Nicolaus Mulerius as crypto-Copernican

Science and Scientology

# Periodiek

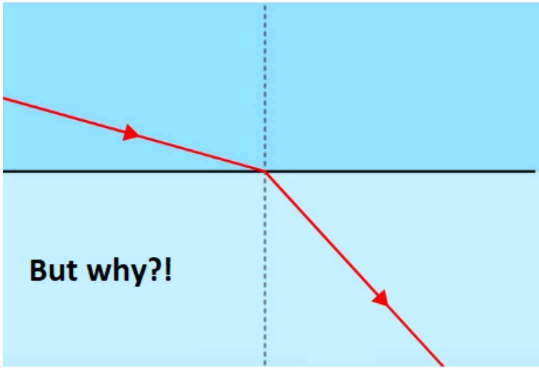
Recurring Magazine | Issue 2020-1


Perio Interview:
Peter Kuipers Munneke

FMF

## Understanding Refraction and Sunglasses Conceptually

“Why is light refracted, for example from air to water?”, “Why is it that all the light that reflects from water is horizontally polarized, causing glare?”. Even though physics mostly concerns itself with “how”, perhaps you still want a “why” answer deep enough to be satisfactory.




## Nicolaus Mulerius as crypto-Copernican

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## Symmetry, Light and Spins in the Flatland

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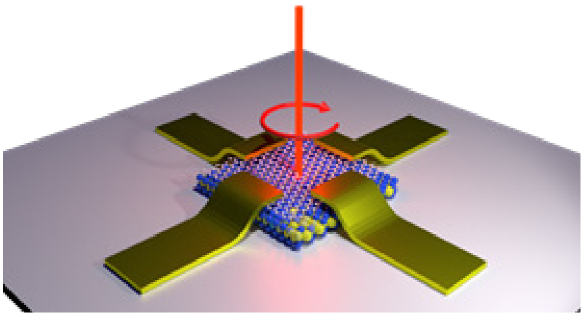

# In this Periodiek



## From the Editor in Chief

I hope you have all been well this past half year or so. The corona crisis has affected all of us in some way. The Periodiek is no exception. Origionally planned to be published in early march, it is now finally here.

Among other things, we now print the Periodiek at different printing company. This edition of the Periodiek also features a brand new column, the exchange article, for which we get a piece written by association/ magazine and publish it in the Periodiek, and vice versa.

Do you have any ideas or suggestion for the Periodiek, or would like to become an Editor? Send us a mail at perio@fmf.nl

*Robert Mol.*


**Editors**
Robert van der Meer,
Vedang Sumbre,
Tesse Tiemens,
Robert Mol

**Authors**
K. Glimmerveen,
H.D. Guimarães,
A. Dongelmans,
R. Modderman,
H. Kubbinga,
N. Kalantar,
F. Hendriks,
T. Tiemens,
J. Hidding,
I. Rotko,
R. Mol

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**Print run** 1150 pieces

**Press** BladNL.nl

**ISSN** 1875-4546

**The Periodiek**
is a magazine from the Fysisch-Mathematische Faculteitsvereniging and appears three times per year. Previous issues can be found at perio.fmf.nl. The board of editors can be reached at perio@fmf.nl.

# From the Board
## Chairman

AUTHOR: **I. ROTKO**

Dear reader,

I want to extend to you a greeting from the 62nd board of the FMF. Our board year began a few months ago, and has thus far been marked by the ongoing coronavirus pandemic. As you may expect, this has greatly limited what we can do as an association, but I hope you can rest assured that we are trying our best to make the most of the circumstances and provide our members with everything we can safely and responsibly give. Despite all the challenges, we are extremely happy, and first and foremost proud to have your trust placed in us, and I believe that we can take the FMF in a direction that is good for it, and allow the association to grow even in these challenging times.

Although it is still very early to say anything definitive about our year as a board, one of the things that I am proud of my board for so far is cooperation; we have been working very closely with our brother associations, as well as professors and research groups on many projects. Through events organized in collaboration with all these parties we hope that we can bring our members, all the students and staff of our respective programmes, as well as the whole of the FSE closer together. I think, and certainly hope that you will get to see some of the fruits of this work a bit later on in the year.

FIGURE 1: Iisakki Rotko, the chairman of the FMF.

This year we have had to, in many ways, reinvent the wheel. In this light, I am extremely thankful to all of our members, committees, and partners for thinking with us of what we can do, instead of simply giving up because the usual things aren't possible. I think our members are our greatest resource exactly for this reason, and I'd like to thank all of you for your understanding, energy, effort, and creativity.

Lastly, I want to say I am extremely proud of the restraint and responsibility that our members have been showing in dealing with all the restrictions that the pandemic has brought with it. I hope all of you are doing well both mentally and physically. If there is anything we can do to help any of you, please don't be afraid of letting us as a board know via email (board@fmf.nl), or if a more personal conversation is more to your liking, you can find the contact details for our confidential advisors on our website (https://www.fmf.nl/vereniging/confidential).

I wish all of you the best year, and look forward to meeting and talking to as many of you as possible.

