Expedition Strategy
A week full of strategy consulting

Inside View
The importance of composition

Francken Abroad
Studying at Stanford University

Francken Vrij
Composition

23.2 Composition

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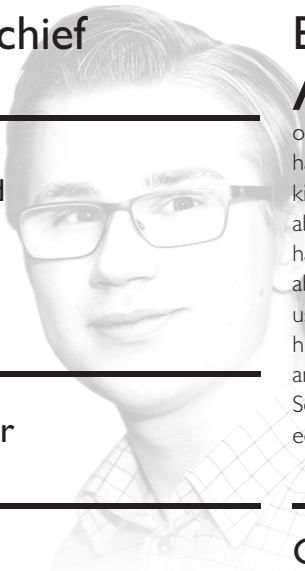

Editorial

A good Francken Vrij is a composition of an amusing chairman's preface, an overview of some Francken activities which you shouldn't have missed, an interesting article, a brain cracking puzzle, and of course a member writing about one's journey (through life). This edition has it all! Prof. dr. M. A. Loi has written an article about perovskite solar cells, Gertjan has written us a lovely poem, and Hilbert will tell us about his time in the USA. Also, this edition will feature an article about expedition stragegy by our own Secretary. I believe we have composed a great edition and hope you'll enjoy reading it!

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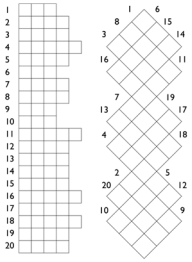
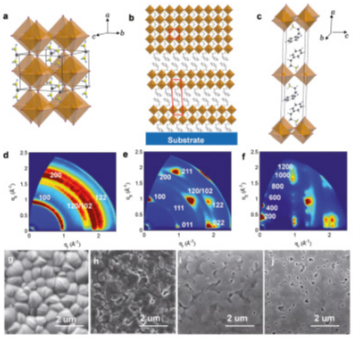
Edition 23.2

21 Inside View

Prof. dr. M. A. Loi

Professor Loi writes about tin-based hybrid perovskite solar sells and its power conversion efficiency and the challenges compared to lead-based solar sells.





34 Composition of the Francken Vrij

Jasper Pluijmers

Jasper explains some theory behind composition, and applies it to the Francken Vrij.

29 Puzzle

Gertjan Pompstra

For this edition Gertjan has writen a poem for, there is only one problem: it's a puzzle. Can you solve his riddle?
Also, from this edtion onwards, we'll award a real price for the first person who sends us the solutions to the puzzle.

Chairman's Preface

By Joris Doting

The music we play in the Franckenroom, the eight cards in your hand while you're hungover on the couch, the way your beer tastes and foams. It all has to do with one word: composition. But it doesn't stop there: the people in your committee (or board), your burger from the Burgerbakkerij, and the posters on the wall. Basically, everything is a composition. So are the formulas that describe the laws of physics, this piece of text and even this entire Francken Vrij. But back to the music. As you may know, we have had a piano in the Franckenroom for about a year and a half now. This beautiful piece of furniture is quite symbolic, as a lot of composition has been done on such an instrument throughout history. Not to forget that our honorary member, prof. de Hosson, played it at the farewell party of our other

honorary member, prof. Francken himself. Writing our own textual compositions, such as 'Het Harmonie Lied', 'Mag ik dan een Rietje?', and the 'Borrelcie Ballad', to existing melodies till the early hours of the morning are some of the fondest memories I personally have of the Franckenroom. The piano was an invaluable tool to accomplish this. But alas, by now the piano is old and out of tune (even more so than when we got it). Therefore, I say we invest in the right places and restore this symbol of our history, study and community to glory, if necessary by replacing it with a worthy version!

News of the Associaton

By Chantal Kool

Time flies… basically always. A lot has happened in the world, including a shutdown in the USA, a Brexit which is still not off the table, and Queen was number 1 again in the Top 2000. More importantly, there also happened a lot within our beloved association. Therefore, I would like to help you all with refreshing your memory and remind you of the best activities we had in this edition of news of the association.

Karting with the Sportcie

Maybe partly due to my love for Formula 1 racing, the Sportcie decided to go to Kardinge to go karting. This is probably one of the few activities where all the participants were sober and, although this was the case, the difference in driving abilities was... interesting. Eventually after two rounds of racing and a finale, Gerben was the king of the track, putting all of his TrackMania experience into practice. Finally, I am happy to announce that no injuries (besides bruising) occured.

Tour de Francken

This year again le Tour de Francken took place. To no one's surprise, Teampje Onzin managed to bike themselves to victory once again. For the first time in history, a board team also competed (sorry Leon, Joris and Bradley), but didn't win because of my *mediocre* adting abilities. A lot of mountains and sprints were conquered that night, and the next morning all the participants felt the exhaustion of this heavy trip (at least I did).

Kerstdiner

The hallway in Gebouw 13 was filled with long tables once again. Everyone did their best at creating a delicious dish, ranging from soup to amazing deserts and pastas. The wine consumption was pretty reasonable and the sjaars were playing some kind of game called *"stiften"*, for some reason. To make the Christmas vibes "complete", the Franckenroom was transformed into a ravecave, how cosy!

Karakterborrel - Tram 13

This "welcome to 2019" Karakterborrel was a bit different than the ones before. For this borrel, we moved to the pub Tram 13, a pub that is a bit smaller than Jut and Jul, but serves Hertog Jan in bottles and has the option to use their fryer to fry *bitterballen* and *loempia's*. Although this will probably be the only time there will be a borrel in this pub in 2018-2019, everyone was very enthusiastic and we started 2019 with a great event!

TNO excursion

It was time for a Francken delegation to travel to The Hague to discover what is happening at TNO Headquarters. We travelled classically with vans, beer and music at volume 100 to visit the defence & safety

related department of TNO. The day consisted of some talks about what happens at this department, alternated with demonstrations of some of their projects. The day ended with a borrel, dinner in The Hague, and a lot of us being very enthusiastic about TNO.

Crash & Compile

This year the Crash & Compile was organised at our new sponsor, Belsimpel, at the Grote Markt. The programming competition was won by our coding heroes, Callum and Piter, who actually compiled, whereas lot of the other teams excelled in crashing. At Belsimpel, we got a tour through the company, they ordered the much appreciated combination of sushi and pizza, and the recruiters made sure we were not short on *"bittergarnituur"* and beer.

