimum at the origin to one of the two new minima. Once in one of the new minima, the original reflection symmetry is spontaneously broken: performing such a reflection changes the background value of the scalar field and transports you to the other minimum.

Whether the field value goes to the right or the left minimum is influenced by quantum fluctuations, and as a result it will not end up in the same minimum in all of space. Different regions in space will thus have different background values for the scalar field and boundaries, i.e. topological defects, will form in space where the background value jumps from one value to another.

Good to note is that the two minima, although corresponding to different background values of the scalar field, nevertheless yield the same interactions for the particle (because the potential as a whole still exhibits the reflection symmetry) so there is no difference in actual physics between different regions. This is analogous to the fact that the lattice structures of two different regions in a crystal are in principle the same but can have a different orientation. Here the interactions of the particle are the same, but the background value of the scalar field is not.

This scenario of a phase transition and the corresponding formation of topological defects, is actually believed to have happened in the very early universe (albeit in a more complicated manner than explained above). As the universe expanded it cooled and phase transitions occured and many defects should have been formed, all with very interesting properties. One can for example show that generically the pointlike defects will act like magnetic monopoles (!) and the two dimensional defects, called domian walls, will have repulsive (!) gravitational fields. However, as of yet such topological defects have not been observed. Our understanding is that this is because of inflation, i.e. a period of exponential expansion of the universe. The idea is that at a certain time all these topological defects would have been generated, but afterwards inflation took place and all these defects basically got pushed out of the observable universe. So the defects should be present in the universe, but they are simply out of our reach. But who knows, maybe we're lucky and we do happen to live close to other regions and the corresponding defects and we will eventually be able to observe some of them. *En bij deze rust de theoreet zijn koffer.*

# Life after Francken

By Christiaan van der Kwaak

**I finished my** master in theoretical physics in 2010, after having served as chairman on the Francken-board in 2005-2006. I decided that my future would not be in physics, and that I would switch to become a macroeconomist, as mathematical skills are also crucial in this profession, while you are more directly engaged in public policy.

As I started from scratch, with hardly any economics knowledge other than following the economic news, I enrolled in the Tinbergen research master in Amsterdam, specifically designed to prepare students for PhD research. Coming from a physics background, I thought this master would be easy for me, but I was seriously mistaken. Although I managed to finish the two-year master with good grades, I had to work harder than I did in Groningen.

It is a common mistake among natural-sciences students and professors to think that anything with less mathematics must be easier than physics or mathematics. And although I personally know how difficult it is to finish a master in physics, I can say that economics is very complicated as well. The mathematics is not the reason, as it is easier than the mathematics you have to do in physics. However, a problem arises because you try to model the behavior of people, instead of objects that always and everywhere have the same key-characteristics, which is not true for the objects that economists study, namely human beings.

So what does my work look like? In a sense it is very similar to the life of a physics PhD-student.

I spend 80% of my time doing research and 20% of my time in teaching and bachelor thesis supervision. Economics research has both similarities and differences when compared with physics research. The similarities are that both use mathematics, although the mathematics used in physics is more complicated and more advanced. However, if you look at a theoretical macroeconomic paper, it is also filled with mathematical equations, first order conditions and Lagrangeans.

> *It is a common mistake among natural-sciences students to think that anything with less mathematics must be easier.*

Economics differs from physics in two respects. The first aspect is that economic intuition plays a much more important role than in physics. In every scientific paper, you have to be able to describe in intuitive terms what your main result is, without any recourse to formulas. The mathematics in this respect is a tool that serves to advance understanding of economic phenomena. Papers are usually rejected when authors are not capable of conveying the intuition behind a result. Whereas my impression from physics is that the mathematics is more leading, and intuitive understanding (without formulas) is less important. I was left with the feeling that I could do all the equations, but without truly understanding what the mechanisms and intuition behind my results in physics are.

Another difference is the direct applicability and relevance to the public debate. Macroeconomics deals with the economy as a whole, for which politicians are (partially) responsible. As a macroeconomist you have the tools to evaluate macroeconomic policy initiated by the government. For example, we can explain why a tax-hike will be good or not good, or what the macroeconomic effect is of a reduction in barriers to fire an employee. My supervisor, Sweder van Wijnbergen, prominently features on television and radio to explain his views on government or central bank policy.