Iisakki Rotko,
Chairman

# Nicolaus Mulerius as crypto-Copernican

AUTHOR: **H. KUBBINGA**

Nicolaus Mulerius was the first professor of exact science at the University of Groningen, nominated at its very beginning, in 1614. Unfortunately, his reputation suffers from all kinds of misunderstandings. On the occasion of the 400th anniversary of the University, in 2014, several of these have been clarified, the most important being his full though (almost) secret support for the heliocentric world picture of Copernicus. As to the status of Holy Writ—which denies the Copernican system—the University of Groningen was indeed sometimes more Roman than Rome's Curia. Here we intend to focus on one of the astronomical instruments with which Mulerius is depicted at his Academy Portrait of 1618, a painting by an unknown master.

## Nicolaus Mulerius (1564-1630)

Nicolaus Mulerius was born on Christmas Day 1564 in Brugge, in the Southern Netherlands (now Belgium). At the beginning of the Dutch Revolt against Spain the Protestant family moved to the Northern Provinces, to Leiden, where Nicolaus later enrolled as a student of medicine. Having passed the PhD he settled as general practitioner in Harlingen (Friesland), before following a call to the city of Groningen to become Provincial Physician. Importantly, studying Medicine was often the only gateway to topics belonging to what we would call exact science: chemistry, physics, and/or mathematics, where 'mathematics' also stood for astronomy. So it came to be that he was nominated, in 1614, Professor of Medicine *and Mathematics* at the brand-new University of Groningen. At the University, the Faculty of Theology dominated, if only by its sheer number of students. Indeed, the founding father of the University, Ubbo Emmius (1547-1625), had been anxious to make it even more rigidly Calvinistic than the University of Leiden, the cradle of Dutch orthodoxy. In the very same spirit Emmius succeeded, in 1618, to convince Franciscus Gomarus (1563-1641)—the exponent of contemporary ultra-Calvinism—to settle in Groningen. This is to say that, from the very beginning, the text of the Bible was the cornerstone of all education. Undeniably, there were also classical entrepreneurial skills in the game, since by sticking to the letter of the Bible quite some—very well-paying!—*Lutheran* students from the German lands could also be lured to Groningen. Hence the curious fact that academics in the revolting Dutch Republic—not only those of Groningen—were sometimes even more text-bound than the theologians of the Roman-Catholic Church, members of the Curia in Rome. Indeed, if, for instance, the Old Testament has it, in Joshua 10:13, that Joshua

FIGURE 1: Henk Kubbinga (EPS History of Physics Group), retired UG historian of science.

commanded Sun and Moon *to stand still* in order to have more time to beat the enemy of the people of Israel, then it is self-evident, for such a theologian, that Sun and Moon *moved before*. This very same fragment—in connection with some other—was used by people of all Christian denominations to defend the geocentric world picture, with due reference to the foremost natural philosopher since antiquity, Aristotle.

## Mulerius' writings

As an early devotee of astronomy Mulerius published, still as a physician, an instruction for the use of the astrolabe (Franeker, 1595) and a set of astronomical tables entitled *Tabulae Frisicarum [..]* (Alkmaar, 1611). In 1616, by now a professor, he finished a treatise on astronomy proper: *Institutionem astronomicarum [..]*, published in Groningen. All the time he had also been working on a new edition of Copernicus' masterpiece, *De revolutionibus [..]*, the third since 1543. Indeed, in 1617 appeared *Nicolai Copernici Torinensis. Astronomia instaurata [..]*, in other words: a renewed version of Copernicus' astronomy. Mulerius took care not to publish it in Groningen, but in far-away Amsterdam, by Willem Jansz. Blaeu, probably hoping that his Groningen colleagues, most of all the theologians, would be busy enough to overlook it. There was all reason to do so: an earlier Dutch proponent of Copernicus' ideas, the great Simon Stevin, had been severely criticized by Ubbo Emmius, the University's founder and anno 1617 revered colleague of Mulerius. It is indeed odd to see that one of the masterminds of the early 17th century—Simon Stevin—introduced all kinds of novelties in the Dutch world of science, while working as an engineer in the service of Prince Maurice of Orange Nassau, the commander-in-chief of the army of the Dutch Republic on its way to independency. The *Hypomnemata mathematica* (1608) or *Mathematical Memoirs*, for instance, originally published in Dutch, broadcasted i.a. the Copernican system, novelties which Stevin developed during his daily intercourse with Prince Maurice, a very-interested outsider. Where Stevin was more or less free to do what he wanted, Mulerius had to be careful—very careful—indeed.

