Renewable Energy
Solutions from solution!

Puzzling Puzzles
Why should we solve puzzles?

The US of Francken
The first in a trilogy of a year in America

Francken Vrij

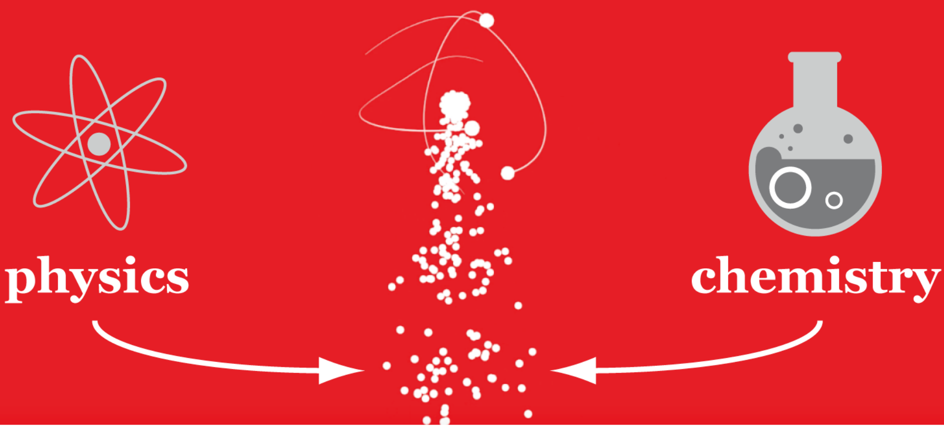
Solutions

21.1 Solutions

Zernike Institute for Advanced Materials

You want to build the next generation of solar cells, starting from molecular building blocks? You want to change the world of computing by assembling revolutionary memory materials atom-by-atom? Or you want to develop materials preventing or curing disease? Then have a look at the Bachelor, Master and PhD programs related to and inspired by the Zernike Institute for Advanced Materials' research lines.

explore the world of advanced materials for the bottom up design of the future



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Zernike Institute for Advanced Materials

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university of groningen

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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.

Are you interested in joining our team for a Bachelor-, Master-, or PhD-project? Check our website http://www.rug.nl/research/zernike/education/ on the different educational programs or directly approach us via zernike@rug.nl.

Edition 21.1

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Editorial

As the new editor in chief I present you the first Francken Vrij of this academic year. The theme of this edition is 'Solutions', a very nice theme which can be interpreted in a lot of different ways. I have seen a lot of people struggling with the monster puzzle of the previous edition, but we received only one solution. Sjieuwe, Edwin and Thom you can collect your prize at the editorial board. The correct solution was 'completed'. This time Steven has reversed the process, he made the solution and wants to receive a puzzle. I hope you enjoy reading this Francken Vrij.

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Chairman's preface

By Anton Jansen

Although only the first few months of the academic year have passed, lots of interesting activities and events have already taken place. We as the board are getting more and more used to running the association and efficiently solving problems when they arise. Since this edition of the Francken Vrij is all about (finding) solutions, that is what I want to talk about. The way I see things, there are two kinds of problems. With some problems you can clearly see the path you need to take to solve them, and it is a matter of putting in the work that makes it difficult. A good example of this would be cleaning up a Francken barbeque, it is quite straight forward but it still needs to be done. Then there are also problems where the path to the solution itself is not clear, and actually finding the right path is already 90% of the solution. I think most (if not all) of physics falls in the second category. The hard part of physics is usually finding the path to the solution, not the actual solving of a problem. From a psychological perspective I think the second kind of problems are really interesting because they require creativity to find the solution. I recently read a book called Psycho Cybernetics which talks about how you can utilize your creative imagination to solve problems. One thing I read is that solutions to problems that require us to be creative often do not appear to us when we are thinking really hard on the problem, but they come to us when we are doing something unrelated. In science, there are actually quite a lot of stories about this phenomenon. One of the more famous examples is the discovery of the structure of benzene by Kekulé. Kekulé could not solve the structure of benzene in his daily research, but the solution finally came to him when he dreamt about a snake biting its own tail (and yes, I believe creativity can also work through our dreams).

Anyway, the moral of this story is that you should not always be completely engaged in a problem, but also relax, and let your creativity do its work. I wish you all happy reading of the new Francken Vrij!

News of the Association

By Willeke Mulder

Time flies when you're having fun. Since the installation of the new board, it is all about finding practical new solutions to different problems. This is the first time I'm writing the News of the Association as secretary of T.F.V. 'Professor Francken', which could be a problem for people lacking memory or creativity. My solution is introducing a new policy: working and writing in the Franckenroom, accompanied by Francken members, in order to get inspired through looking back all the pictures made at the activities. In the last few weeks many memorable memories were created, and I will summarize a few of them below.

Free 'grilled cheese sandwishes'

If there is something that we love, it is the well-known Vlam-tosti's at Francken. With this idea in mind, Francken offered unlimited free grilled cheese sandwishes, also known as the 'Dutch Tosti', everyday. After the brilliant idea of our treasurer, to offer different ingredients to make the most creative tosti's, he brought pesto, brie, honey and many more ingredients to build your own delicious creation. Freshmen were introduced to the Francken room and the room was filled with students during every lunch break.

Game night

All board games were dug up from the attics and closets for this Game Night in the Francken room. Instead of playing computer games like Call of Duty or Sporcle, card games like Klaverjassen or dice games like Mexen, Francken members were playing Monopoly, Risk, Regenwormen and many more games. For the real board game lovers there were even members daring to play two games simultaneously.

Crash & Compile

Our beloved Scriptcie has been put to work again! In collaboration with Quintor, Francken organized a Crash & Compile. Everyone was greatly impressed by the Pokémon themed adventure the Scriptcie devised, and, as shown above, some points were given for Pokémon outfits. The compile competition was won by YpkeYpkeGuusGuus, consisting of Ypke and Guus. Congratulations!

September barbecue

With flying colours, we surpassed the number of registrations of the barbecue last year! Nearly 150 students and staff members showed up to enjoy all the unlimited beer and meat. Already after a few hours, every belly was filled and we could stay outside till late in the evening and enjoy the warm and cozy summer breeze.

What is the time?

During the barbecue, our beloved clock was 'gebrast' by the study association for Biology and Life Science & Technology, Idun. After receiving the brasletter, some Francken members found out that it would take at least two weeks to get our clock back. As it is of course essential to know when it is 'Vier uur, Bier uur', they started operation 'Reclaiming the clock'. The board members were spammed with emails, messages and phone calls that were all about the same question: 'What is the time?'. Eventually it took less than a week to get the clock back to the Francken room!

Renewable energy: Solutions from solution!