DNV-GL and the Winterborrel

With a modest delegation we biked to Vinkhuizen on the windiest day of 2019, -sigh-. At DNV-GL, we received talks on what they are doing at this marine/oil and gas based company. We got a tour through the different simulation and testing facilities. After all those talks about multi-flow fluid phases, we immediately moved on to another multi-flow fluid phase, but this in the form of Ice's and beer at the Winterborrel. The Franckenroom was turned into a winter wonderland with a lot of Ice, and all the participants tried to complete their stamp cards by completing activities, alternating between drinking and exercise.

Expedition Strategy

By Chantal Kool

Every year around September you see posters popping up around the faculty about Expedition Strategy (ES). For a couple of years I was already interested in joining, but the timing was a bit unfortunate. This year I decided that I really wanted to join this event, so I postponed my board duties for a week (sorry guys) and signed up. This event promises a week in which you will visit different strategy consultants, strategy what…? Let me first elaborate on what strategy consulting actually is.

Every student probably has heard about consulting before, the formal definition being: providing expertise to third parties in exchange for compensation. There are a lot of different fields and expertise within consulting, ranging from technology consulting to financial consulting to strategy consulting. What is then the expertise of strategy consulting you might ask? Strategy consulting is focussed on developing strategies for companies which help them realise their long-term goals. A selection of the different tasks strategy consulting is concerned with: product pricing, merging companies, private equity, expansion strategies and more. Since the nature of the projects is so diverse, people who are very good at digesting new information very quickly and who have a very strong analytical insight are needed. Besides only analytical skills, strong social skills are desired. You have to be able to do convincing pitches and to pinpoint the exact needs of the client by asking the right questions.

Enough about strategy consulting itself and back to ES. ES is open for members from

T.F.V. 'Professor Francken', Risk, Vesting and Lugus. A selection of 21 students plus the board of ES departed on November 25th by train to our Ibis budget hotel in Amstelveen. After a quick borrel to get to know each other it was time to head to bed, since we had to get up early on Monday. The week started with a visit to Strategy&, where we had a warm welcome with basically a second breakfast (a trend that would continue for the rest of the week). Every company visit consisted of an introductory talk followed by a case and, for the companies we visited in the morning, a lunch. In the afternoon we moved to the top of the Rembrandttoren to Bain & Co. After the formal part of the day we went out for dinner with the consultants from Bain, with the best red wine I ever had (I still need to check what wine this was). The day ended somewhere in a bar with craft beers, perfect!

The next day we started the day at Simon Kucher & Partners, a company focussed on product pricing. In the afternoon we went to Roland Berger. Both companies originated in Germany, whereas most of the other ones are from the USA, which created a slightly different atmosphere and company philosophy. With the consultants of Roland Berger we went to Joop Braakhekke's restaurant Le Garage, where we again enjoyed an amazing dinner. On Thursday morning we exchanged Amsterdam for Rotterdam where EY Parthenon is located. Situated right next to the Maas and with an office interior just as beautiful as the set of Suits, it promised to be an interesting afternoon. After a case for a cookie company and dinner on the spot, the evening started. In the evening we had a course on how to talk Rotterdams;

this resulted in the most hilarious situations of the week. If you want to know if I learned anything, just ask me once about this experience… When we were all fluent in Rotterdams we decided it was time to quickly head back to Amsterdam in the "partybus". Loaded with coloured LED's, a fridge filled with beer and a very decent sound system (read: a driving club) we headed back to Amsterdam where we classically ended the night in a karaoke bar. On the last day, the Boston Consulting Group (BCG) was on the programme. With everyone pretty tired from all the cases and the busy schedule, it was much appreciated that BCG decided to not let us tackle another case. Instead, they invited the improv comedy group Boom Chicago for a crash course on pitching. As someone who took improv comedy classes and does some acting on a regular basis, this was one of the highlights of this week. After a final dinner with the consultants from BCG, it was time to get back to Groningen., exhausted.

As you can probably tell from my experiences I had an amazing week. It is a unique opportunity to get to see so many strategy consultants in such a short time. As an (applied) physicist/mathematician you might think you are behind on business knowledge, but trust me that this is not the case. You might not know some specific terms, but with your analytical skills there is so much you can already do. Joining Expedition Strategy is an experience I can recommend to everyone, whether you are interested in a certain company, strategy consulting in general or even if you are only starting with your orientation on the job market, you will surely have a very inspiring week!

Comic

By Bradley Spronk

STUDYING AT STANFORD UNIVERSITY

By Hilbert van Loo

In the late summer of 2018, I had the pleasure of boarding a plane and crossing the Atlantic to embark on a journey in the United States of America. After spending 6 years (studying) in Groningen, it was time to start my final six months of being a student at Stanford University, which is formally called my (industrial) internship. To be quite fair, this internship is probably very akin to a typical master research project, also because I decided to stay here for six months instead of the obligatory 3 months.

For the people that do not know me at Francken, I'm Hilbert, I recently turned 25 years old, and have been involved in a variety of ways with Francken in all my years in Groningen. Most people will either know me as the chair of the board of '14-'15 (*Bestuur Ingenieus!*) or as that guy that brews the majestic drink we call '*Gebouw 13*'.

Figure 1: The Oval is a big patch of grass in front of the main buildings. You see a gardening team working on this part of campus basically every other day.

Silicon Valley

One of the main struggles in preparing for my journey to the sunny West Coast was the problem of housing. Of course housing in Groningen is bad, but here in the Bay Area (that's the area surrounding the San Francisco Bay) it is horrible. House prices have risen like crazy due to the insane influx of engineers to all the tech companies. A quick Google search will give you a list that entails more or less all the companies you use the hardware or software products of on a daily basis. (Apple, AMD, HP, Alphabet (i.e. Google), Facebook, Intel, Netflix, NVidia, Tesla, etc.).

The presence of these companies makes this area quite a special place. Especially for students here at Stanford, it's an amazing opportunity to be able to study in a place that is surrounded by all these career opportunities. This also makes it (relatively) easy for students here to land an internship for the summer, which in general is a big thing in the US. Where in the Netherlands we have relatively small summer breaks that we use to travel around or watch the Tour de France, students here work for most of the summer in internships (almost every summer!). It seems that doing a lot of "high-level" internships is also a necessity for finding a good job after your studies. Also, for a lot of students in the US, this is their way to earn money for the rest of the year (the internships pay really well).