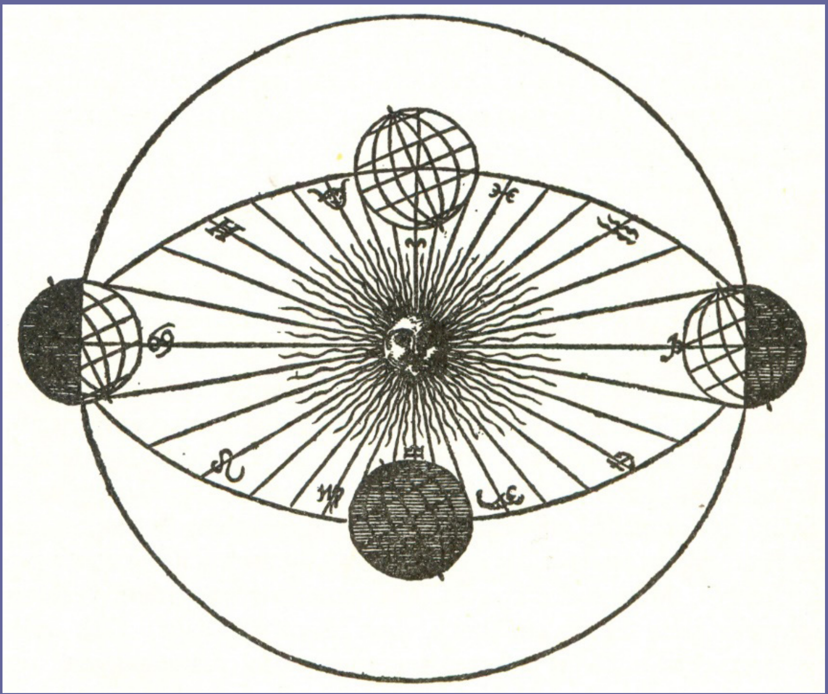

**FIGURE 2: Nicolaus Mulerius in academic gown and lace-collar by an unknown master (oil on canvas, 1618). The text stipulates that he was depicted at age 54 (upper left) and that, from 23. August 1617 onwards he served as the fourth Rector of the Academy, as our University was called at the time. The painting is actually exhibited in the Senate's Room of the Academy Building (Broerplein 1, Groningen) (photo: Dirk Fennema).**

## Mulerius' portrait; the two instruments

In 1618, then, Mulerius was among the first Professors to be honored with a painted portrait, in oil on canvas, meant to be exhibited in the premisses of the University. Actually it decorates the Senaatszaal of the Academiegebouw, in the city centre, at Broerplein 1. Most unfortunately, the name of the artist is unknown: it is not indicated on the painting, neither are there any souvenirs in the archives of the university. A pity for him, since, as we will see, he did a very good job (Fig.2). The painting shows a proud, slightly smiling Mulerius, in formal academic gown and lace collar, with two astronomical instruments: a system of three orthogonal rings hanging downwards from his left hand, and a wooden sphere on an equally wooden footing, under his right hand, on the table. That it concerned indeed *astronomical* instruments became clear when, after a tour through the literature, the ring system could be identified as a so-called *annulus astronomicus* or *astronomical ring dial*, the prototype of which had been produced by the technical genius Gemma Frisius (ca.1534). Indeed, the three orthogonal rings could be folded together to form just one *annulus*, a property allowing to keep it, let's say, in a leather holder or, even better, a wooden case furnished with felt. Two of the three rings stand, each, for fundamental astronomical notions: the local celestial *meridian*—whose plane passes through Groningen—, and the celestial *equator*, whose axis passes through the polar star, Polaris. The third and innermost ring is freely revolvable within the sphere of the other two. This third ring is in fact a double ring, the inner one being freely revolvable within the other. That inner one carries two sighting vanes, together a diopter, such that the position of heavenly bodies can be measured, at least in principle. Mulerius carries it between the thumb and the forefinger of his left hand thanks to a small ring fixed to the meridian: the position of that small ring indicates the northern latitude of the city of Groningen (at the time known to be 53¼°, in Frisius' notation), that is, on the hypothesis that the instrument was made on Mulerius' initiative. This hypothesis is very plausible, since the second instrument pictured on the painting represents something truly unique in the history of astronomy and must have been thought out, here in Groningen, by Mulerius himself; for reasons to be dealt with below we called it a *terrula*. As to the materials used for the rings of the *annulus*, it must have been brass, as most of the other surviving copies testify[1], perhaps *gilt* brass to avoid weathering, with black ink to mark the engraved scales and the signs of the zodiac. The *annulus* was used in the classroom to familiarize students with the elements of astronomy, i.a. with mapping the heavenly bodies, while preparing those students for serious astronomical observations with grand-scale look-alikes. Tycho Brahe (1546-1601) at his observatory on the isle of Hven, in the Sont, for instance, had a huge so-called *equatorial armillary* (since 1580), an outdoor instrument consisting of three rings (including a double one) of about 155 cm diameter, but for the rest identical to Frisius' *annulus*. Travelling to Hven was not given to anyone, so Mulerius simply showed his students the picture reproduced in Brahe's work *Astronomiae instauratae mechanica* (1602), a folio-format book featuring all the instruments devised and used at Hven. Importantly, we know that Mulerius owned a copy of that book. In fact, all the books referred to in the foregoing were part of his private library: the two earlier editions of Copernicus' masterpiece, Stevin's two-volume *Hypomnemata mathematica,* Gemma Frisius' book in a 1584 edition, several works by Brahe, not to speak of Kepler's *Astronomia nova* (1609) and *Dioptrice* (1611), and many other classics which constitute the history of astronomy. This may be deduced from the catalog of his library, made up in 1646 on the occasion of its auction.