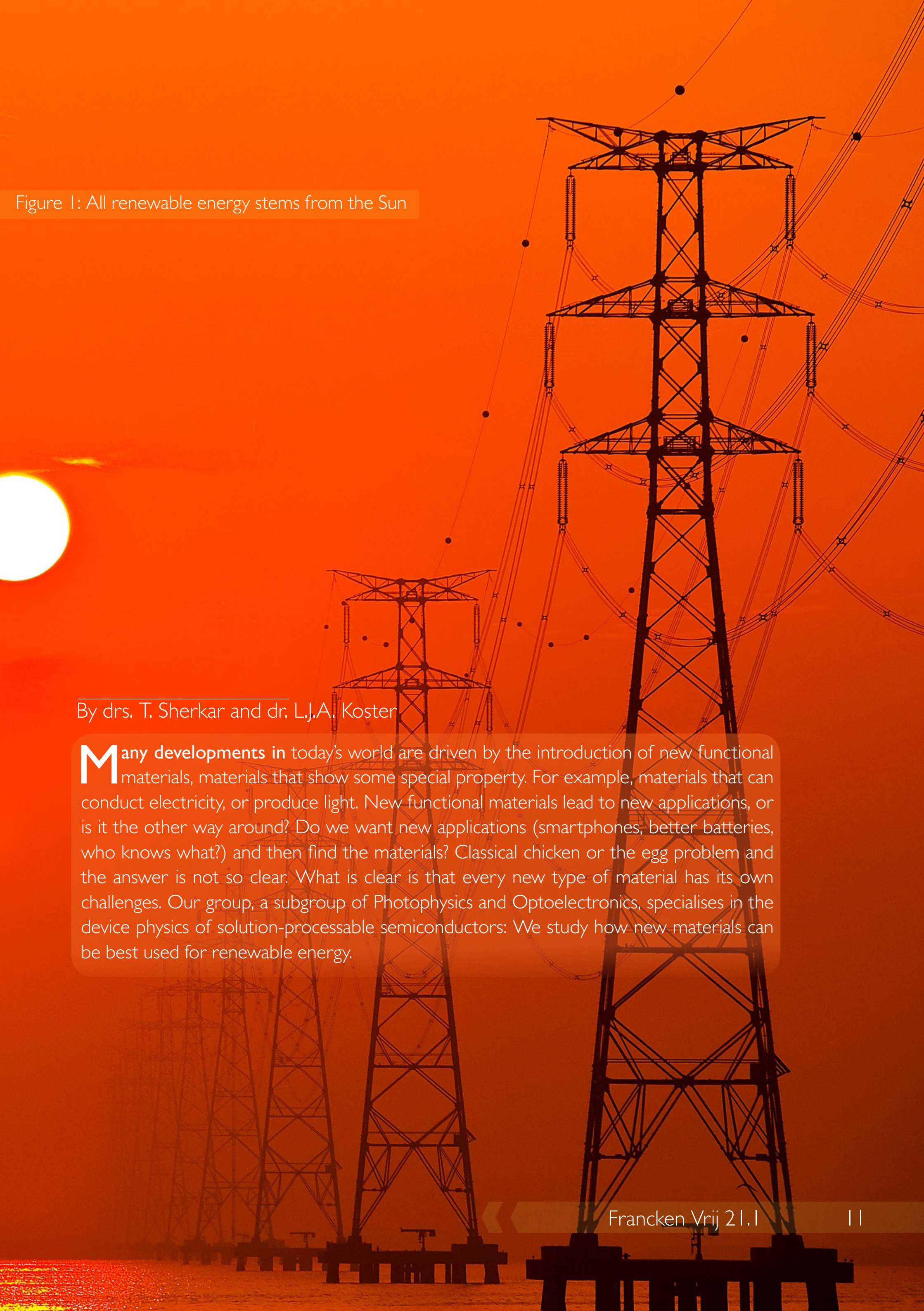

Figure 1: All renewable energy stems from the Sun

By drs. T. Sherkar and dr. L.J.A. Koster

Many developments in today's world are driven by the introduction of new functional materials, materials that show some special property. For example, materials that can conduct electricity, or produce light. New functional materials lead to new applications, or is it the other way around? Do we want new applications (smartphones, better batteries, who knows what?) and then find the materials? Classical chicken or the egg problem and the answer is not so clear. What is clear is that every new type of material has its own challenges. Our group, a subgroup of Photophysics and Optoelectronics, specialises in the device physics of solution-processable semiconductors: We study how new materials can be best used for renewable energy.

Global energy consumption is constantly on the rise, with the Energy Information Administration predicting an increase of 48% in current consumption by 2040.[1] Today, more than two-thirds of total energy consumed is produced by conventional (or non-renewable) energy sources, i.e. oil, gas, coal etc. With pollution levels rising and climate change no longer a fantasy, affordable clean energy is the need of the hour as we submerge ourselves into a sea of electronic devices. The solution is right above us, the sun, see Fig. 1. We receive enough energy from the sun in 1.5 hours to satisfy yearly global energy demand. Technologies that can harvest energy from the sun into usable energy are called renewable energy technologies. These hold the future to sustainable energy production and their importance cannot be overstated. One such technology is solar cells which convert solar energy to usable electricity. Solar cells made from organic and hybrid materials offer several advantages as compared to inorganic photovoltaic cells viz. integration in buildings, cost benefits by means of roll-to-roll manufacturing, etc. There are more options for renewable energy, though, such as thermoelectric generators. By using new materials, these devices can be made via solution processing.

What we do

Why?

In order to meet the global energy need in a sustainable way alternative sources of energy need to be developed. This is largely a matter of finding better materials, processes and device structures. Our field, device physics, contributes to this quest by identifying which materials properties need to be improved in order to improve performance (efficiency, stability, cost). A close collaboration between chemistry and physics is required to make progress.

How?

What we do is figuring out how devices work and how their performance is dictated by the properties of the materials that were used. Our work focuses on functional materials that can be easily processed from solution. This means that using the materials to make a functional device requires little energy and is cheap. Our strategy for doing device physics is combining experiments with simulations. Simulations help to better understand the experimental data. Experimental data, on the other hand, is crucial to make sure the simulations are realistic.

What?

We work on perovskite solar cells, organic solar cells, and organic thermoelectrics.

Perovskite solar cells

Perovskites have a ABX_3 crystal structure, with the A atom occupying the void in the BX_3 cage. Hybrid perovskites used as materials in solar cells have the composition $CH_3NH_3PbI_3$ (Fig. 2), with CH_3NH_3 being the organic part and PbI_3 being the inorganic part, hence their name. These hybrid

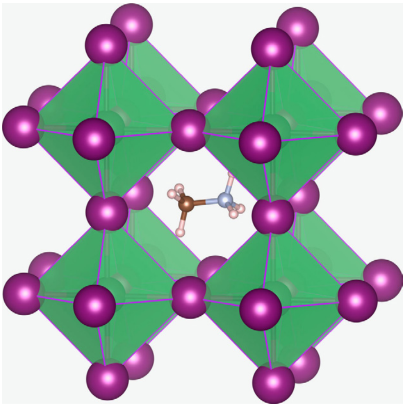

Figure 2: Perovskite ($CH_3NH_3PbI_3$) structure, with the PbI_3 cage and a rotating CH_3NH_3 ion in the centre.

perovskites can also be processed from solution, which makes their processing economical and energy efficient.

Perovskite solar cells have attracted significant attention in the last few years due to the unparalleled improvements in efficiency: Never before has a new type of solar cell improved so rapidly. The first such solar cell had an efficiency of 3.8% in 2009.[2] The current world record exceeds 22%. However, the understanding of the device physics is still limited. We use a combination of experimental and theoretical techniques to shed light on their workings.

Recently, it was suggested that the high performance of perovskite solar cells originates from the presence of ferroelectricity in the perovskite, which is hypothesized to lower charge recombination in the device. Ferroelectric polarization of the material would then push electrons and holes in different directions, thus limiting recombination. In a recently published paper,[3] we investigated and quantified the influence of mesoscale ferroelectric polarization on the device performance of perovskite solar cells. We implemented a 3D drift diffusion model to describe the solar cell operation. Study of microstructures with highly-ordered polarized domains shows that charge transport and recombination in the solar cell depends significantly on the polarization landscape viz. the orientation of domain boundaries and the size of domains. In the case of the microstructure with random correlated polarization, a realistic scenario, we find indication of the existence of channels for efficient charge transport in the device which leads to lowering of charge recombination, as evidenced by the high fill factor. However, the high open-circuit voltage, which is typical of high performance perovskite solar cells, is unlikely to be explained by the presence of ferroelectric polarization in the perovskite.

We have developed a device model[4] which quantitatively explains the operation of perovskite solar cells, including charge generation, drift and diffusion of charges and recombination. We fit the simulation to the experimental data of vacuum deposited perovskite solar cells (made in Valencia, Spain) over multiple thicknesses and study the device behaviour under different operating conditions to delineate the influence of the external bias, charge-carrier mobilities, energetic barriers for charge injection/extraction and, different recombination channels on the solar cell performance. By doing so, we identify a unique set of material parameters and physical processes that describe these solar cells. We identify areas for improving the efficiency of these solar cells. This is the first device model quantitatively explaining the device physics of perovskite solar cells.[4]

Our current research includes study of grain boundaries (interfaces between different grains of perovskite in a thin-film) which affect the solar cell performance. In what way, remains to be found out. We are also collaborating with research groups in the Netherlands and in Spain to explain the influence of different device structures and charge generation profiles, which can help to design improved solar cells with record efficiencies.

Organic solar cells

The organic materials used in organic solar cells are conjugated. This makes them semiconducting. Organic solar cells potentially have many advantages over their inorganic counterparts -such as cheaper manufacturing, and being flexible and lightweight- but to date their efficiency has still been much less than inorganic solar cells. However, in a recent paper,[5] we have shown that there is no fundamental reason why this should be so: organic solar cells can be as efficient as inorganic ones and that a doubling of the efficiency is possible, taking them into the 20%-efficiency realm (comparable to silicon solar cells).

In contrast to inorganic semiconductors, light absorption in organic semiconductors does not directly result in free charge carriers. Instead, it produces excitons, which comprise an electron and a hole. The electrostatic interaction between the electron and hole that make up an exciton is so strong that the excitons do not split up spontaneously. Therefore, all organic solar cells must consist of two materials: an electron donor and an electron acceptor. At the interface between these materials, the exciton can be broken up by transferring the electron to the acceptor as this is energetically favoured. After this necessary dissociation, the electrons and holes reside in two different materials, reducing the probability that they will recombine, i.e. meet and eliminate each other. Clearly, organic solar cells are rather different from their inorganic counterparts in terms of materials, structure, and characteristics.

To get to higher efficiencies we study the influence of morphology, charge transport, recombination processes and the quality of the materials on solar cell efficiency. In a recent paper, we have demonstrated a clear link between one of the key parameters of any solar cell, the fill-factor, and the balance between charge transport and recombination.[6] This finding is an excellent example of how the interplay between experiments and simulations can be used to significantly improve our understanding.