My research deals with the macroeconomic consequences of fiscal and monetary policy in an environment where commercial banks are undercapitalized after a financial crisis. I use so-called DSGE models to do so. This is already quite a bit of economics jargon, so let me in turn explain about DSGE models, fiscal policy, monetary policy, and the role of (undercapitalized) commercial banks.

DSGE stands for Dynamic Stochastic General Equilibrium. DSGE models aim to describe the behavior of the economy as a whole by analyzing the interaction of many

*Figure 1: Christiaan at the board weekend in 2006.*

microeconomic decisions by agents, such as households, business-firms, governments, central banks, etc. The decisions usually regard macroeconomic variables such as consumption, investment, savings, labor supply and labor demand.

These models are dynamic, because DSGE models study the evolution of the economy over time. Stochastic implies that the economy is affected by random (unanticipated) shocks, such as a technology shock. General equilibrium refers to the fact that in these models prices and interest rates adjust to clear all the markets. The way you construct these models is actually quite similar to some of the problems in physics. For example, households usually want to maximize their utility, which they receive from consumption and from leisure. However, households need to provide labor to earn income which can be used to purchase goods for consumption. Households are usually subject to a budget constraint, which tells them how much they can spend for a given amount of hours worked. So how do we determine the optimal behavior of the household? We construct a Lagrangean with the objective function (the utility function), subject to the budget constraint (with a Lagrangean multiplier), and take first order conditions. Similarly, we can derive first order conditions for the other agents in the economy. The complete set of equations is then solved, for which we almost always need a computer.

Fiscal policy is policy that is executed by the government. Areas of fiscal policy are government spending on goods, transfers from the rich to the poor, tax-policy and debt-policy, i.e. how much debt to issue to finance existing expenditures. This is important for the macroeconomy, as government budgets in most Western countries constitute approximately 50% of the economy.

Monetary policy is the process by which the central bank controls the supply of money, often targeting an inflation rate (increase in prices) or interest rate to ensure price stability. The key instrument of most central banks is the interest rate. A lower interest rate makes saving less attractive, which induces people to spend more

*Figure 2: Christiaan with his fellow board members at the Gala in 2006.*

today instead of tomorrow (for which you have to save). At the same time, borrowing becomes more attractive, which induces firms to borrow more to invest today. Monetary policy has a large influence on the macroeconomy. In fact, some people say central bankers (who are in charge of monetary policy) are even mightier than politicians nowadays.

My research deals with the effectiveness of fiscal policy in an economic environment where commercial banks are undercapitalized after a financial crisis. Commercial banks are responsible for channeling savings (for example household deposits) to firms that need a loan. Commercial banks are mostly financed with debt (deposits are a form of debt), and with a little bit of net worth/equity. Commercial banks are limited in the amount of debt they can raise for a given amount of net worth. Undercapitalized implies that banks have relatively too much debt, and too little equity. This prevents them from providing new loans, which prevents non-financial firms from investing in new projects that generate economic growth. I show in my research that fiscal policy becomes less effective when commercial banks are undercapitalized, and have large holdings of risky sovereign debt on their balance sheet, as was the case for commercial banks in Southern-Europe during the eurozone crisis in 2010-2012. The direct link of my research with the current policy debates is an aspect that I really appreciate about my economics research.

*Back to my roots, and an oppurtuntity to visit Francken from time to time.*

What I like about economics is the combination of rigorous mathematics on the one hand, and the need to have a clear focus on the economic intuition behind your results. You have to be able to explain in laymen's terms what is going on, and why the policy that you are prescribing is the right one. I am not at the stage yet where I talk to policymakers, but it is something that I would like to do in the future. Soon I will be finishing my PhD, after which I will return to Groningen as an assistant professor macroeconomics. Back to my roots, and an opportunity to visit Francken from time to time.