*[1] Just google 'annulus astronomicus' and you will find quite some other historical copies.*

**FIGURE 3: An impression of the relation between Sun and Earth in the heliocentric hypothesis (discard, for the moment, the signs of the zodiac). From: the title page of Ph. van Lansbergen's book *Reflections on the daily and annual course of the terrestrial globe [...]* (in Dutch; 1629). The observer should be positioned in the Sun, as suggested by its face-like outfit. Courtesy: Tresoar Library, Leeuwarden.**



## The 'terrula' as a QRC for Copernicanism

The second instrument consists of a wooden sphere on an equally wooden pedestal. The sphere is surrounded by five brass belts, in a particular order. By studying a magnified version of the painting, that order could be read out. Given Mulerius' Copernican mindset the question was how to interpret these belts in terms of a coherent set of astronomical—and perhaps geographical—notions in a heliocentric context. A contemporary engraving of the Earth in its annual relation with the Sun, embelleshing the title page of an essentially Copernican tract, proved revealing. We mean the *Reflections on the daily and annual course of the terrestrial globe [...]*, published in 1629 (in Dutch), by Philips van Lansbergen, an astronomer from Middelburg. In Fig. 3 we reproduced only that picture. It presents snapshots of the Earth at four particular moments in time: the winter and summer solstices and the vernal and the autumnal equinoxes.
Each of the Earth pictures features an axis, a set of meridians and, moreover, the equator, the two tropics and the two polar circles. On the right, then, we see the Earth at its sommer solstice: just follow the connection line between the Sun and the Earth's center and you will see that it cuts the northern tropic. On the left, the Earth passes apparently through its winter solstice. The motion of the Earth appears to be clockwise, since the upper picture shows the Earth at the vernal equinox, the lower picture corresponding to the autumnal equinox. The trajectory of the Earth is characterized by two great circles: the one of its trajectory and an in-plane circle, a kind of meridian. In order to better understand Mulerius we add, in the mind, a *third* great circle, perpendicular to the in-plane circle and passing through the vernal and the autumnal equinoxes. In other words: a set of *three* perpendicular great circles characterizes the annual motion of the Earth around the Sun, with a north pole of its own.

In Fig. 3 we further see the Earth's axis tilted to the left, but this is a matter of view point. Just imagine yourself not *before* but *behind the paper* on the line Sun-vernal equinox and observing the system: you will see that this changes all. Take your time. Seen from behind, the Earth's axis is tilted to the right while it moves *counterclockwise* around the Sun.

Now we are sufficiently well-equipped to enravel the secrets of the second instrument, the one on the table and on top of which all five fingers of Mulerius' right hand rest. For a better understanding we will refer below to the replica of this item, made in 2014 and reproduced in Fig. 4. Take your time, again, to check, first, that all five belts are there and, second, that their order corresponds with the original (the latter is difficult to see, OK, but focus on the outermost belt which symbolizes the in-plane great circle of Fig. 3).

It is crucial, now, to realize that the wooden ball stands at once for *both* the terrestrial globe *and* the celestial sphere defined by the Earth's orbit around the Sun. Hence its name: 'terrula'. To begin with the latter: above we hinted at three mutually orthogonal great circles defining that orbit and these are readily retraced on the instrument: two of them, the meridians, reproduced as belts, pass through the north pole, while cutting the horizontal belt, i.e. the Earth's orbit, at four points. Hence the conclusion that the tiny screw pointing forward refers to the vernal equinox. The remaining two belts are related

**FIGURE 4: Replica of Mulerius' 'terrula' made in 2014 by Geert Fikkers (wood) and Anton Stoelwinder (brass and steel). The diameter of the globe is 12.0 cm. (University Museum Groningen).**

to the Earth itself. One of them is tilted to the right over an angle of some 20-25° with respect to the Earth's orbit and, therefore, cannot but be the Earth's equator. Consequently, we may read that angle as 23½°, the value accepted at Mulerius' time. We also see the equator passing through the vernal equinox, symbolized by the tiny screw. Apparently, the Earth is depicted the moment that it passed through the vernal equinox, that is, on 20 March 1618, let's say, at 12:00 AM[2]. Moreover, we may imagine the Earth's axis passing through its center and perpendicular to the equator: it will cut the surface in the upper right, at a distance of 23½° from the orbit's north pole. Keep that point—the Earth's north pole—in mind, while assessing the last inner-belt, making an angle of an estimated 25-35° with the equator. Now we should acknowledge the difficulty, even for an experienced painter, to depict spatial relations—here interfacial angles—numerically correct. If this is indeed the case there is all reason to read that angle as 36¾°, such that the inner-belt's axis cuts the surface at a latitude of 36¾°, measured from the Earth's north pole; this makes for a latitude of (90 – 36¾) = 53¼° with respect to the equator. It can scarcely surprise, after the foregoing, that this happens to be the latitude of … the city of Groningen. Hence it is that we may safely guess that the axis of this inner-belt passes straight through the Olle Grieze, the tower of the Martini church at the Grote Markt, which was already there in Mulerius' time, or perhaps—with somewhat more poetical license—through the tower of the Academy Building at Broerplein 1.

Two queries to conclude. The first concerns the portrait painting (Fig. 2), more in particular Mulerius' vaguely mysterious smile, coming close to that of Leonardo da Vinci's *Mona Lisa*. The painting features a self-conscious Mulerius who duly enjoys the moment of being eternalized by the painter, but there is more: the smile of one who, a tiny little bit mockingly, teases the observer. In short: he appears able to see something that the onlookers of the painting, let's say the theologians of the University, could—lucky Mulerius!—definitely *not* see … What might this be?