Stanford

Besides being a top-notch University, there are other aspects about Stanford that make it a nice place. When I arrived here in August, the California sun was still shining

bright and every day the mercury hit a steady 25°C. It was actually surprising to see how quickly you get used to good weather every day. I think it took two months before I experienced the first rain.

There are a few things that Dutch people might not like about going to the US, but it is pretty different here compared to the rest of the country. For starters, the main mode of transportation on campus is by bike! This might sound like the most normal thing ever, but here in the US everyone is used to driving to work/university by car. Also, having a beer in a park like the Noorderplantsoen is something that is widely accepted in Groningen, however in the States public drinking (or having an open container of alcohol in public) is prohibited almost everywhere except for… you guessed it, Stanford.

One of the cool and very different things of studying in the US is seeing how campus sports play a big role in university life. It's pretty impressive to go to a football game (on campus!) where the stadium is about as big as the Amsterdam Arena (it has 50 000 seats). It is especially crazy because they only play a few home games every year, so the stadium is not used most of the time. Also in other sports Stanford invests a lot of time, money, and effort in letting student athletes perform on the highest possible level. Just to throw a small little fun fact in here to give you an idea about how seriously they take sports here: if Stanford was participating in the '16 Rio Olympics as a country it would be the number 10 ranking country in terms of Olympic medals (the Netherlands is number 11 in that ranking)! Although I'm not taking courses here and therefore didn't take exams, there is something else that is notably different about exams. The Stanford honour code dictates that students can't be formally surveyed

during their exams, meaning that once the exam starts all teachers have to leave the room! If you want to ask a question about the exam, you have to go outside of the exam room to ask the teaching assistant. Although I've been told that cheating does not really occur, I can imagine it might be tempting for some people. I don't think the honour code is the full reason for this, but it's also remarkable how much more homework and take-home exams students have here compared to Groningen.

Brain inspired computers

So let's introduce you to the research topic that I've been working on here at Stanford. As you all know, computers have become essential in all aspects of modern life (e.g. Franckenmembers playing CoD, Sporcle, or participating in a Crash&Compile). The continuous improvement of computers, partially dictated by Moore's law, which states that the number of transistors on a chip doubles every two years, has been going on for decades. Due to fundamental physical limitations, Moore's law will end at some point in time, raising the question: how will computers evolve after Moore's law will break down?

This fundamental limitation in the fabrication of smaller and smaller transistors, combined with the development of new algorithms in the field of machine learning, calls for a new era of computers. In the early 1990s, researchers started to investigate how to tackle this problem by developing "neuromorphic" computers. Like with many great nature-inspired inventions, the idea is to be able to fabricate computers which work as the brain works. Where a conventional computer based on CMOS

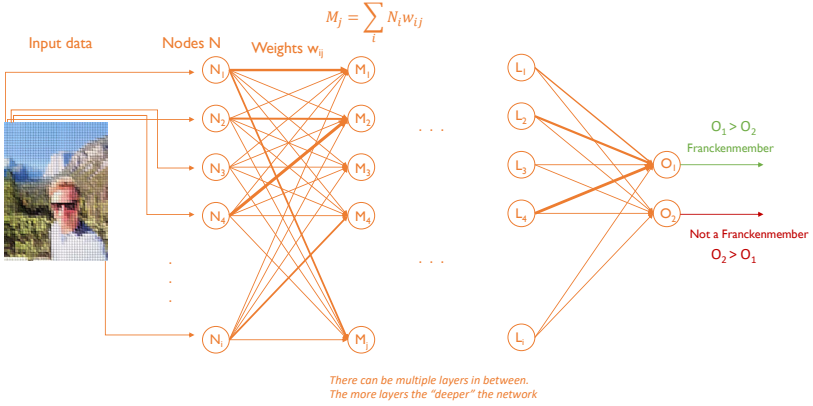


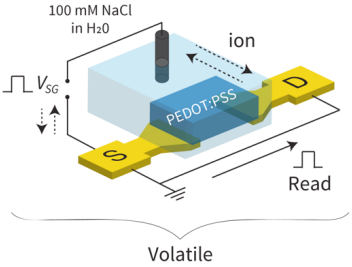
Figure 2: Schematic overview of an artificial neural network. See text for explanation

Figure 3: Stanford Stadium

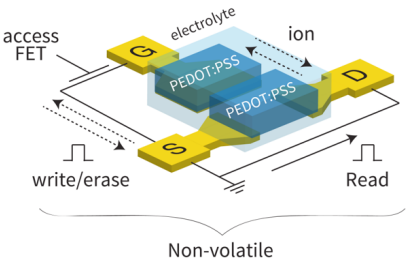
technology works with transistors which make them a digital binary system, the brain works in an analogue fashion. Furthermore, the human brain has the extreme advantage of a very low power consumption of ~20W. This power efficiency, combined with the massive parallelism that the brain has, makes it an ideal system for specific tasks like pattern recognition, decision making, and (machine) learning.

Artificial Neural networks

To briefly explain how this neuromorphic hardware would operate, let's take a look at how artificial neural networks work. Artificial neural networks consist of several layers of nodes (circles in fig. 2). These nodes are connected by weights (arrows in fig. 2). The network receives an input which could, for example, be a picture of a Franckenmember (i.e. each node receives a single value based on the color intensity of a certain pixel). The input the next layer receives is determined by the value of this pixel, but also by the weight (thickness of the arrow) that connects two nodes. The node sums all its inputs and the value it passes along is again weighted by a new set of weights. This process continues for several layers until a final output layer is reached. In this output layer we could, for example, end with two nodes, where one node represents the detection of a Franckenmember and the other node the detection of a non-Franckenmember. Which of these two nodes receives the highest value determines whether the algorithm detected a Franckenmember or not. In the learning



Volatile



Non-volatile

process we would show the algorithm pictures of both Franckenmembers and non-Franckenmembers. Based on whether the algorithm gives the correct output or not, we update the weights in the network (the arrows), so it would be closer in the future when it would see a similar picture.

The idea of neuromorphic computing is to do all this logic in hardware. Input signals would be voltages, weights would be resistors and the values that are passed along are therefore currents (i.e. Ohm's law). To do this, it is of the utmost importance to create a resistor that we're able to modulate in different resistance states. You could see this as an analogue memory element (not storing a zero or a one, but storing some analogue in between value/ resistance).