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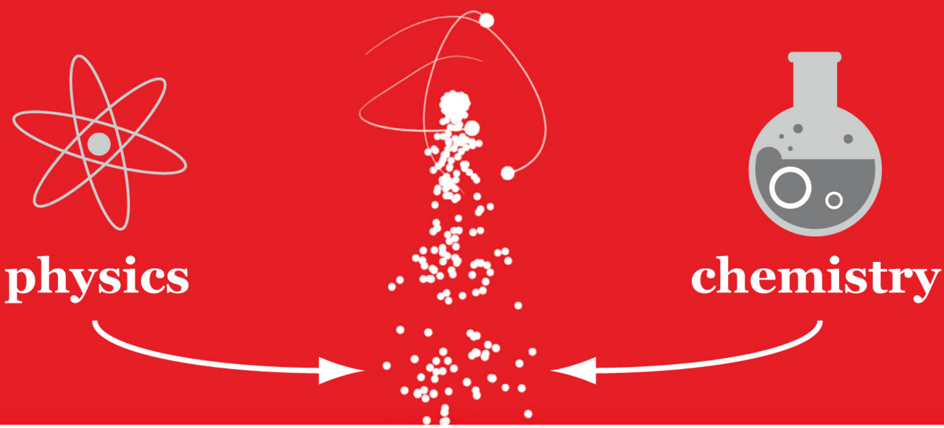


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Our activities cover both Bachelor and Master levels in the field of Physics and Chemistry. But, since it is our mission to train a new generation of researchers in cross-disciplinary approaches to research and equip them with the diverse skills required by modern science, we also have programs breaking the traditional boundaries between disciplines. We are very proud on our interdisciplinary Top Master program Nanoscience in this regard, which was rated the best Master program of the Netherlands the last four years in a row by national study guides. Next to this, we also offer the High Tech Systems and Materials Honours Master, which tackles real-life product development challenges in the same interdisciplinary fashion.

Additionally to the Bachelor and Master education, the Zernike Institute has the responsibility to train approximately 150 current PhD students to become independent, high level scientists. The main component is 'hands-on training', working side-by-side with the research staff of the institute.

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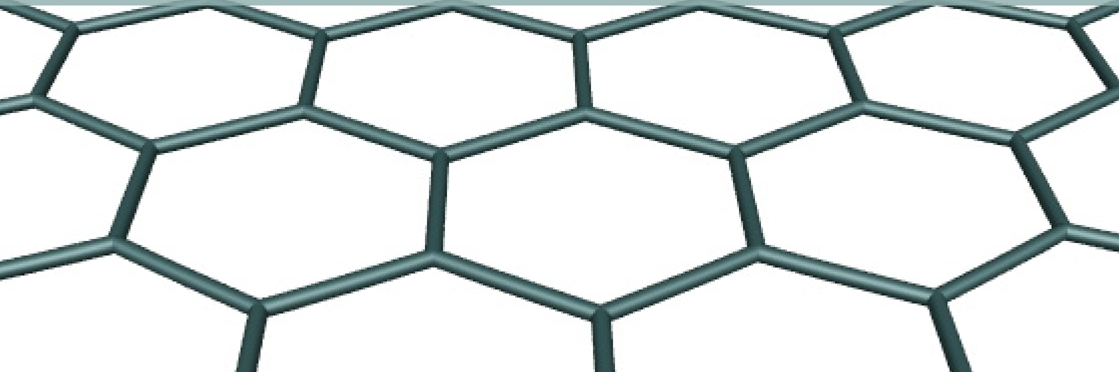
# From Martini to dom

By Peter Jacobse

**Once upon a** time, there was a guy who studied some kind of blend of chemistry and physics at the University of Groningen. After obtaining his bachelor degree at this prestigious institution, he decided to perform the last part of his study at another prestigious university, situated in the gezellige city of Utrecht. Even though he opted for broadening his scientific as well as personal perspective by moving to the Randstad, he never forgot his northern roots. Neither did he ever forget the amazing students association that has given him so much over the years. *Klaverjas*, mexen, kingsen, Hertog Jan, slightly drinkable coffee, foreign excursions, Yeni Raki, ASML, suspicion towards other students associations in the same building, good music, bad music, Left4Dead, bussing, barbecues, Pappa Joe, tea, Trackmania Nations, 30-ing, aasspel, dancing half naked on a table, seeing that Gertjan Pomstra is dancing half naked on a table again, toasties, 'kneits netses gozahs le'ah', friendships and zombies. Everytime he reflected upon all the miraculous moments he had experienced at the 'T.F.V', he had to suppress a tear of melancholy. Of course I'm talking about Peter Jacobse, and that happens to be me.