The second concerns one of the calculations made by Mulerius, namely the one on the ratio between the volume of the Earth and that of the Great Sphere defined by the Earth's annual orbit and the two pseudo-meridians (Fig. 3). In 1616, in his textbook *Institutionem astronomicarum […]* he claims that that Great Sphere is big enough to contain, in his notation, 1500000000[3] terrestrial globes, that is, in our system 1,500,000,000 Earths; in the margin of the text Mulerius even specifies the technical term for this number: 'sesquibimillione', or one and a half billion. Unfortunately, he doesn't give the detailed calculation, but you may try to reconstruct it. Essential data are provided elsewhere in the book: the Archimedean ratio of the circumference of a circle to its diameter (yes, indeed, our $\pi$) is 22/7; the length degree at the equator corresponds to 15 German miles, the then-current astronomical length unit (used i.a. by Brahe)[4]. The question, then, is to reproduce Mulerius' calculation leading to a distance Sun-Earth. Elsewhere, he, Mulerius, calculates that distance from Ptolemy's value of 1,210 times the Earth's radius. How do the two outcomes compare to each other?

Among those able to solve both queries five copies of the book mentioned below are raffled. Send your solutions—well-detailed, of course; no numerical conjuring tricks—to the Editors of *Periodiek,* sit down, and wait•••

**Acknowledgement:**
The author is indebted to Prof. Dr. Jeff De Hosson (Applied Physics, Materials Science; Zernike Institute for Advanced Materials) and his staffers Paul Bronsveld, Vašek Ocelík and David Vainchtein for profound discussions on Mulerius' instruments and to Geert Fikkers (Groningen), Feike Slager (Dokkum), Anita Slagter (Groningen) and Anton Stoelwinder (Gorredijk) for skillfully producing the replicas and their accessories. He thanks Prof.Dr. Herbert Löhner for kind support.

**Background reading:**

Henk Kubbinga, *The astronomical instruments (1618) and Catalogus librorum (1646) of Nicolaus Mulerius, with an essay on his place in the history of science,* Groningen: Groningen University Press, 2014.

*[2] The city of Groningen still stuck to the (anti-Roman!) Julian calendar, so in 1618 the vernal equinox was passed on March 10th.*
*[3] Do note the use of the decimal-positional way of writing numbers, probably borrowed from Regiomontanus and fully in line with the innovations in number theory as proposed by Simon Stevin; the works in question of both authors were part of Mulerius' library.*
*[4] 1 German mile = 7.2 km.*

# Symmetry, Light and Spins in the Flatland

Zernike Institute for Advanced Materials, University of Groningen, The Netherlands

AUTHOR: **M.H.D. GUIMARÃES, F. HENDRIKS, J. HIDDING**

We like symmetric things. From the graceful flowers in our gardens to the works of Escher and the music of J. S. Bach. But physicists and mathematicians like symmetry even more (although that might be debatable). In physics and mathematics one can use the symmetries – or lack of thereof – in a system to simplify problems, calculating much simpler equations or even getting the answers to questions just by looking at which symmetries a system does or does not have.

Symmetry considerations have been regarded as a basic thing in science since the dawn of science itself. However, the development of quantum mechanics and solid-state physics promoted symmetry concepts to a much more prominent role in our understanding of Nature's laws. A beautiful theorem illustrating this was shown by Emmy Noether in 1915[1]. Loosely speaking it states that for every continuous symmetry in a system there is a corresponding conserved quantity. For example, if the equations that describe a system do not change if t is replaced by t + dt, then energy is conserved. Another example is the conservation of linear momentum, which is due to the presence of translational invariance. In this case the equations do not change if we move our whole system by an amount dx, from 'x' to 'x + dx'.

The arguments illustrated above are examples of continuous symmetries, as a sphere is symmetric under rotations through an angle that could take continuous values. A crystal or molecule on the other hand, has atoms placed in specific places, which break the continuous translational and rotational symmetries into discrete steps. This reduction of symmetries is the basis of solid-state physics and some fields of chemistry, like stereochemistry. This concept allows us to design better electronic devices and chemical components just by looking at the symmetry properties of crystals and molecules.

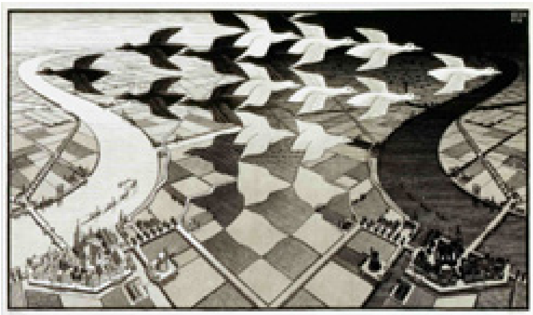


Figure 1: Escher - Day and Night

### Symmetric sheets of paper

Two-dimensional (2D) layered materials, like graphene, can be used to beautifully illustrate how symmetry considerations in solid-state physics can be used to obtain basic properties of the system that can be measured in the lab. Layered materials are crystals in which atoms are connected to each other by covalent bonds forming a 2D layer, which are then stacked onto each other via weak van der Waals forces, akin to sheets of paper stacked onto each other in a pile. It was recently discovered that single layers of these materials can be peeled off the bulk crystal and deposited onto substrates[2] where one can study their optical, electrical, and mechanical properties.