Organic electrochemical transistors

To further introduce my research here, I'll give a small introduction to the concept of an organic electrochemical transistors (OECT). Organic electrochemical transistors consist of an organic semiconductor channel connected to two electrodes which represent the source and drain contact. The organic film is immersed in an (aqueous) electrolyte, which is in contact with a third electrode, which acts as the gate of the device. Analogues to how a field-effect-transistors work, the potential at the gate electrode modulates the conductivity of the channel. Where an FET relies on a field effect to modulate the number of free charge carriers in the channel, an OECT changes its conductivity by injecting ions from the electrolyte in the channel, which changes the redox state of the polymer.

Due to the fact that OECTS rely on the injection of ions in an organic film, its capacitance is huge (orders of magnitude higher than that of a conventional MOSFET dielectric). This is because the organic film is doped over its whole volume, therefore we often refer to this type of capacitance as volumetric capacitance versus the "normal" areal capacitance. A non-trivial consequence of this is that the capacitance of such a transistor is mainly determined by the active material (the organic semiconductor) and not (as strongly) by the dielectric.

Electrochemical neuromorphic organic devices (ENODes)

The actual device that we make here is very similar to an OECT. The main difference here is that the gate electrode in an ENODe is made out of an organic semiconductor that also has a volumetric capacitance. We therefore now have two organic films sandwiching an electrolyte. This device is now basically a super capacitor, where one of these sides (the side we refer to as the channel) is connected to two electrodes (which enables measuring the conductance of this film).

By applying voltage pulses to the gate film, ions flow from the electrolyte into the channel, in turn (de-)doping the channel. After this modulation, the gate is disconnected by means of an access transistor, which assures the device doesn't discharge. The amount of charged stored on the device determines the conductance state of the channel and therefore enables the conductance to be gradually modulated. This gradual modulation represents a changing weight in an artificial neural network. I don't really have room here to tell you the part that I focused on. In short: I mainly spend my time here focussing on using solid state electrolytes (instead of using aqueous electrolytes) and also using new organic semiconductors.

Concluding

The experience of studying abroad was probably one of the most awesome things I did in my studies (of course next to being in the Franckenboard). Learning about a different culture, studying in a different environment, and meeting a lot of new people is something I would advise anyone to do. If you have any questions (about the research or going to the US?), or are thinking about doing something similar and want to chat, feel free to contact me!

Why composition and structure are important[1]

By Prof. dr. M. A. Loi

Three dimensional (3D) perovskite materials with an ABX_3 structure (where A is either an organic or an inorganic cation, B is a divalent metal cation, and X is a halide anion) have demonstrated superb properties as light absorbers in photovoltaic devices. Thanks to the intensive research efforts of a large scientific community over the past 8 years, lead-based hybrid perovskite solar cells (HPSCs) have achieved an impressive (above 23%) power conversion efficiency (PCE).[2] At the same time, researchers have also demonstrated progress in improving the thermal and photo stability of this kind of solar cell by using more stable precursors and robust hole/electron transport layers.[3,4] Despite these outstanding achievements, the toxicity of lead causes concerns about the possible large-scale utilization of this new type of solar cell.

Therefore, attention has recently turned towards lead-free HPSCs with the idea of replacing lead by less toxic metals. Among the various alternatives to lead, tin (Sn) has great potential as the Sn-based hybrid perovskites display excellent optical and electrical properties such as high absorption coefficients, small exciton binding energies, and high charge carrier mobilities.[5–7] However, the record PCE of tin-based HPSCs has remained at about 6% for more than 3 years since the very first reports by the groups of Snaith and Kanatzidis.[8,9]

The main challenges for further improving the PCE lie in preventing the easy formation of Sn vacancies due to their small formation energy and the fast oxidation of divalent Sn^{2+} into more stable Sn^{4+}. This causes high levels of self-p-doping in Sn-based

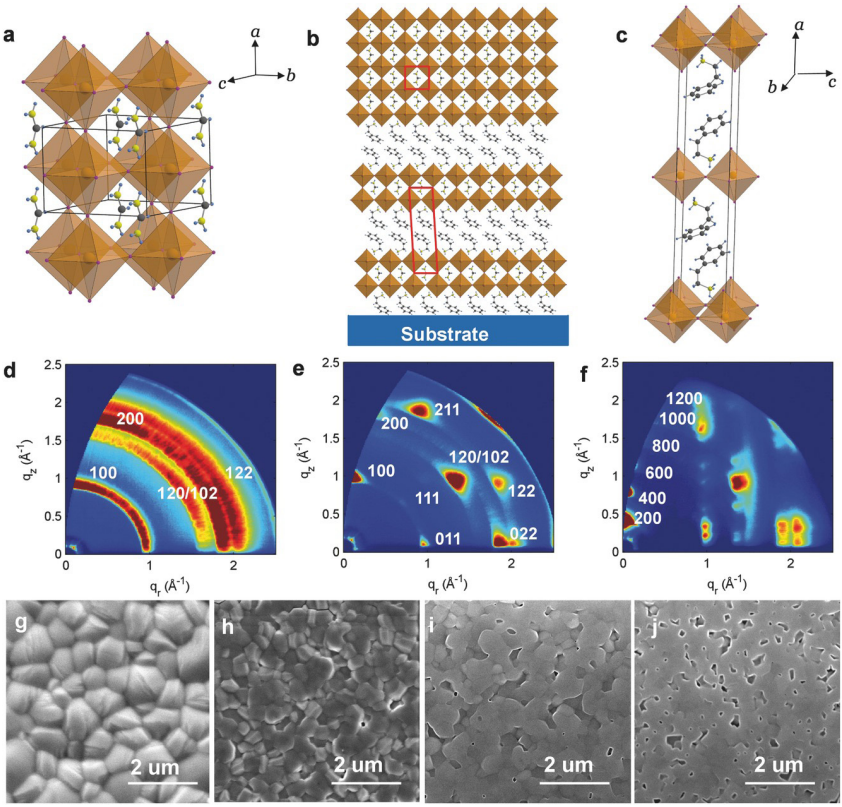


Figure 1: Crystal structure and morphology. Schematic crystal structure of a) 3D reference $FASnI_3$, b) 2D/3D mixture (2D 0.08 M), with the unit cells of each component outlined in red, and c) 2D PEA_2SnI_4. Respective GIWAXS images of samples annealed at 65 °C recorded at an incident angle of 0.25°: d) 3D reference, e) 2D/3D mixture, and f) 2D film. g–j) SEM images of FASnI3 films with different 2D Sn perovskite concentrations (0, 0.08; 0.12, 0.16 M).