After following my master classes in Utrecht, performing my master research in an AFM/STM group and doing some more specialized courses in Enschede and Delft, I obtained my master degree and was hired by Utrecht University as a PhD. As a result, I'm still living in this extraordinarily *gezellige* city. The only difference between now and two years ago is that I've now completed the transformation from a student to a machine that turns coffee into papers.

Utrecht has a lot of parallels with Groningen in the fact that it is a student city of moderate size, with a compact and interesting historical city center. Just like Groningen, there's more than enough night life. Although it is 1.5 times the size of Groningen, it has a similar feel when walking through the streets in the center, one of a provincial capital, its history being dominated by the presence of an ancient university. However, there is one thing in which Utrecht really trumps Groningen. Outside of the city, you'll immediately find yourself in either the liveliness of the Randstad or the beautiful nature of the Heuvelrug, Gooi, Betuwe, Veluwe or het Groene Hart. Groningen, on the other hand, has cows.

Let me change pace and move on to a subject that we all share a weakness for: science! Much to my delight, I was told by mister Wijnbergen that the topic of this issue of the Francken Vrij would be 'crystal'. Let me make crystal clear how this subject affects my PhD in many facets.

The main structure I'm looking after is the graphene nanoribbon (GNR), which is a narrow strip of the twodimensional crystal graphene. Although it shares many favorable conductance properties with this parent material – which makes it super promising for nanoelectronics – it has the additional benefit that it has a finite band gap. This is a prerequisite for things like diodes and transistors, which are not particularly unimportant in electronic circuitry.

> I've now completed the transformation from a student to a machine that turns coffee into papers.

The way we make these ribbons is in a bottom-up process. First we design precursor molecules and synthesize them in the chemistry lab. That's right. Chemistry. The branch of science that tends to evoke allergic reactions in some physicists. It's dirty, smelly, hard work with hazardous materials and nasty solvents like ether, chloroform or sometimes simply boiling, concentrated sulfuric acid. But somebody has to do it, and in the case of Utrecht University that someone is Peter Jacobse. Carrying out chemical reactions is only part of the job, and afterwards I will need to make sure that the molecules are really pure, which can be achieved by a technique like chromatography or … recrystallization. It takes a lot of effort, but somehow, after isolating the pure stuff that you need and wiping away the sweat and tears, it is even rewarding. It's rewarding to be able to make these quirky structures that nobody has ever made before. But let's not exaggerate it. I mean, it's only a small step for a Peter.

Once finished with the chemistry, we put these building blocks into an ultra-high vacuum setup where they are pumped down to 10-11 to 10-10 mbar. We evaporate them onto a gold or copper single crystal which is subjected to a heat treatment, and in this way they'll couple and fuse together. If everything goes well, we end up with

> Chemistry. The branch of science that tends to evoke allergic reactions in some physicists.