One of the main differences between organic and inorganic semiconductors is their very different dielectric constant. Organic semiconductor typically have a low relative dielectric constant (3-4) which means that Coulomb interactions between charges are significant. As outlined in one of our publications, [4] this limits the efficiency of current organic solar cells. We are closely collaborating with several groups at our institute to design, synthesise and characterise organic semiconductors with increased dielectric constants.

Organic thermoelectrics

In the quest for renewable energy, the possibility to recover waste heat must not be overlooked. Thermoelectric generators (Fig. 3) can convert such waste heat to electricity without any moving parts by creating a voltage when there is a different temperature on each side. Such generators rely on the Seebeck effect: When a temperature gradient ΔT is applied to a material, a voltage difference ΔV may be generated. The Seebeck coefficient is defined as $S=-\Delta V/\Delta T$. The effect is dominated by the contribution from diffusion of charge carrier which tends to push charge carriers towards the cold side of the material until a compensating voltage has built up. Therefore the sign and magnitude of the Seebeck coefficient depend on the doping level of the material. For n-type semiconductors, electrons dominate and S is negative, for p-type S is positive.

For a given temperature difference, the efficiency of a thermoelectric generator is a function of **ZT**, where **T** is temperature and $Z = S^2\sigma/\kappa$, where σ is the electrical conductivity and κ is the thermal conductivity. Efficient thermoelectric generators require materials with high conductivity σ and Seebeck coefficient **S** while having low thermal conductivity κ.

Organic semiconductors have attracted increasing attention as low-temperature thermoelectric materials, offering the pos-

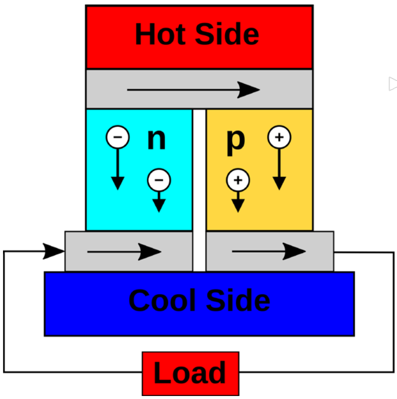

Figure 3: A thermoelectric generator can convert a temperature difference into electricity and requires a p- and n-doped semiconductor.

sibility of fabricating low-cost, large-scale and flexible thermoelectric modules. The thermal conductivity of organic semiconductors is intrinsically low, leaving the conductivity and Seebeck coefficient as the most important parameters for optimization. So far the development of n-type thermoelectric organics lags behind the development of their p-type counterparts. Our group is currently investigating a series of fullerene derivatives for their suitability as n-type thermoelectric materials. A close collaboration with the chemists (Hummelen group) enables us to fine-tune the chemical structure. Recently, we achieved the best Seebeck coefficient and conductivity ever reported for fullerene derivatives processed from solution. Our study shows that rational molecular design is an effective way to advance the development of organic n-type thermoelectric materials.

Outlook

New materials have shaped the world around us and this has always been the case. An ancient example is the transition from the Stone Age to the Bronze Age. The shift from stone to bronze as the preferred material for making tools and weapons dramatically impacted our forebears. This shift led to many improvements in agriculture and brought with it changes in the way people lived.
Solution-processable semiconductors will make possible new applications, changing our daily lives. Affordable, flexible displays; printed electronic devices; wearable electronics; and bio-sensing are just a few examples. To make this a reality, we need new ideas, new approaches, and new researchers.

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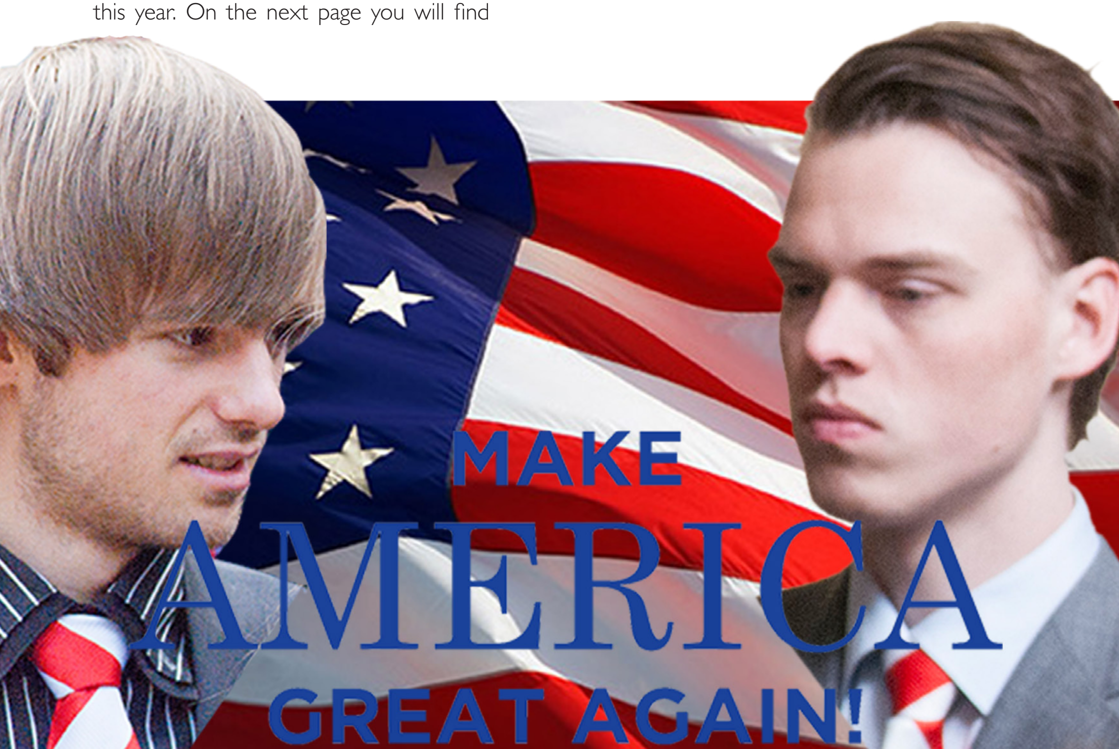
For more information, please visit our website.

Make Francken Great again!

In America

By Jasper Pluijmers

This year you won't be finding the usual Francken Abroad column, but don't worry because we'll still have Francken-members writing about their adventures abroad. Instead of a different writer every edition, Joran Böhmer and Rob Jagt will both be writing a column in every edition this year. On the next page you will find Joran's first edition about his master research at MIT, Boston. Rob's stor will start furtheron in this Francken Vrij, introducing his master research at CalTech. So if you want to follow what they are doing this year you should keep reading the Francken Vrij. Make America great again!



Studying Abroad Starring: Joran Böhmer

By Joran Böhmer

Let me first introduce myself… I'm Joran, I've been a member of the Francken community for around seven years and I study Applied Physics. I served a year in the board of year '13-'14 as the company commissioner. I haven't travelled a lot in my life and travelled outside of Europe only once before (if I'm not counting the Buixie trip of '12 to Istanbul). With over three years of study delay, I think I've spent enough time enjoying Groningen. So now I figured it is my time to do something new and exhilarating and what a great way to combine this with my Master's research! I've been accepted to do this at MIT, which is near Boston (in Cambridge). I'll kick this first edition off by planning the trip, continuing with my first impressions of being here. I will limit this edition to the trip and Boston itself. But don't worry, there are still two more editions to come!

Like all big changes, a plan to study abroad tends to develop very rapidly. No matter how much time you get to set your mind

This sounds easier than most people think it is and the truth is that it actually is.

to it, at some point the events will go faster than your mind can adapt to it. What started out as just an idea and the gathering of small pieces of information, quickly turned into a state at which it felt like there was no turning back. When I contacted a professor at home and told him which university I liked to go to, it didn't take too long for the e-mail to arrive that the host professor

Joran at MIT poker club

was happy to take me into his group. This sounds easier than most people think it is and the truth is that it actually is. You don't need to be exceptional in any way as long as you have the willingness for this to happen. From the moment the ball started rolling I was being pushed to complete subsequent steps, being guided by the host professor together with contacting people with similar experiences. Obviously it ended up in a bunch of last-minute fixing. Therefore it's advised to start at least six months ahead of the planned date of departure. This is true especially when travelling to the US. For some miraculous reason these bureaucrats need three times as much information as from any other country. This goes together with triple the amount of posts that need to put signatures on the forms concerned. Also, because they drown in the amount of information you give them, it's easier for the following contact persons to ask you for the same information again instead of trying to find it in one of the never ending dossiers of you that exist by now. Persistence is definitely required, but it is all except difficult to manage the preparations as long as you don't try to do it all by yourself.

And then I arrived in Boston. Boston is a fantastic city to live near. It's actually a pretty small city, which can easily be explored by foot. It's not as crowded compared to some other huge cities in the US. However, it has some huge imposing buildings that portrait the skyline of Boston and this can be seen from one of the many parks. In contrast to what I thought, the summers in Boston are incredibly hot. So I had the perfect circumstances to restore from my jetlag by walking around Boston and hanging out in the parks.