perovskite films, with consequent severe recombination losses for charge carriers. Therefore, attempts to reduce the background carrier (hole) density have been made by incorporating SnF_2 into such films to fill tin vacancies and suppress oxidation of Sn^{2+}.[10]
However, an excess of SnF_2 deteriorates the perovskite film morphology and the device performance,[10] implying that the SnF_2 concentration must be kept low with the consequence that the background carrier density in these HPSCs is still too high to achieve equivalent performance to the lead-based perovskites. Therefore, it is necessary to develop new and more effective strategies to further reduce the background carrier density and improve the device performance of tin-based HPSCs.

In this article we report a PCE as high as 9% for tin-based HPSCs in a p–i–n planar device structure. These devices show negligible hysteresis and light soaking, with the background carrier density lowered by more than one order of magnitude compared to a reference cell incorporating an SnF_2 reducing agent. We demonstrate that addition of a very small amount (0.08 M) of layered (2D) tin perovskite in 0.92 M 3D tin perovskite induces superior crystallinity and a well-defined orientation of the 3D $FASnI_3$ grains (hereafter referred to as 2D/3D mixture perovskite). The extended ordering and packing of crystal planes improves the robustness and integrity of the perovskite structure and helps to suppress the formation of tin vacancies and therefore the background carrier density. The high degree of crystallinity and the preferential crystal orientation are fundamental for the improved solar cell performance. Moreover, the 2D/3D-based HPSCs have much higher stability upon exposure to light and ambient conditions due to the enhanced robustness of the perovskite film.

We prepared the tin-based perovskite films via a single-step spin-coating method with antisolvent dripping. The films were subsequently annealed at 65 °C for 20 min. We obtained pristine 3D $FASnI_3$ perovskite films, acting in this work as the reference, from a precursor solution comprising formamidinium iodide (FAI), SnI_2, and SnF_2 with a 1:1:0.1 molar ratio, in a mixture of dimethyl sulfoxide (DMSO) and N,N-dimethyl-formamide (DMF).

Our 2D/3D samples were made from a precursor solution containing mixtures of stoichiometric 2-phenylethylammonium iodide (PEAI) xM, FAI (1−x)M and 1 M SnI_2 and 0.1 M SnF_2, where x is 0, 0.04, 0.08, 0.12, and 0.16, corresponding to stoichiometric $FASnI_3$, $PEA_2FA_{49}Sn_{50}I_{151}$ (n = 50), $PEA_2FA_{24}Sn_{25}I_{76}$ (n = 25), $PEA_2FA_{15}Sn_{16}I_{49}$ (n = 16), and $PEA_2FA_{11}Sn_{12}I_{37}$ (n = 12).
We further assessed the effects of adding a small amount of 2D perovskite and of thermal annealing on the structure and orientation of the FASnI3 crystals with respect

to the substrate using grazing incidence wide-angle X-ray scattering (GIWAXS). Figure 1 d–f shows the GIWAXS patterns of the pure 3D, 2D/3D mixture and pure 2D perovskite films (annealed at 65 °C) recorded using an incident angle of 0.25°. The reference 3D film exhibits Debye–Scherrer-like rings whose positions correspond to those of the dominant peaks in the XRD pattern. The rings actually consist of many isotropically distributed spots, indicating significant randomness in the orientations of the grains within the polycrystalline $FASnI_3$ film. In contrast, the 2D/3D film (0.08 M) exhibits Bragg spots located around the same rings, indicating a strongly textured film morphology with preferential orientation of the grains with respect to the substrate.

In summary, the 2D tin perovskite functions as a seed layer to induce large-scale crystallization and orientation of the 3D $FASnI_3$ grains (see Figure 1b). The strong tendency of the 2D perovskite to form highly ordered, aligned structures is confirmed by GIWAXS patterns of the pure PEA2SnI4 films (Figure 1f). The 2D structure could be indexed according to the reported monoclinic unit cell with an a-axis of 32 Å, highly oriented perpendicular to the substrate. We speculate that the organic PEA+ cations are oriented perpendicularly to the substrate, and the van der Waals interactions of the benzene ring between the interdigitate PEA+ cations may facilitate self-assembly of the inorganic SnI_6 layers parallel to the substrate, inducing strong orientation and crystallization of the 2D PEA_2SnI_4.

Figure 1g–j shows scanning electron microscopy (SEM) images of the different perovskite films. The reference film has compact morphology with very few pinholes. The $FASnI_3$ grains range from 0.5 to 2 µm and pack together irregularly with rather sharp grain boundaries. Previous work has shown that grain boundaries in lead perovskite films have high concentrations of structural defects such as dangling bonds or vacancies. Therefore, grain boundaries function as trap centers for non-radiative recombination. Moreover, they give rise to energy disorder which is an obstacle for charge transport.

This may also apply to the case of $FASnI_3$ films, in which the tin vacancies are the dominant defects due to their low formation energy. The addition of very small amounts of 2D perovskite seems to fuse the FASnI3 grains together and blurs the grain boundaries. This observation is consistent with the improved crystallinity and larger grains indicated by the XRD patterns of the 2D/3D films. However, when the concentration of 2D perovskite increases up to 0.16 M, many pinholes appear in the $FASnI_3$ film, making the morphology far from ideal for the fabrication of solar cells.

To test the effects of the morphological and crystallographic changes in our $FASnI_3$ films on solar cell performance, we implemented them in devices using structures of the type ITO/poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT:PSS)/$FASnI_3$/C_{60} + 2,9-dimethyl-4,7-diphenyl-1,10-phenanthro- line (BCP)/Al as depicted in Figure 2. We chose C_{60} as it produces not only a more uniform and dense electron transport layer but also avoids the need for solvents.