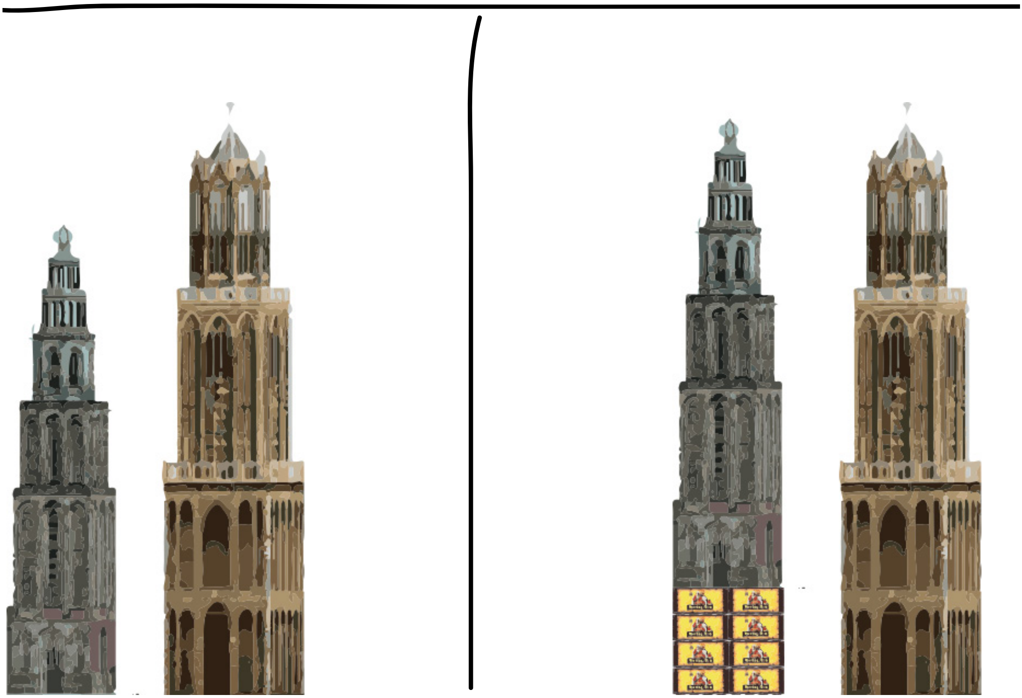
one-dimensional crystals known as graphene nanoribbons, having a width of 1 nm and a length of roughly 50 nm. The sample is inserted into our scanning tunneling + atomic force microscope and we analyze the structures that we created with atomic precision. With this amazing machine you can actually look at the hexagons of carbon (benzene rings) and molecular orbitals, and maybe the occasional substitutional nitrogen atom. By changing the bias voltage, we can even do spectroscopy on the structures and find out all intricacies about the electronic structure. And this electronic structure is something that I also routinely calculate myself using density functional theory and tight binding. As a result, my research spans quite a range of theoretical and experimental physics and chemistry.
In addition to my own research, I like to meddle with the experiments of my colleagues. A few of my colleagues are trying – sometimes successfully but not always – to assemble quantum dots (if well-defined, also known as nanocrystals) into a honeycomb lattice. In this way, the energy levels of the individual dots will hybridize into graphene-like bands, with characteristic Dirac-cone features. Every time my colleagues get it right, not only the supercrystal is highly ordered, but also the atomic rearrangements within the nanocrystals with respect to each other, which shows up nicely when observing the supercrystal in reciprocal space using techniques like GISAXS (grazing incidence small-angle scattering). Another example that I was more officially involved in was looking at the twodimensional arrangements of flat molecules on metal surfaces. The molecules feature electrostatic and van der Waals interactions between them, which determines their arrangements in twodimensional supercrystals.

My team mates are not the only ones messing around with nanocrystals and supercrystals. In fact, Utrecht University has a strong tradition in research related to hard condensed matter, soft condensed matter, and everything in between. One research topic in another group involves ordering nanocrystals inside micelles – basically small soap bubbles – into spherical supercrystal arrangements. Subsequently, they want to arrange the micelles themselves into a supercrystal arrangements. At least, that is what I understood from the fascinating PhD thesis "Towards Crystals of Crystals of Nanocrystals: a Self-Assembly Study" by Bart de Nijs. On the other hand, the people on the floor above me are shooting their lasers into photonic crystals and the people of chemistry are shooting X-rays into zeolite crystals or crystals of organic materials to elucidate their structure. Let me summarize by saying that in Utrecht, we like to do it periodically.

Oh, and I don't want to brag, but the Dom is just a bit higher than the Martini Tower, although admittedly, the latter has a better name.


*Peter Jacobse was still 20 here, buixie 2011*

Groninger students trying to compensate



# Monster Puzzle

By Arjen Kramer

**These three puzzles** are related, squares with the same letters have the same values. The goal is to make a word of the bottom row of the crossnumber puzzle, using the lettervalues you found in the puzzle. The second puzzle is a "skyscraper", each row and column contains the numbers1 to 8, the numbers around the outside tell you how many skyscrapers you can see from there. In the third puzzle, every row and column of the 7x7 grid together with it's two border fields contain the numbers 1 to 9. Send your results to the redaction, the admission with the most correct values for letters wins something