The first thing that I noticed is that everything is big. This holds for everything from cars, streets and buildings to all of my household goods and of course the true Americans. These household goods include my porch, barbecue and fridge! This last thing is necessary, because all foods and

drinks are triple the size as Dutch items. Unfortunately, for beers this only holds for the price tag. The fact that everything is enlarged sees to it that huge things don't stand out any more.
Boston appears to be known as a cycling city when you look at some of the souvenirs to buy. However, allowing bikes to ride anywhere, obviously shouldn't give a city the prefix 'cycling'. It's evident that cycling doesn't come that naturally for the Bostonians. Nearly everyone is wearing helmets and after sunset you might be able to spot some fairground attractions wearing helmets with flashing lights, while they heavily ring their bell as they pass by. The effect that this has on me, while riding a bike, is that drivers tend to be extremely careful and give me right of way very frequently. Also, people look at me like I'm crazy when I'm telling them I'm grabbing my bike to go home after some party (or social as they call them). I already lost count on how many times I needed to say: ''It's ok, I'm Dutch.''.
Overall, the US delivers constant laughing attacks. About its incredibly poor view on health, about its 'bigger and more is better' attitude, about its unnecessary complex bureaucracy, about its marketing and commercials and especially right now about its politics… 'Murica will not bore me!


Boston at day

Alumni Committee

By Friso Wobben

Recently, after a period of absence, the Alumni Committee has been revived with three members: Irina Versteeg, Max Kamperman and myself, Friso Wobben. The purpose of why our committee has been resurrected will be to re-engage with the alumni of our association through e-mail, LinkedIn and events. And that is why we want to bring the following to your attention:

LinkedIn Group

For some time now, T.F.V. 'Professor Francken' has had a LinkedIn group for its members and alumni, but little has been done with this group and the number of members is not representative for the size of our association. We want to make this group a platform where members and alumni can find each other and get relevant updates about Francken and related events. That is why we want to invite you to join this group, and ask you to invite your fellow (former) students with this link: *professorfrancken.nl/linkedin/*

Half Lustrum Event

Previously events for alumni were only organized once every lustrum, which meant that missing one of these would leave you without an event for ten years. To us, this gap seems a bit too big to bridge, and that is why we decided on organizing such an event twice per lustrum: one in Groningen during the lustrum, and one in the Randstad half way between two lustra. That is why we want to announce, with reservation, the half lustrum event:

Date: 20th of May
Location: Utrecht
Time: Late afternoon or early evening

For all other matters, we can be reached at alumni@professorfrancken.nl and we hope to see you at the half-lustrum event!

Life after Francken: Resevoir Engineers

By Ir. Thijs Huiskes

Apparently there is life after Francken. It is hard to imagine, but at a certain moment you have to collect your certificate which is the start of a new set of events which are then called "your life". And believe me, Life after Francken is quite fun! After some delay I started working in a field in which I find many aspects that are important to me in a job. The interesting technical aspect is very important to me, as is the continuous learning curve, besides the amount of responsibilities and impact that comes with a company that has a medium to small size and friendly atmosphere.

For people that do not know me: Thijs, 29 years old, graduated a few years back and lived during my student life mostly in the Franckenkamer. I have been "active member" since my first year to my last year, probable highlight was being member of the board of Francken, but I also did a few years of active duty for this magazine.

So I could tell you all kinds of things about my life after Francken, about the social life I (might) have, about the fact that I happily live together with my girlfriend in Utrecht, about all the nice travels I did in the past three years, and about all other kinds of social-personal stuff a psychiatrist might be interested in, but I am not going to. I am going to use the amount of precious space I got to tell you about my profession, how I came there, and if you are lucky, also why I like it so much.

Life after Francken

So what did I do after Francken? When I got my diploma, my thesis supervisor, who also happened to be programme director of physics, asked me if I already got a job. My answer was "no". There was a temporary job gap to be filled as a programme/study coordinator, and since I had been part of the Board of Programme Directors (opleidingsbestuur) as a student member, I was a suitable candidate. So there I accepted this temporary (three months) job. "Perfect", I thought, "now I have three months to search for a job". The temporary three months became a temporary five months, which became a seven months, until the temporary gap became a permanent gap. That gave me a signal: look for a job or find yourself being a programme coordinator for the next five years. Since I really wanted a technical job, I really started searching. After ten months, I finally found a job.
Applied physicists usually go to companies

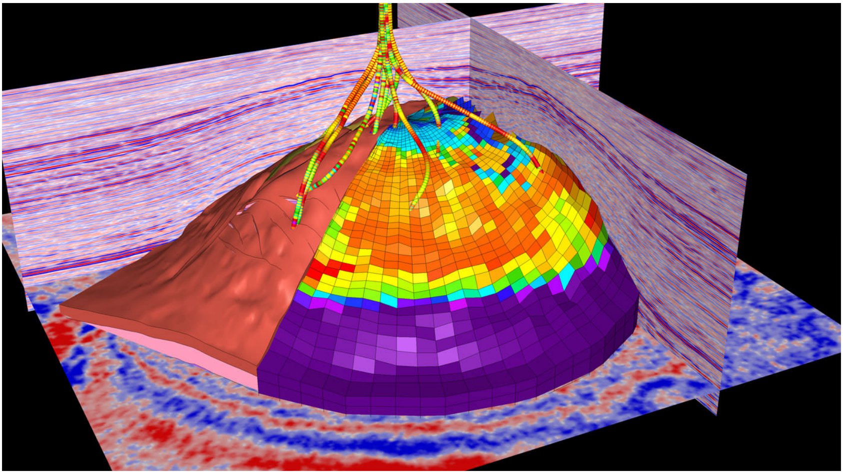


Figure 1: Coarse gridded dynamic 3D model. When analytical modelling is not sufficient (very complex cases, or three-or-more phase reservoirs), numerical 3D modeling can be used to understand the reservoir. Static structures (build by geologists) are used to construct a dynamic numerical model

as Philips and ASML. I tried to avoid those kind of companies, since I didn't like machines and other practical stuff. I like physical transport phenomena and solid mechanics, so why not look for that? An idea emerged: I recently went to some seminars of prof. Rien Herber (Geo-Energy), who talks about all kinds of things that happen in the deep subsurface. So I asked him for some advice and tips, and one full list of companies further resulted in me googling EBN (which I didn't know as a company). They happened to have a job opening as trainee reservoir engineer (which I didn't know as a profession). I immediately called and asked if applied physicists are allowed to apply for the job opening. The lady of HR didn't know, but she warned me that I had one day to hand in my letter and resume, since they wanted to select candidates. One thing came after another, and three weeks later I had a job as reservoir engineer.
Two and a half years later, I might be able to say a thing or two about reservoir engineering.

Reservoir Engineering
EBN is the company that owns and maintains the government part of the Dutch subsurface (read: gas, oil, and possibly geothermal energy), it is basically a government owned company, like ProRail or TenneT. So EBN is partner in Dutch concessions with companies like NAM and Total. There are about 250 producing fields in the Netherlands and thousands of producing wells. These fields are partially owned by EBN, and keeping track of reserves and production forecasting is part of the job of a reservoir engineer.
So here is the mandatory part of describing the work I do. The descriptions and situations are grossly simplified, so please forgive my short and somewhat boring way of quickly describing the fundamentals of reservoir engineering. Nevertheless, I keep

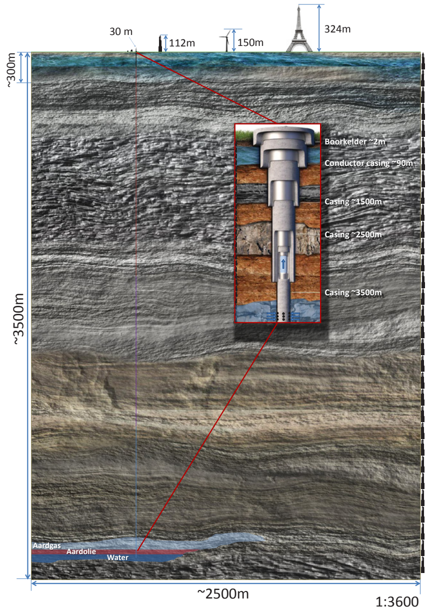


Figure 2: A schematic overview of the subsurface and a well.