Graphene, as we call such a single layer peeled off graphite, is perhaps the most well-known example of a 2D layered material. In graphene the carbon atoms form a hexagonal lattice, such that the crystal possess a 60º rotational symmetry, i.e. you can rotate the whole crystal by 60º and it will look exactly the same. Graphene also has a few mirror-plane symmetries, in which planes can be defined to divide the crystal, with the left and right side of the crystal being perfect mirror images of each other. Finally, graphene possesses an inversion symmetry point at the center of the hexagon, such that, if we move an atom located at (x,y,z) to a point (-x,-y,-z), the crystal structure remains unchanged. If you list all the symmetry operations of graphene, it can be shown they will form a 'space group'. All the possible space groups can be listed and numbered, ranging from 1 (least symmetric, few operations) to 230 (most symmetric, a lot of symmetry operations). Graphene's space group is number *191* while graphite is number *194*, so graphene maintains several of the many symmetry operations of its very symmetric three-dimensional equivalent.

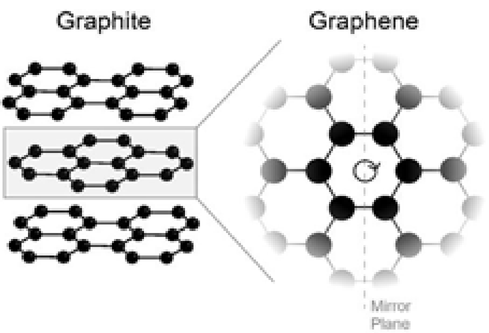


Figure 2: Graphite and graphene, with some of its symmetry operations

The crystal symmetries of graphene can be used to explain its well-known zero bandgap, where the conduction and the valence bands touch each other at a single point in k-space. For this, we only have to take into account that the electronic conduction is given by the weakly-bound electrons in the pi-bonds, and the crystal symmetries mentioned above[3].

A beautiful example of how the symmetry of the crystal impacts its electronic properties is the comparison of graphene with hexagonal Boron Nitride, or hBN for short. This material looks exactly like graphene, but instead of carbon atoms it contains Nitrogen and Boron. The presence of two different atoms breaks the 60º rotational symmetry: now we need a 120º rotation to preserve the original structure. The same happens to a few mirror symmetries and the inversion symmetry we had in graphene. Just using this symmetry analysis can tell us that the degeneracy, or zero-bandgap, in graphene should be absent in hBN. And indeed, hBN is an insulator with a bandgap of 3.4 eV!

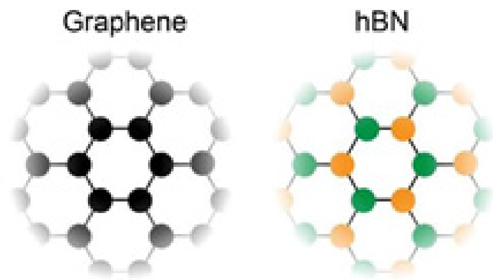


Figure 3: Graphene and hBN

## Symmetry and spin-orbit coupling

Spin-orbit coupling is the interaction between an electron's orbit and its quantum spin. In atoms it is usually described by the Hamiltonian: $\hat{H} = \alpha L \cdot S$ , where $\alpha$ is a constant, L is the orbital angular momentum and S the spin angular momentum. In solid-state physics, the orbital angular momentum is often replaced by the crystal momentum k. This means that in a crystal the energy levels for spin-up and spin-down depend on the direction of propagation! This leads to some funny phenomena.

One material that has a particularly strong spin-orbit coupling is tungsten diselenide (WSe2). Like graphite, it is layered and can be peeled down to a single layer. And like hBN, it is hexagonal, but with a W atom on one corner of the hexagon and two Se atoms on top of each other on the other corner. Because of its very strong spin-orbit coupling, electrons with the same energy propagating in different directions have different spins. This can also be understood using simple symmetry arguments.

Two symmetry operations are important here: spatial inversion symmetry and time-reversal symmetry. As we discussed before, spatial inversion will take an atom placed at (x,y,z) and put it at (-x,-y,-z). For a monolayer of WSe2 this operation does not exist because W and Se occupy opposite corners of the hexagonal lattice. Time-reversal symmetry will reverse the arrow of time, taking electrons propagating in one direction and reversing their momentum. But time-reversal will also change the electron's spin from up to down, like a soccer ball rotating clockwise will rotate counter-clockwise if we reverse time. In mathematical form, the effect of time-reversal symmetry for an electron with energy E with spin up (↑) and momentum **k** can be written as: $E(k,\uparrow)=E(-k,\downarrow)$. For spatial inversion symmetry we can write: $E(k,\uparrow)=E(-k,\uparrow)$, since this operation will reverse the momentum, but not the spin direction. Now we can see that it is the lack of inversion symmetry in WSe2 that allows for this funny effect of spin-momentum relation. If we had both symmetries the energy levels for both spins would be degenerate for all k: $E(k,\uparrow)=E(k,\downarrow)$.