For the fabrication of the reference cell based on 3D $FASnI_3$, we used SnF_2 as a reducing agent to reduce the background

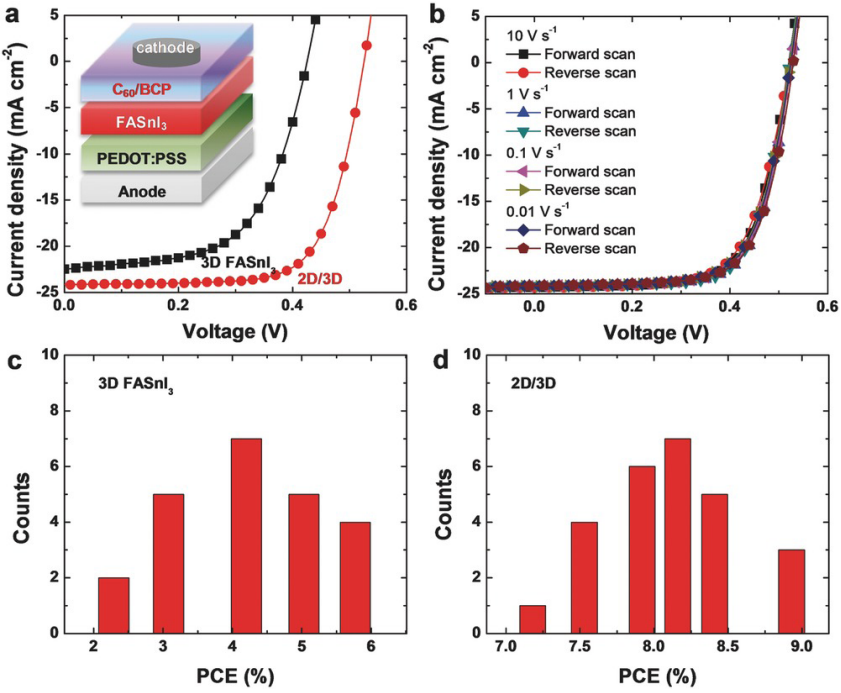


Figure 2: Device structure and characterization. a) J–V curves under one sun AM 1.5 G condition for the champion devices containing pure 3D and 2D (0.008 M)/3D perovskite (the inset shows the device structure), b) forward and reverse sweeps of the J–V characteristics of the champion 2D/3D perovskite cell measured at different rates, c) histogram of the reference cell reproducibility, and d) of the 2D/3D perovskite devices.

Device	VOC [V]	JSC [mA cm^{-2}]	FF	PCE [%]
3D	0.458	22.5	0.58	6.0
2D/3D	0.525	24.1	0.71	9.0

Table 1: Figures of merit for devices with 3D tin perovskite and 2D/3D tin perovskite layers under one sun condition.

carrier density. The reference device has an optimum PCE when the concentration of SnF_2 is 0.1 M and beyond this concentration the device performance deteriorates. This is because the excess SnF_2 forms aggregates in the $FASnI_3$ film as indicated by previous studies.

We further investigated the effect of thermal annealing on the device performance. Optimum performance was obtained when the active layer was annealed at 65 °C. The performance dropped significantly at higher annealing temperatures, most probably due to the formation of tin vacancies. This again highlights the importance of depositing high-quality $FASnI_3$ films at low temperature for efficient tin-based HPSCs. Figure 2a shows the current density (J)–voltage (V) characteristics under one sun illumination of the best performing reference cell, displaying a VOC of 0.458, a Jsc of 22.5 mA cm^2, fill factor (FF) of 0.58 and PCE of 6.0%. We list all the device parameters in Table 1. Figure 2c shows the distribution of PCE for the reference cells; the broad variation indicates poor reproducibility over the 20 fabricated devices.

We used the same experimental conditions to fabricate devices with 2D/3D films where PEAI was added to the active layer with different concentrations. We obtained the best performing devices with a 0.08 M concentration of 2D perovskite in the $FASnI_3$ film, and we observed a significant drop in performance for higher concentrations of 2D perovskite. This is because the pin holes in the perovskite active layer (see Figure 1j) give rise to shunt paths and direct contact between the cathode and anode, with consequent high leakage current.
Figure 2a shows the J–V characteristics of the best performing device with the 2D/3D film and a comparison with the best reference cell. The 2D/3D device shows a VOC of 0.525 V, a JSC of 24.1 mA cm-2 and an FF of 0.71 resulting in a PCE of 9.0%. It is important to note that this is the highest FF and PCE reported so far for all-tin-based perovskite solar cells. Moreover, the J–V curves of these solar cells are identical for forward and reverse scans and different sweeping rates (negligible JV hysteresis), as shown in Figure 2b. We also point out that this device shows no obvious light-soaking effect, which is confirmed by the fast saturation of the steady state photo- lumines-

cence (PL) upon photoexcitation with a 400 nm laser. The absence of hysteresis and light-soaking effects in these devices is very important, as it represents a sign of their reliability. These phenomena often affect Pb-based HPSCs and render the device performance unreliable. To further confirm our observations, we independently tested the steady state PCE of the device using 2D/3D mixture. The 2D/3D-based device from a different batch with a PCE of 8.8% (from J–V measurement) has a very similar steady state PCE of 8.5%, confirming the reliable device performance. The PCE statistics (Figure 2d) of more than 20 devices demonstrates the small variation and good reproducibility of our 2D/3D devices compared to the reference devices.
The device containing the 2D/3D film shows substantially improved performance parameters with respect to the 3D reference: 15% higher VOC, 7% higher JSC, 20% higher FF and 50% higher PCE.

The integrated JSC values (23.8 mA cm^{-2} for 2D/3D-based device and 22.2 mA cm^{-2} for 3D-based device) from the external quantum efficiency of incident photons to electrons (EQE) measurement confirm the value of the photocurrent density measured using the J–V characteristics.

In order to gain deeper insight into the 50% improvement in device performance with the 2D/3D film, we performed steady-state and time-resolved PL measurements on the different $FASnI_3$ films. The 2D/3D film has significantly improved emission intensity and lifetime, indicating much lower trap density than the pure 3D film. These results confirm that the extended ordering of the crystal planes and the reduced number of grain boundaries help to reduce the trap density in the perovskite film. As mentioned earlier, the highly ordered and oriented crystal planes parallel to the substrate may form fast transport pathways for the charge carriers in the device. In this case, the long-lived charge carriers can be transported efficiently to the respective electrodes before recombination occurs, which leads to the improved FF and JSC in the device.