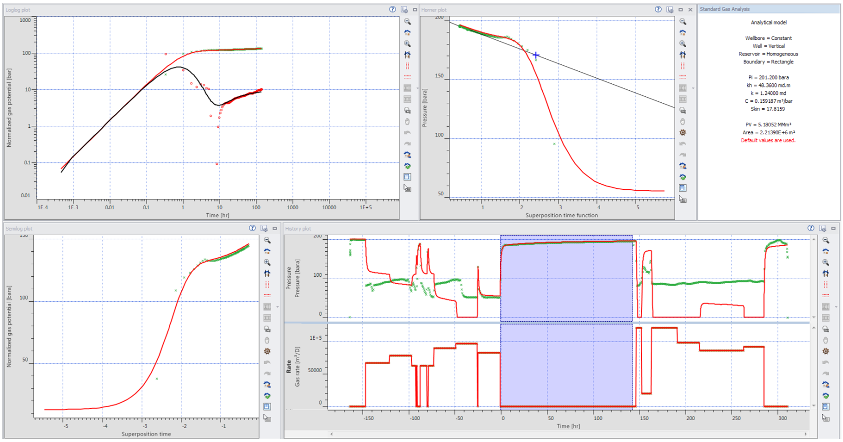


Figure 3: Putting high resolution pressure and its time derivative on a log-log scale (and fitting it with a model) leads to knowledge about the productivity of the well (kh, S) and the derivative leads to recognizing nearby no-flow-boundaries, multiple layer structures or other anisotropies, etc

being enthusiastic about even the simplest things in this field. (My colleagues keep coming to me for discussions about formulas – as they call it).

The biggest problem of working on structures in the subsurface is that you can't check or measure what is happening. You can construct many models, but you can never go 3 kilometers down to investigate a structure of a few square kilometers. That is a big difference with many other engineering fields. You have to work with the stuff you can measure and collect: pressure, production rates (volume), temperature, gas and liquid composition and properties and a lot of rock properties which you usually get from geologists (porosity, permeability, water saturation in the rock, heterogeneity and anisotropy, etc. etc.). What can we do with that?

First: what is a reservoir? Simply put, a reservoir is a piece of rock that is porous and permeable, which is under a rock that acts as a cap (to keep the fluid in). Usually, it is between 2 and 3 km deep. The subsurface starts with sand and clay, and then starts becoming rockier due to consolidation of material. So basically, we are standing on a flat mountain of a few kilometers deep, and we want to extract a useful fluid from the roots of the mountain. Where to look and how to get there are different areas covered in geology, geophysics and drill engineering (to name a few). For now, just suppose we have a reservoir, and it is gas filled.

Some basic RE principles

Real gas law

So here are some of the most essential principles to understand a whole bit of reservoir engineering: the real gas law, material balance and Darcy's law . The first one is a reminder of one of the simplest principles of Thermodynamics:

$$PV = znRT$$

Where z is the ideal gas law deviation factor, for most pressures between 0.9 and 1.1. The subsurface at a certain depth has constant temperature, so extracting gas from a reservoir is a game between P, z and V. This concept is used in the description of the material balance, or "principle of conservation of mass", which basically means: in an isolated system, the amount of gas in gas in the reservoir at $t = t_0$ is equal to the amount of gas extracted from the reservoir plus the amount which is in the reservoir at $t = t_1$.

Material Balance

As described above: knowing initial conditions and the amount of extracted gas leads to an indication of the amount of original gas in place. If we use the real gas law to determine the real gas volume at initial conditions t_0 and any moment later t_1, we get:

$$V = \frac{RT}{V_{m,sc}} \frac{z_{t_0}}{P_{t_0}} G_{t_0} = \frac{RT}{V_{m,sc}} \frac{z_{t_1}}{P_{t_1}} (G_{t_1} - G_{t_1})$$

Where $V_{m,sc}$ is the molar volume at standard conditions, and G the volume of gas at standard conditions. This can be rearranged to find

$$G_{t_0} = \frac{G_{t_1}}{1 - \frac{P_{t_1} z_{t_0}}{P_{t_0} z_{t_1}}}$$

Which basically means: if you know initial and current pressure, and know the amount of gas that has been produced, you

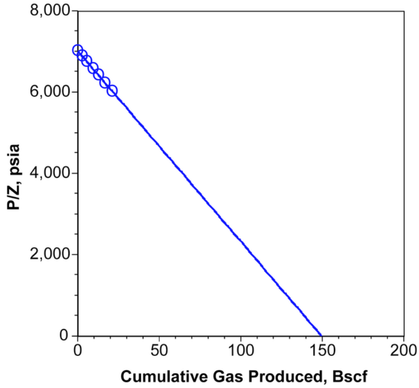


Figure 4: P/z vs IGIP plot. Using production and pressure data can be used to construct a material balance. This type of analysis can be expanded by using many kinds of tools, using dynamic data to understand reservoir characteristics.

can calculate the initial gas in place (IGIP). Thus: "how big is the field?". This simplified principle is shown graphically in figure 4.

Darcy's law

The radial flow equation (wells are usually vertical) for gas in permeable media is called Darcy's law. This principle is used in several applications, like production predictions and well test analysis (see fig 5). If we ignore possible constants and correction factors to correctly use certain reservoir shapes that roll out the solution of radial diffusivity equations, we get:

$$q = \frac{th(p_{avg} - p_{wf})}{B\mu[ln\frac{r_e}{r_w} - \frac{3}{4} + S]}$$

The flow is proportional to kh (permeability and net height of the reservoir), ΔP, and inversely proportional to the viscosity of the fluid multiplied by some factors that define the drainage area around the well. B is a factor that is always taken into account but is not that important from a physical perspective: it is the conversion factor for the amount of gas in a unit of volume in reservoir conditions (high P and T) to the unit of volume in conditions above ground, usually standard or normal conditions. For more info, use google or start and this wiki page.
\http://petrowiki.org/Fluid_flow_through_permeable_media#Line-source_solution_to_the_diffusivity_equation

Conclusion

So now you understand the basic principles of reservoir engineering. I hope the attached pictures give an impression of the variety of things a reservoir needs to do and know. What's next? For now, I have enough fun with keeping learning within this field. But you never know, I might soon end up somewhere completely else.
Typical Reservoir Engineering Figures
not match the observed history. This is called history matching. Since gas volume measurements are usually considered less accurate than pressure measurements, the models are usually used to match the pressure data.

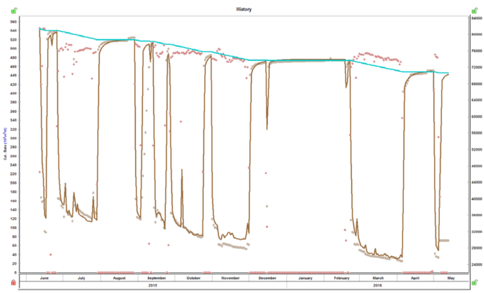


Figure 5: History Match. Any type of model is not valid if the model cannot match the observed history. This is called history matching. Since gas volume measurements are usually considered less accurate than pressure measurements, the models are usually used to match the pressure data.

Why is it so expensive to travel by airplane?

By Rob Jagt

It is 7 ‘o clock in the morning and I am on my way to the airport. The destination? Los Angeles! After 7 beautiful years in Groningen it is time to leave and start something new. For a period of 9 months I am going to study at Caltech (California Institute of Technology) for my MSc thesis in Applied Physics. I have been asked by the Francken vrij editorial board to write a trilogy about my time here. In the first part of this trilogy I’ll try to explain what I am going to do and specifically why it is relevant. The inspiration for this part? The fact that I totally got screwed over the price of my flight ticket.

The title question has many answers and given the fact that Econometrics is my hobby I would love to talk about the algorithms used to determine the price of my plane ticket, which so effectively squeezed every penny out of my wallet. But given

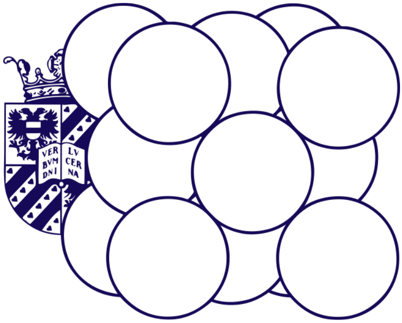


Figure 1: The Francken logo, together with its beautiful fcc crystal structure.

the fact that the number of industrial engineering students reading this article is negligible I'll just stick to the more fundamental core of the cost of flying an airplane.

To start with, let's look at our beautiful Francken logo containing a face centered cubic crystal. What is so special about this crystal? It is one of the two configurations in which you can stack spheres on top of each other and obtain the highest possible density. Most metals used to build planes have these high density crystal structures. This brings us to a more fundamental phenomenon that materials that tend to be very strong usually are very heavy and reversely materials that are very light tend to be very weak.

This is shown schematically in figure 2. Here the strength of the material is shown as a function of its mass density. Now the crux is that airplanes have to be strong enough to not fall apart in mid-air, but at the same time they should be as lightweight as possible to reduce the fuel needed.
For the airline industry reducing the weight of airplanes is a very lucrative business. The lighter the material used to build the airplane, the smaller your wings need to be, the less powerful your engine need to be and the less fuel you need to use to reach your destination. Because this makes the plane even lighter you again need less surface area for your wings, even smaller engines and yet again less fuel. This positive feedback has as a result that for every kilo-

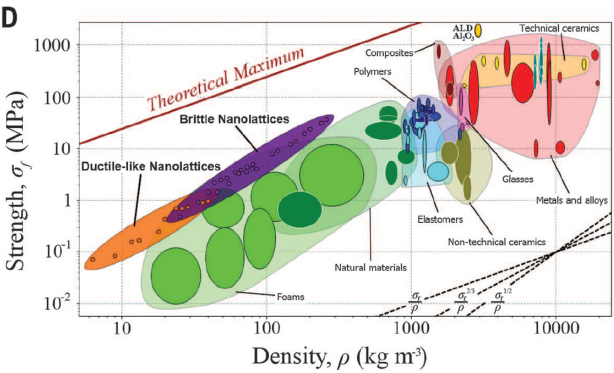


Figure 2: Experimental strength data against density for existing materials.

gram of weight you save on your airplane, you eventually save 6 kilograms. This explains why my airplane weighs a staggering 220.000kg to transport 366 people.