## Optical properties

In WSe2 we can explore this funny spin-momentum relation using light. How come? Well, as mentioned before, WSe2 is a layered material just as graphene. However, unlike graphene, WSe2 has a direct band gap at specific points in the Brillouin zone. These points are labeled as the K and K' point and have opposite momentum. The direct bandgap in monolayer WSe2 makes it much more efficient to address its states with light.

So what, there are plenty of materials with direct band gaps, right? True, but the interesting thing with WSe2 is that the states at the K and K' points can be selectively excited using circularly polarized light. This means that right-handed circularly polarized light excites electrons in the K point, while left-handed circularly polarized light excites electrons in the K' point. And do you still remember that funny spin-momentum relation, where electrons with opposite momentum have opposite spin? The same applies here! Due to the lack of inversion-symmetry these electrons will have opposite spin. This allows us to excite electrons with specific spins in this material using light, something which is not possible with graphene.

On the other hand, graphene allows for much better spin conduction[4]. And so, combining the conduction properties of graphene with the optical properties of WSe2 would be a match made in heaven. This is exactly one of the things we try to do in our research group. We create sandwiches of these 2D materials by stacking the materials on top of each other in order to combine their properties and get the best of both worlds (Fig. 4). These properties make layered materials very attractive for applications in spintronics, where the electronic spin instead of the electron charge is the information carrier.

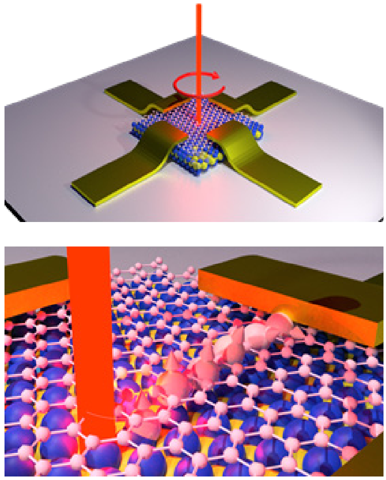


Figure 4: An illustration of a graphene/ WSe2 stack with gold electrodes (top). The laser light excites electrons with specific spins in the WSe2 which are able to diffuse along the graphene flake to one of the electrodes (bottom).

## Chirality

Another important symmetry operation that plays a major role in chemistry and biology also shows up in two-dimensional materials: chirality. A molecule, material or object is said to be chiral if it cannot be taken into its mirror image through a rotation, just like your right foot for example. A chiral molecule, such as glucose and the DNA, can be taken into its optical isomer through by taking its mirror image, in a similar way that your right foot looks like your left foot when reflected by a mirror. They are the same basic structure (a foot), but have different chirality (left and right, Fig. 5).

Let's now take our graphene example. Graphene is not chiral. We apply a mirror plane and it looks exactly the same. But now, if we put another graphene layer on top of it and twist by a small angle with respect to the first one… Voilá, we have a chiral graphene structure!

In fact, just like glucose, this chiral graphene bilayer shows circular dichroism[5]. This means that this structure absorbs circularly polarized light in different amounts for right- and left-handed polarized light, and is a direct consequence of chirality. The degree of circular dichroism is then defined as CD=(I_+-I_-)/(I_++I_- ), where I_(+(-)) is the reflected light

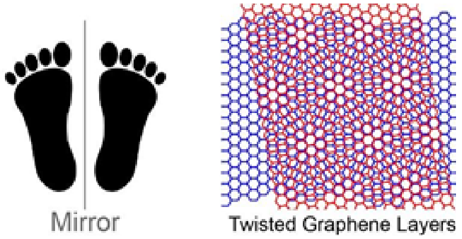



Figure 5: Your left foot is taken into your right foot by a mirror operation. Twisted graphene layers have the same properties. Both are examples of chiral materials.

intensity for right- (left-) handed polarized light. This we can measure in our lab.

A simplified schematic of the setup we use in our group to measure the circular dichroism is shown in figure 6. We modulate the polarization of our laser between left- and right-handed circular polarization by using a photoelastic modulator (PEM). Half of the light is split off by a beam-splitter and its power is measured by a photodetector (PD1). The other half is focused on the sample. The sample reflects the light back to the beam-splitter, and this back reflected light goes into a second detector (PD2). From the ratio of the two detector signals we can calculate the reflectance and absorption. Since the polarization of the laser oscillates between left and right circularly polarized, the measured reflection and absorption are oscillating as well, and with the same frequency. The peak-to-peak amplitude is the difference in absorption of left and right handed

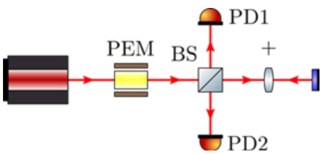



Figure 6: A simplified version of a laser setup to measure circular dichroism.

polarized light. Using a lock-in amplifier we can measure this difference very accurately. Figure 7 shows the result of one such measurement.
Other experiments can also be performed with the same experimental setup. For example, we can measure spin and charge diffusion in a single layer of a transition metal dichalcogenide (TMD) like WSe2 even though these crystals do not have a chiral structure. They do, however, have a net magnetization after excitation with a strong circularly polarized laser beam (pump), and this breaks the symmetry of the material in such a way that they reflect left- and right-handed circularly polarized light differently. We are currently expanding our experimental setup to study this phenomenon.