## Horizontal

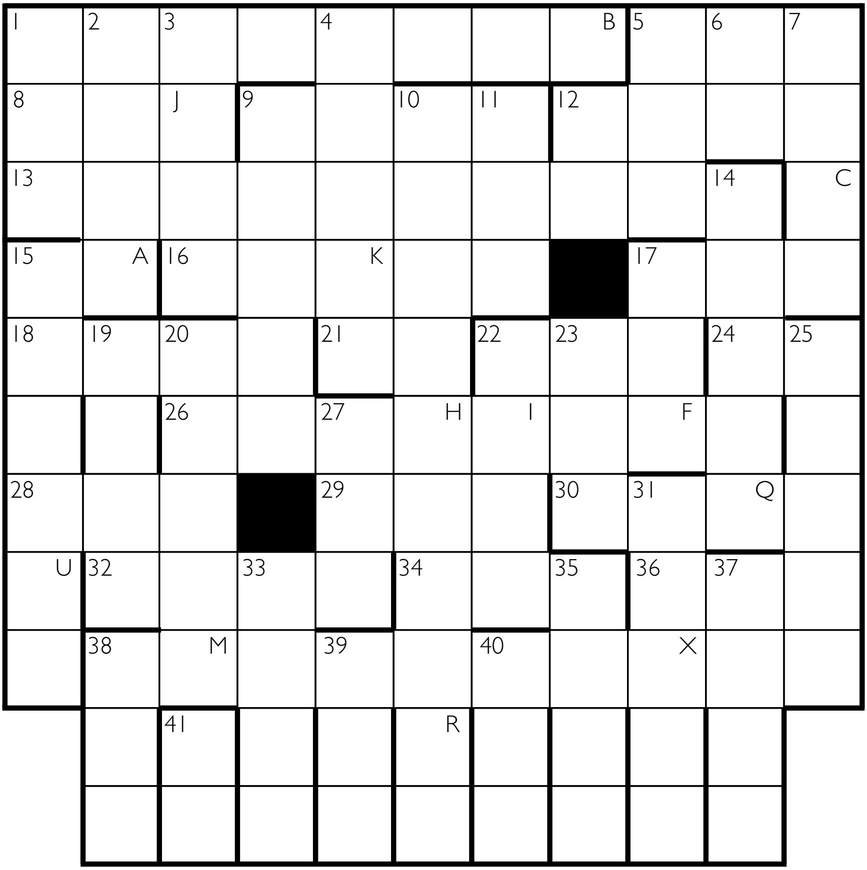
1. The product of three consecutive numbers
5. The digits are in order from low to high
8 . A number associated with a fictional British person
9. In this year, the editor-in-chief was called Ruger
12. The smallest number that is the product of 5 distinct primes
13. A pandigital number that's the square of another number in this puzzle

## Vertical:

1. The wordvalue of a title which has a group of 3 letters in alphabetical order.
2. Can be divided by Horizontal 15
3. The difference between this numbers' two prime factors is 2234
4. Has rotational symmetry
5. A lucky number
6. The page number of the last page of a story about dark energy
7. Has only one prime factor but is not prime

15. A divisor of Vertical 2
16. The cube of the page number on which an ode to old study-coördinator Frank van Steenwijk was written
17 . The first two digits and the last two digits are both divisible by three
18. A perfect number
21. A prime number that has a twin
22. Form a pair of amicable numbers with Vertical 23
24. The number contains exactly 6 different letters
26. The first few constants in the taylor expansion of $1/(1-x-x^2)$
28. The wordvalue of the title of an edition in which the Franckenmember Abroad is in the USA
29. Has a rotational symmetry
30. Is divisible by Horizontal 24
32. The smallest number that can be written as the sum of two cubes in two different ways
34. All digits are the same
36. A multiple of $\sqrt{1+2\sqrt{1+3\sqrt{1+4\sqrt{1+\dots}}}}$
38. A pandigital number of which the first n digits are divisible by n

9. if the second digit was doubled, this number would be a palindrome
10. a pandigital number
11. The sum of the digits is 17
12. An odd number that can not be written as the sum of two squares
14. A fermat prime
15. The cube of a prime number
17. Associated with a movie about animals
19. The first two digits and the last two digits are the same
20. Four times this number is this number reversed
22. (First digit^Second digit)*(Third digit^Fourth digit) = this number
23. Forms a pair of amicable numbers with Horizontal 22
25. The first two, the first three and the first five digits are all squares
27. The sum of two squares
31. Product of the letters: **GOLDQ**
33. -100 + product of the letters **DORSTN**
35. -87 + product of the letters: **GREAT**
37. -17 + product of the letters: **QUEEN**
38. Product of the letters: **BEER**
39. (3/2) * product of the letters: **AIVD**
40. 4 + product of the letters: **VRIJ**
41. Product of the letters: **DT**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