So how can we decrease the weight of the airplane without jeopardizing the structural integrity of the airplane? To answer this question we take a look at the following two architectural structures: the pyramid of Gizeh and the Eiffel tower of Paris depicted in figure 3 & 4. When we look at the weight and the height we see that although both structures have a comparable height, the pyramid of Gizeh weighs a lot more then the Eiffel tower. That is because the pyramid of Gizeh is of uniform density, whereas the Eifel tower is made of fractals. This lowers the weight significantly, therefore the lower parts of the structure have to support less weight, which means you have to use less materials etc.

The idea is to use this concept of architecture to make ultra strong and simultaneously lightweight materials. An example of this can be seen in figure 5. This is a microlattice on top of a regular dandelion.

Figure 3 & 4: Left: The great pyramid of Gizeh, 5.75E6 tons and145 meters high
Right: The Eiffel tower of Paris, 9.4E3 tons and 324 meters high.

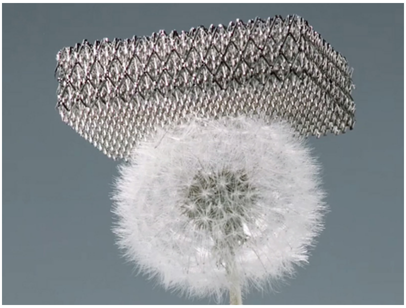
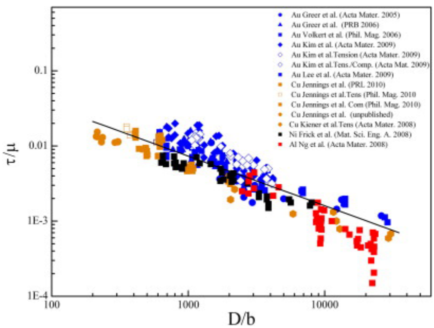


Figure 5: Example of a microlattice on top of a dandelion. Produced in Hughes research lab.

Due to the architecture of the lattice it has extremely low density and the dandelion is able to support the weight of the microlattice. However, adjusting the architecture of the material is only part of the story in creating our ideal low density high strength materials. Although these microlattices are very lightweight, they are not very strong. In order to increase the strength of these materials we need to reduce the dimensions down to the nanoscale.

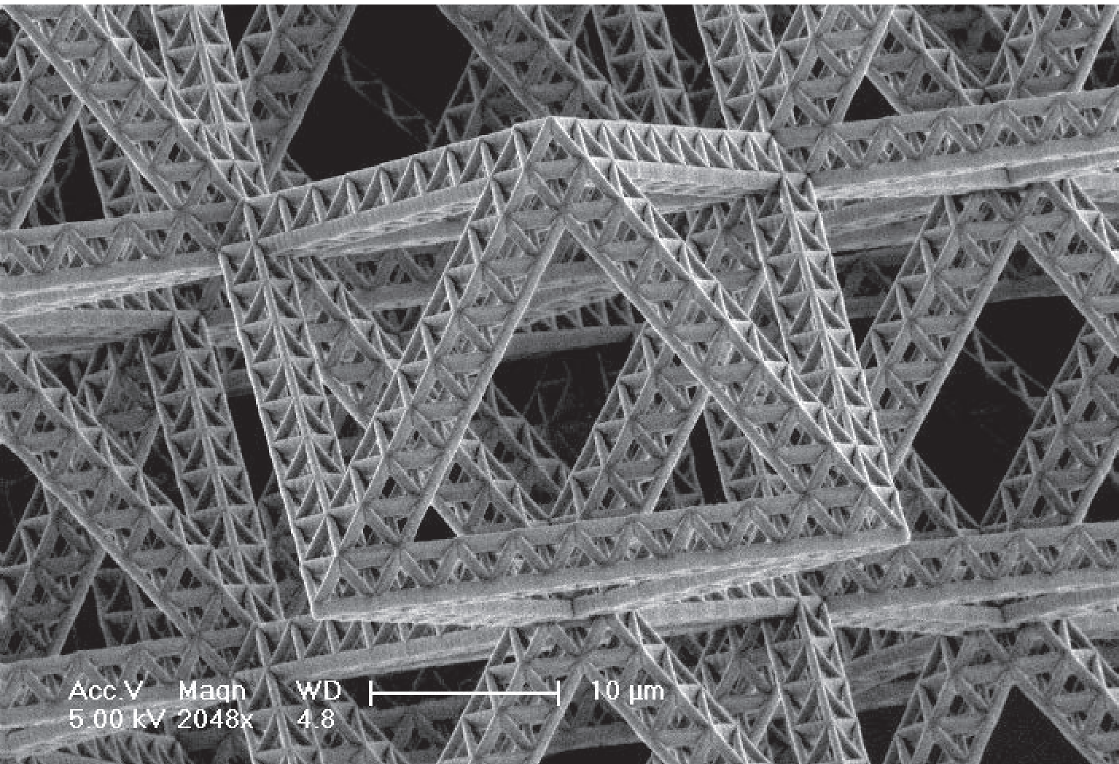
The phenomenon that materials tend to become stronger when their dimensions are reduced is generally referred to as a size effect. This phenomena have been known for quite some time and is also something our beloved honorary member prof. dr. J.Th.M de Hosson (or as he prefers it: Jeff) worked on together with my professor (prof. dr. Julia R. Greer) here at Caltech. Fig. 6 is from a review paper they wrote together

Figure 6: Shear flow stress normalized by shear modulus on appropriate slip system for most face-centered cubic (fcc) metallic micro- and nano-pillars tested in compression and tension to date.



in 2011 and shows a compiled plot of the resolved shear stresses normalized by the appropriate shear modulus as a function of diameter divided by the Burgers' vector for most of the currently published data on the non-pristine fcc nano-pillars subjected to uniaxial compression or tension. Basically what it tells us is that these materials get stronger when you reduce the dimensions. So combining the size effects present at the nanoscale and the architecture of the materials you can decouple strength from density and make materials that are both strong (and tough) as well as extremely lightweight. In this way you can reduce the weight of airplanes significantly and hopefully my flight back will not be as expensive as my flight to LA. In the next episode of this trilogy I will talk more about these nanoscale architected materials and how they are created. As a spoof in figure 7 you can see a teaser of how such nano architected materials may look like and we will see that size actually does matters!

Figure 7: Hollow nano architected trusses, made out of fractals.



On problems and solutions

By Remko Klein

Imagine you are in one of the exam halls of the Aletta Jacobs building, and you are about to start an exam. As soon as the examiner gives you the OK to start, you – being a smart student – swiftly go through the entire exam to get an idea of what you are dealing with. Whilst doing this you realize some questions instantly inspire fear and doubt, whilst others are a major confidence boost.

For example, don't you just love it when you read a question and it turns out that they have basically already given you the answer, and you just have to check that it is indeed correct? For example, you are doing Calculus 1 and in question 1a you are given some kind of differential equation, and they ask you to verify that a given function is indeed the solution. Sure thing! Just take some derivatives, do some basic arithmetics and poof, you're done. So long, and thanks for all the points!
But of course, eventually you run out of these sort of questions and you have to start trying to solve the more daunting ones. These are the ones that actually force you to come up with the answer yourself. So for example, question 1b could demand from you to actually solve a certain differential equation, rather than to just verify a solution. This usually requires actual thinking and perhaps even creative thought, which of course is much more difficult to

achieve.
Anyway, let me summarize the point I'm trying to make here: verifying a given solution to a problem usually seems much easier than actually solving the problem and thereby obtaining the solution yourself.

P vs NP

Now, there is actually a very famous problem in mathematics that, in a somewhat restricted setting, deals with this question of whether indeed verifying is easier than solving. This is the so called P versus NP problem, and it is one of the six remaining unsolved Millennium Problems (one of the originally seven problems has been solved). If you happen to be able to solve it you will be awarded the hefty sum of one million dollars and instant fame (though if you happen to solve it in a particular way you might actually become infamous, but more on that later).
Formally, the problem can be stated as: does P = NP hold? Where, loosely spoken, NP is the set of all decision problems whose solutions can be verified sufficiently fast by a computer algorithm[1] and P is the set of all decision problems that can be solved sufficiently fast by a computer algorithm.
To clarify: decision problems are problems that have a definitive Yes or No answer. The P vs NP problem thus only deals with this specific type of problems. (For an example text box on the 'subset sum' problem.) Also, sufficiently fast in this context means: in polynomial time. This means that if the algorithm needs n pieces of input, it can give you the answer in some time t that scales as a polynomial in n, i.e. $t \sim O(n^k)$ for some $k > 0$. So in practice the time needed might still be very large if k is very large, but at least it doesn't grow exponentially with n.