Concluding remarks

In conclusion, we have demonstrated all-tin-based HPSCs with efficiencies of up to 9%. The addition of a trace amount of 2D tin perovskite initiates the homogenous growth of highly crystalline and oriented $FASnI_3$ grains at low temperature. The high degree of order has three positive consequences: (i) a reduced number of grain boundaries; (ii) the suppression of tin vacancies or Sn^{4+} and a consequent reduction in background carrier density by more than one order of magnitude compared to pristine $FASnI_3$ films; (iii) a longer lifetime of the charge carriers. Therefore, devices based on a 2D/3D tin perovskite layer benefit from low trap-assisted recombination, low shunt losses of the charge carriers and efficient charge collection. Moreover, the improved crystallinity of the active layer re-

sults in more stable HPSCs. Thus we overcome the bottleneck that has long been faced by tin-based HPSCs and demonstrate a way forward to further improve their performance.

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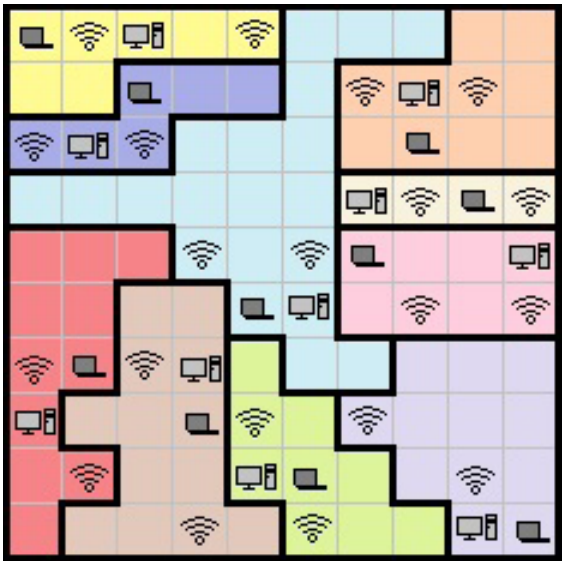
Puzzle

By Gertjan Pompstra

We know you are here for the puzzle, but before we start with the puzzle the Francken Vrij has two announcements: We have noticed that people love to make the puzzle, but don't always want to go through the trouble of sending us an e-mail to check their solution, therefore from this edition onwards we'll try to include the answers to last edition's puzzle! Our second announcement is that from now onwards the Francken Vrij actually awards prizes. So, from this edition onwards the puzzle will actually be very competitive (and no Steven, people can't win a mallard with retroactive effect).

So as promised, here is the solution to last edition's puzzle:



Before we start with the puzzle, I would like to start with a word composition in the form of a poem:

On one of the shortest days of the week, I did write,
A text message on the day before New Year's night.
I pressed a column of buttons and said I would attend,
And I will bring even a number of drinks for a friend.

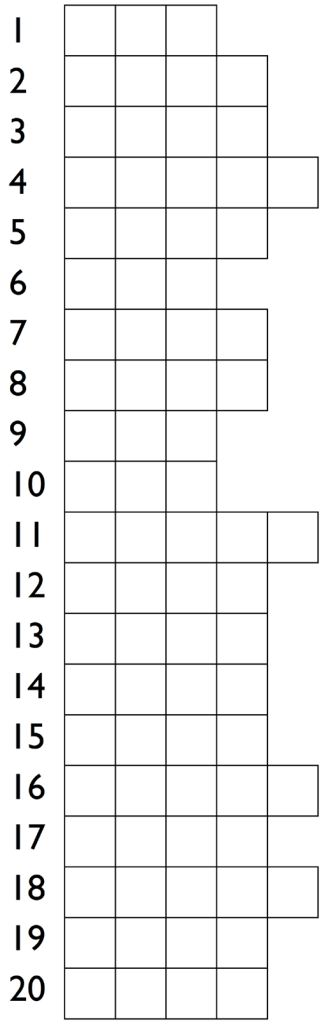
At a triangular roofed house was the party's location,
I entered as I heard the radio was tuned to a Dutch station.
The presenter announced the Dutch time and an Iron Maiden song,
As the singer counted off, the conversations went on.

At that moment we talked about researches on the faculties,
Somebody said he wired a tree to the power of a number of batteries.
Another one spoke about rabbits and their growth in population,
He said, three hundred years from now, they will cover the nation.
Someone else studied on a number of composite particles,
For which he had published their prime components in some articles.
All the square tables were used to play games,
Games with all different odds and different aims.
I looked for faces that were not on the dice in the glass,
As well as cards that weren't used in a game of klaverjas.
At one game a single bet kept on doubling in a glimpse,
And in the end, we all divided a perfect amount of drinks.

Back to the puzzle. Each diagonal column in the right grid should contain unique "words" composed of distinct non-negative single digits. The first type of words consist of the digit elements of a set of numbers. For example, the word belonging to the description "numbers divisible by 3" should have the digits 0, 3, 6 and 9.
The second type of words are answers on descriptions, which coincidentally can be expressed with the right number of digits. Therefore, a column of four squares with the description "German composer" should contain the digits 2, 1, 3 and 8.

The order of digits of each word in the right grid depends on their place. That is, if the two previous words would cross, then the digit 3 should be inside the crossing square. The left grid can be used to place the words of which you do not know their order yet.

Good luck with the puzzle! You can e-mail your solution to the editorial board and you might win a another puzzle!!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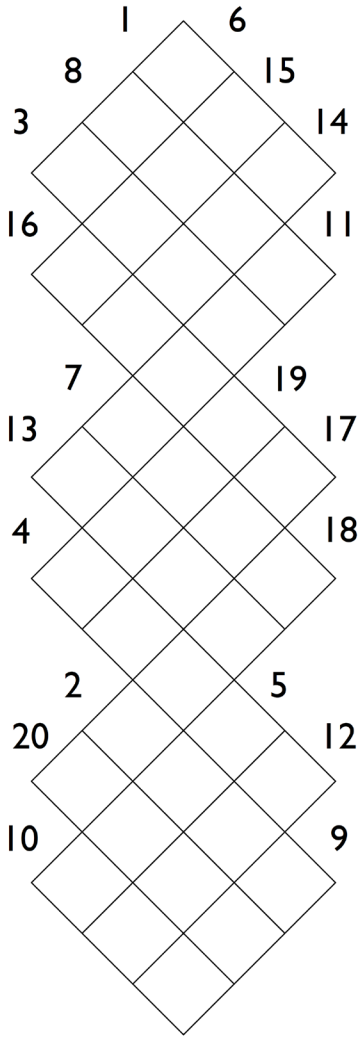
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ASML

Be part of progress

'More than a tech job'
Meet Pieter Smorenberg, a 2017 Delft University of Technology graduate who recently found himself back at university, this time explaining to students how technologically fascinating his job is.