1: Here 'a computer algorithm' means a deterministic Turing machine, but let us not delve into these matters.

Example: The 'subset sum' problem

An example of a decision problem is the 'subset sum' problem, which is the problem of finding out whether a given set of integers has a subset whose elements add up to zero. So, for the set {1,-1, 2,4} the answer would be Yes, whereas for {-5, 3, 4} the answer would be No.

Now imagine you have a set of n integers. If someone gives you a solution to the subset sum problem for this particular set (i.e. someone gives you a subset that is claimed to sum to zero), then you can calculate this sum and verify that it is indeed zero. In fact you can do so in polynomial time, since $t \sim N$. Therefor the 'subset sum' problem is contained in NP.

However, it is unknown whether or not there exists an algorithm that – in polynomial time – can actually produce for you a subset that sums to zero. It is thus not known whether the 'subset sum' problem also lies in P. (The fastest known algorithm needs exponential time to produce a subset.)

Given the above, let us first note that it is immediate that the set P is contained in NP (i.e. easily solvable naturally implies easily verifiable). However, whether the converse statement is true or not remains unknown. Therefor the P vs NP problem can be formulated as: can all decision problems whose solutions can be verified sufficiently fast by a computer algorithm, also be solved sufficiently fast by a computer algorithm?

True or not?

As far as I know the majority of mathematicians think that the answer to the question should be negative, i.e. that not all easily verifiable problems are easily solvable. I think most people with experience in problem solving share this feeling; I surely do. However, the fact that this problem is still unsolved means that not a single easily verifiable decision problem has been proven to be not easily solvable, which is quite remarkable.

So what if our intuition is not correct in this matter; what if in fact P = NP holds and you would be able to prove this? Two things might happen, depending on whether the proof is constructive or non-constructive. If the proof is non-constructive, it will not give a method to actually solve a problem sufficiently fast; it will only state that it is in principle possible, but probably not much more. If this happens you would certainly

acquire quite some fame within the scientific community and would of course become a millionaire, but on a grander scheme not too much will happen.
On the other hand, if the proof turns out to be constructive, it does give us a method to actually solve problems sufficiently fast. Such a method could[2] actually have far reaching implications in all kinds of fields of science and also have a dramatic effect on our daily lives. For example, many encryption methods kind of rely on the assumption that indeed some problems are much more difficult to solve than to verify, which in practice is certainly still the case. However, with a constructive proof this might no longer be true and cracking encryptions might become peanuts, with disastrous results! For example, the international banking system might collapse altogether, probably leaving large portions of the world in disarray.
So if you happen to stumble upon a constructive proof, you might want to keep it to yourself so as to not plunge the earth in chaos. "Hey, what about my million dollars!" you say? Well, you could of course just hack some banks and make a lot more (and simultaneously leave the world stable enough for you to actually benefit from it!)

However, the fact that this problem is still unsolved means that not a single easily verifiable decision problem has been proven to be not easily solvable, which is quite remarkable

Anyway, it seems unlikely that indeed P = NP, let alone that someone will come up with a constructive proof and that the given method would indeed be sufficiently fast for practical purposes. But who knows, stranger things have happened I guess... En bij deze rust de theoreet zijn koffer.

2: Here we of course assume that 'sufficiently fast' is indeed sufficiently fast in practice, which certainly need not be the case. It might well be that the polynomial contains large coefficients and high powers of the input, thus leading to very large computation times.

Puzzling puzzles

By Steven Groen

Solving problems is something we all do and need to do. A good example of an activity in which we solve problems is studying physics or making an exam. Solving problems in these settings gives us a theory that predicts nature well, or a high grade on Progress., which can be useful. However, puzzling is a somewhat different activity: When we're puzzling, we bring more problems into our lives, and solving them doesn't really bring us anything seemingly useful. This gives us a new, interesting puzzle: 'What's the use of this puzzling thing?'. A good question! As a mathematics student and puzzling enthusiast, I would say that the use is intrinsic in the activity and the joy it brings, but as I know this is a magazine for Applied Physics students, I will also need to give some useful instrumental application of puzzling. I'll try.

Why bother?

Ever since I was young, which is not long ago, I have always had a large interest in solving puzzles and devising puzzles myself. But was this all a wast of time? Sure puzzling is a lot of fun (and, according to Bertrand Russell, time you enjoyed wasting is not wasted time), but is there also any practical use to it? I believe so! When we puzzle, we train various mental skills, depending on what kind of puzzle we are doing. In particular, creativity and solution-directed thinking are very important for most puzzles. Additionally, the knowledge we gain while puzzling could later be useful for solving an actual (physical) problem. In this sense, puzzling is much like fundamental mathematics. Not only because both are mostly for boring and old people, but also because the applications of them often appear after the

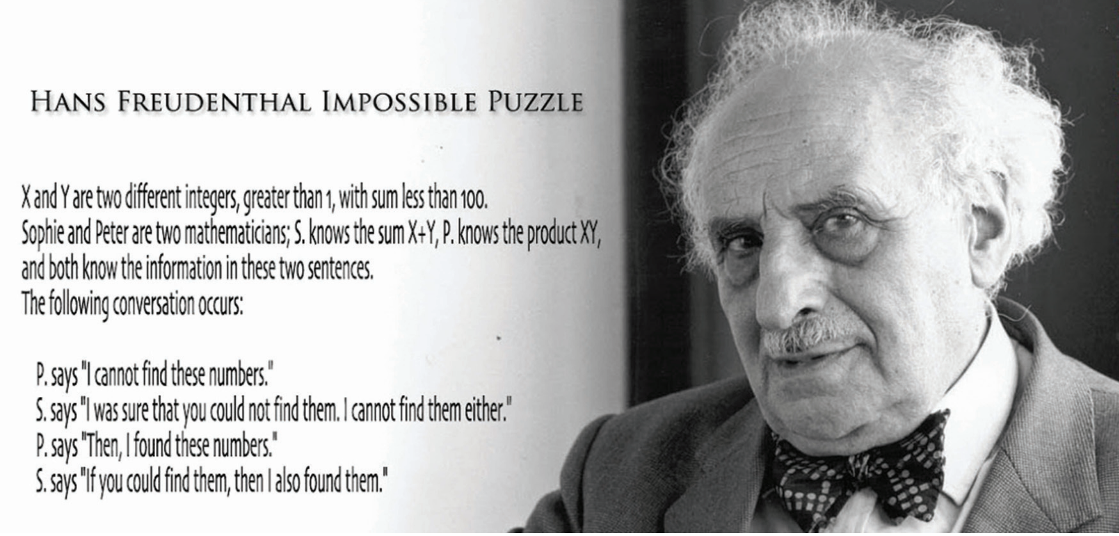


Figure 1: An enjoyable puzzle by Dutch mathematician Hans Freudenthal that took me quite some time to solve.

results are found. A prominent example is that most of the results in number theory were lacking practical use, up to the moment that we found that they are crucial for digital security. Similarly, some puzzles may look too abstract and without a link to reality, up to the moment when you find yourself having to transport a wolf, a sheep and a cabbage across a river on a canoo!

Puzzles with numbers

Above you can see one of my favourite puzzles with numbers. Martin Gardner, the most important name in the branch of puzzling and recreational mathematics, has called this puzzle 'virtually impossible'. Truth is, it just taks lots of time (at least in my case). The puzzle may look quite innocent, but solving it involves quite some number theory and dynamic epistemology. I solved it on paper, using the fact that the Goldbach conjecture holds for these small integers. It took an hour and a half at least. Arjen Kramer, another avid puzzler in our association, solved it more quickly, in a way I couldn't: using MATLAB. As I said, creativity is essential to puzzling.

This example illustrates how solving a simple, recreational puzzle can, by accident, teach you something about number theory. This kind of puzzles is Martin Gardner's specialty, so if you like this, or similar puzzles that take less time to solve, I recommend you to read some books or columns by him. Some other puzzles by him I read are the following:

- A group of Franckenmembers, 20 meters in length, moves through the hallway (20 meters). A hyperactive freshman walks a little bit faster. She starts at the back of the group, walks to the front of the group and then returns to the back. In this time the group has exactly crossed the hallway (that is, the entire group has moved through the hallway). What distance has the freshman travelled?

- Instead of walking back and forth, the freshman now walks in a rectangle around the group, 20 meters in width. What distance has she travelled now? (Warning: this one can't be solved analytically.)
- Is it possible to divide an obtuse triangle into a finite number of acute ones? If so, how? If not, prove it impossible.

Have fun solving these puzzles!

Some puzzles may look too abstract and without a link to reality, up to the moment when you find yourself having to transport a wolf, a sheep and a cabbage across a river on a canoo.

Puzzles with mere words

Anyone who has participated in the Feest met Francken mystery hunt might know what knights and knaves are, and also that I'm quite fond of puzzles related to this. The concept is devised and most usesd by stage magician, mathematician, logician, concert pianist and taoist philosopher Raymond Smullyan. The puzzle I would like to highlight is the following.

Second puzzle: *You've travelled to the island of L4D. On L4D, there are humans and zombies. Humans always speak thruthfully, while zombies always lie. This is not all: inhabitants of L4D understand English, but only answer in 'Bal' and 'Da'. You are aware that these words mean 'yes' and 'no', but you have no idea which is which. You wish to marry a beautiful princess, and her parents are testing you. You have already proved your capability in lifting weights and you've won the yellow shirt in the Tour de L4D. Now, the only thing left to test is your intelligence and ingenuity. For that, the father gave him a simple task. He said: 'You see that medicine man? Aks him a question to which he must reply 'Bal'.' Remember, you don't whether the medicine man is human or zombie.*

There are several solutions to this puzzle. There are a few quite ugly complicated solutions, of which I found one, and a simple elegant one, which I was hoping to find initially. I won't spoil your puzzling fun by giving a solution now, and besides, I think you are perfectly able to find one.

Again, this simple recreational puzzle requires quite a number of logical steps. Raymond Smullyan is a firm believer that solving informal puzzles with common sense teaches us much more than axiomatic steps in formal logic (although he has done quite

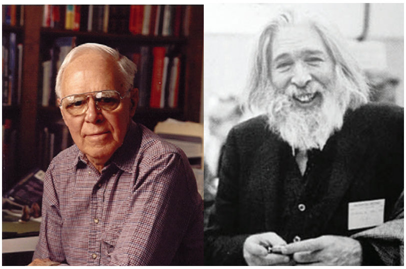


Figure 2: Martin Gardner (left) and Raymond Smullyan (right).

some work with that). He also writes on Gödel's incompleteness theorem and Tarski's undefinability theorem in a way such that anyone can understand it. If you are interested in this kind of puzzles, I would recommend you to read one of his books, especially *What is the name of this book?*. The 271 puzzles in this book include:

- You want to find out whether there is gold on the island of L4D. Every inhabitant knows the answer to this question. What do you ask someone to find out if there is gold? (Remember, they reply with 'Bal' or 'Da')
- Claims: "1: I have wings. 2: None of these two claims is true." *Flies away*
- What is the name of this book?

Ingenuity

Some puzzles, and their solution(s) can teach us a great deal of ingenuity. I think the following puzzle, also sampled from *What is the name of this book?*, is an excellent example of this:

Third puzzle: *Anton and David, approach eachother in the hallway (20 meters in length) on monday. Needless to say, they want to give eachother a box. They both move at a velocity of 2 m/s. A hyperactive freshman starts running in between them, with a velocity of 10 m/s. She runs from Anton to David, then back to Anton, forth to David, ad infinitum, until Anton and David meet. She doesn't lose velocity while turning. Clearly she runs an infinte number of increasingly smaller distances. What is the exact distance she runs?*

Are you thinking about series right now? George Palasantzas? I know I was when I read it, and it is indeed a way to solve the puzzle. You can even make a beautiful space-time diagram and analyse the intersections of her path with the boardmembers'. You'll get the correct solution.
However, there is a much simpler and more ingenious solution. It is easy to see that it takes 5 seconds for Anton and David to meet. The freshman has a constant velocity, so it must be that she travels 50 meters.
A funny anecdote waswhen this puzzle was posed to mathematician and physicist John von Neumann. Within a matter of seconds, he replied 'The freshman travels 50 meters.. Someone asked: 'How did you do that?'. 'Simple', he said. 'I summed the series.'
If even a genius like Von Neumann can learn from the ingenuity in solutions of simple puzzles and riddles like this one, let's be humble enough to conclude: so can we!

Solution

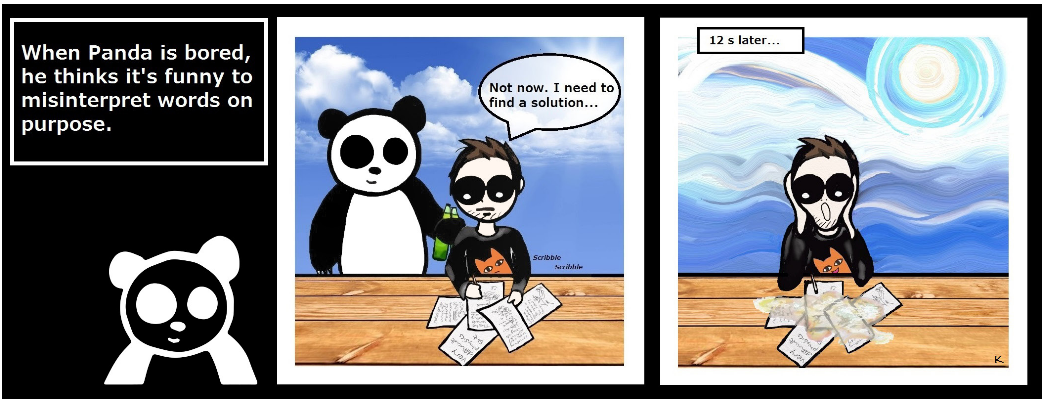
By Steven Groen

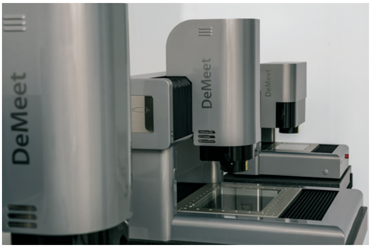
We must say that it took us by surprise when the previous edition of Francken Vrij taught us that some Franckenmembers outside the redaction of the Francken Vrij are also perfectly capable of making an ingenious and challenging puzzle. Credits to Arjen Kramer (the inventor of Kramer primes) for this. Now, as the theme of this edition is Solution, I decided to flip the concept of this rubric: it is now your job to make the puzzle! The solution to your puzzle, however, is given by us, and can be seen below. The interpretation of this table is completely up to you. The reader who admits the most ingenious and original puzzle will win a pet of the my choiche. Correspondence about the prize is of course possible, but highly likely to be completely futile. Good luck!

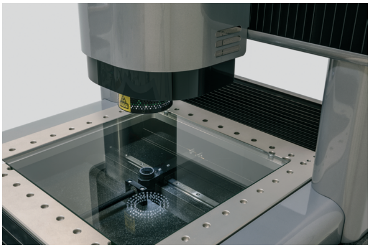
X	A	B	C	D	E
1	YES	30	TWO	FMF	1942
2	NO	0	ACE	FINLAND	1984
3	YES	JUF	JACK	FRANCE	1992
4	YES	32	KING	FIJI	1995
5	NO	JUF	TWO	FRANCKEN	2016

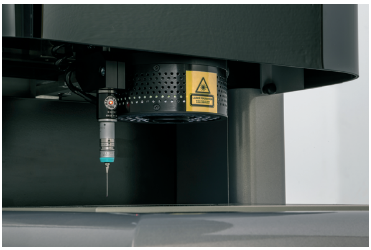
Comic

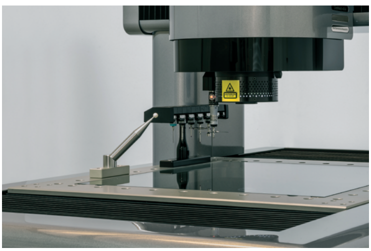
By Kathinka Frieswijk











Schut Geometrische Meettechniek is een internationale organisatie met vijf vestigingen in Europa en de hoofdvestiging in Groningen. Het bedrijf is ISO 9001 gecertificeerd en gespecialiseerd in de ontwikkeling, productie, verkoop en service van precisie meetinstrumenten en -systemen.

Aangezien we onze activiteiten uitbreiden, zijn we continu op zoek naar enthousiaste medewerkers om ons team te versterken. Als jij wilt werken in een bedrijf dat mensen met ideeën en initiatief waardeert, dan is Schut Geometrische Meettechniek de plaats. De bedrijfsstructuur is overzichtelijk en de sfeer is informeel met een "no nonsense" karakter.

Op onze afdelingen voor de technische verkoop, software support en ontwikkeling van onze 3D meetmachines werken mensen met een academische achtergrond. Hierbij gaat het om functies zoals ***Sales Engineer***, ***Software Support Engineer***, ***Software Developer (C++)***, ***Electronics Developer*** en ***Mechanical Engineer***.

Je bent bij ons van harte welkom voor een oriënterend gesprek of een open sollicitatiegesprek of overleg over de mogelijkheden van een **stage-** of **afstudeerproject**. Wij raken graag in contact met gemotiveerde en talentvolle studenten.

Voor meer informatie kijk op **www.Schut.com** en **Vacatures.Schut.com**, of stuur een e-mail naar **Sollicitatie@Schut.com**.

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