Pieter studied precision and microsystem engineering, and now works as an applications engineer in customer support at ASML. He also spends some of his time as one of over 400 'ASML Ambassadors', giving guest lectures at his alma mater university or promoting STEM among school-aged children in the region.

"The more I tell people about working here, the more things I realize I appreciate about the company," he says. "A lot of people don't realize just how big ASML is. You realize it when you visit the campus. You see the big tower, the cleanrooms and parking lots; it's impressive. And then at the complete other end of the scale, almost all of the metrics we work with here are at an atom level – no other company is producing such advanced chip-making equipment."

Pieter has also found more than a career at ASML. "There's so much going on in our company. We have annual technology conferences where you can learn about what's going on in your department, and across the company. You can develop your network, and learn a lot about what other people are working on, and get ideas for yourself."

Celebrating our technology isn't the only way we have fun at ASML. "I go for drinks with the 'Young ASML' group for young ASML professionals," Pieter says. "You get to meet colleagues from all kinds of different departments. It's a really open-minded atmosphere, because everybody is there for the same reason: to share a good evening with each other."

As a customer support engineer, Pieter also gets to travel a lot to customers. "You learn a lot – socially and technically. It's been an eye-opener for me. We're diverse, in terms of education, background, and nationality, but we're all working together as one team because we have the same goal: make this incredibly complicated technology a reality."

Deciding on what your next step will be after your technical master's degree can be challenging. The ASML business course can help! This course will teach you about ASML's semiconductor manufacturing technology and help you develop both the hard and soft skills you'll need to work at a leading-edge tech company. Find out more at **workingatasml.com/businesscourse**

The composition of the Francken Vrij

By Jasper Pluijmers

One thing all students at our faculty are trained in is analyzing a big problem and understanding which smaller (but sometimes still very hard) problems are involved. This is a valuable skill which will prove itself very useful for the rest of your life. It is not something you can specifically practice but rather a skill you will develop over the course of your studies (provided that you actually do some studying). Not only university problems consist of multiple smaller problems but everything you can describe is in essence a composition object. In 2013 Lucien Hardy wrote a paper 'On The Theory of Composition in Physics' wherein he proposes a notation for these composition objects.

The basis of this theory is simple; composition objects consist of other objects and some type of join, which connects the two, in between them. For example a bottle of beer consists of a glass bottle, G, a metal cap, C and of course some quantity of pils, P. We denote the joins between them by indices, such that the whole object could be written like:

$$G^{a_1 b} C^{c}_{a_1} P_{bc} \qquad (1)$$

This is called the tensorial notation, not to be confused with tensor notation. In this case every object is connected by some sort of join. The beer and the cap are connected by the machine which put the cap on it. The beer is connected by virtue of being inside the other two. In this notation the order does not matter, nor does the number next to an index, this number is merely there to distinguish multiple joins of the same type.

As for most of you, theories are quite abstract and you prefer to work with something that you can touch. That is why we are going to give a composition of the Francken Vrij you are now reading.

Let's start with the physical parts: The Francken Vrij is 36 pages so there are 9 pieces of paper, P, held together by 2 staples, S. On these pieces of paper text and pictures are printed, which I will generalize as ink, I. The whole physical object is then described as:

$$FV_{physical} = (\prod_{n=1}^{9} P_b^{a_{1n}a_{2n}})S_{a_{11}\ldots a_{19}}S_{a_{21}\ldots a_{29}}I^b \quad (2)$$

Of course, not every object described with this equation is a Francken Vrij as the ink needs to be printed in a specific way. This is caused by (non physical) joins with other objects. I will denote these non physical joins with greek letters. The most important part of these other objects is the editorial board, B. The editorial board is the connection between the physical and the non physical part of the Francken Vrij, such that:

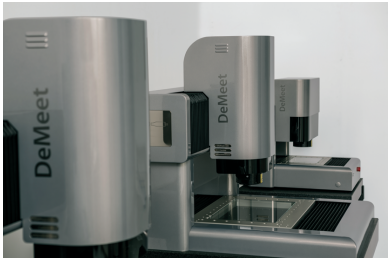
$$FV_{physical}{}_\mu B_\nu^\mu FV_{non\_physical}^\nu \quad (3)$$

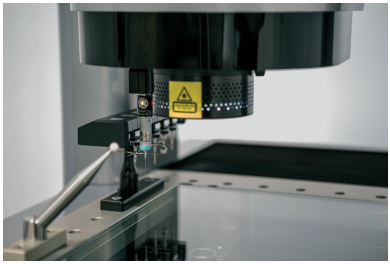
One thing the editorial board does is asking the theorist and other members, T to write something. This is done by messages, M. Let p be the amount of people that have to write a piece, it is trivial to see that there should be $q > 2p$ messages sent.

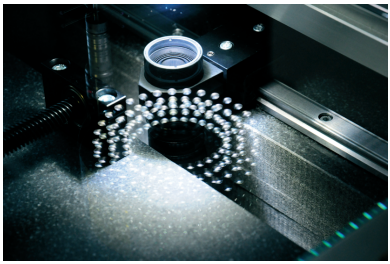
Incorporating this we get:

$$FV = FV_{physical}{}_\mu B_\nu^\mu FV_{non\_physical}^\nu = ((\prod_{n=1}^{9} P_b^{a_{1n}a_{2n}})S_{a_{11}\ldots a_{19}}S_{a_{21}\ldots a_{29}}I^b)_\mu \ldots$$
$$\ldots B_\nu^\mu (\prod_{n=1}^{>2p} M_{\rho i}^\nu)(\prod_{n=1}^{p} T^{\rho i}) \quad (4)$$

As you see this gets complicated real fast and we did not even cover the layout-weekend; the board of the association; and theorists who never meet a deadline. I welcome everyone to try and add to the equation for the Francken Vrij, if you send it to me and I like it I might even reward you with a $G^{a_1 b}C_{a_1}^c P_{bc}$.







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