Besides making a chiral heterostructure, the interlayer twist between two graphene layers has also major impacts on its electronic structure: it can open a bandgap and even make graphene superconduct[6]! The superconductivity phase-diagram of a chiral graphene with a 'magic' twist angle of 1.1° reproduces the phase diagram of high-Tc superconductors based on copper. These superconductors show zero electrical resistance as high as 130 K and could help with the world's energy consumption – avoiding your laptop from overheating when you are gaming. However, high-

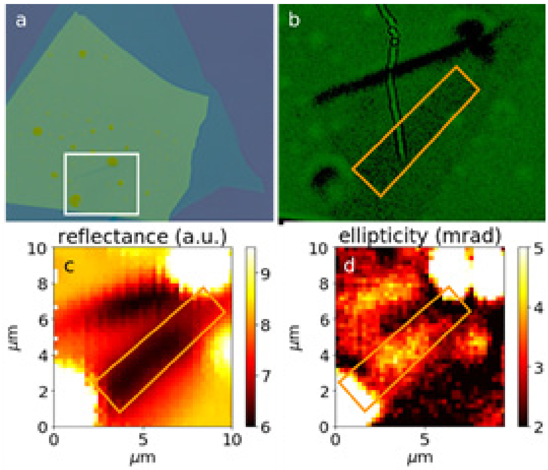



Figure 7: a) A microscope image of twisted bilayer graphene (tBLG) sandwiched between hBN flaked. b) Part of microscope image with enhanced contrast. The tBLG is indicated by the orange rectangle. c,d) Reflection and circular dichroism measurement at 710nm of the area around the twisted bilayer graphene region. The tBLG is again indicated by the orange rectangle.

Tc superconductors are poorly understood, and the hopes are that the discovery of magic-angle twisted graphene can help to solve this mystery.
Playing around with the symmetry properties of a physical system can lead to fascinating and unexpected discoveries. As we show, two-dimensional materials provide a great playground for investigating these phenomena using different optical techniques. This also gives us direct access to the spintronic properties of these materials and allow us to couple light, spins, and charge in a single system.

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2: K.S. Novoselov et al., Proc. Nat. Acad. Sci. 102, 10451 (2005).
3: L.M. Malard, M.H.D. Guimarães, et al. Phys. Rev. B 79, 125426 (2009).
4: S. Roche, et al., 2D Materials 2, 030202 (2015).
5: C-J. Kim et al., Nat. Nanotech. 11, 520 (2016).
6: Y. Cao et al., Nature 556, 43 (2018).

# Meet your ASML Campus Promoter David Homan

## Advertorial

You may have seen the ASML logo around the University of Groningen. You may wonder what kind of company ASML is and what potential careers it has to offer. But what you may not know is that there is someone on your campus who can answer all your questions and more – ASML student campus promoter David Homan.

### So, tell us more about David Homan?

Hi, I'm David, I'm 24, I'm in my fifth year, studying for a Bachelor's in Artificial Intelligence. Five years sounds like a long time to be studying, I know. But I started out in two other interesting fields, philosophy and law, before finally ending up at the study I'm most passionate about. I find a lot of things interesting - outside of my studies, I enjoy everything from reading to learning new languages, from playing the drums to kickboxing, from computer games to card games – right now, my new favorite is Texas Holdem poker!

### You're also a member of study and student associations. Is that how you got to know ASML?

That's right. I was on the board of 'Cover', the study association for the Artificial Intelligence and Computer Science. Board members from university associations from across the country get invited to special 'board days' at ASML, and I was lucky enough to go. I was super impressed. It wasn't just how high-tech it was or the jobs on offer. What was most impressive was the feeling of freedom and dynamic creativity. It's an exciting place, and importantly, it's a company that respects its people. When later they were looking for a campus promoter for our university, I was happy to sign up, and proud to represent ASML.

### What can students expect from you as an ASML campus promoter?

First and foremost, I'm here, anytime, for any questions you have about jobs and life at the company, scholarships and internships, and much more. We can arrange a meeting, but equally

(and as I often prefer!) you can chat to me wherever you find me - I'm always enthusiastic to talk about ASML. Beyond that, what I like about the role is the freedom ASML gives me to make it my own – to think of my own ways to reach out to fellow students. But also that the focus is absolutely not on 'headhunting'. I'm not here to recruit you, I'm here to help you understand the company, so you can make more informed choices when it comes to your career after university.

## Finally, what other career advice would you give your fellow students?

Don't be too focused on your academic results! Just as important is your personal development. I didn't have the best academic results, but I've made certain I've never stopped developing myself in all the areas that interest me. If I'm passionate about something, focus and fulfillment will follow – and that's much more important than high scores alone.

## Put your study to work

We welcome students from all over the world to join us for internships and graduation assignments at our global headquarters in Veldhoven, the Netherlands. Want to see what's possible? Gain hands-on experience and support with ASML scholarships or attend a career event for students and PhD graduates. Learn more at www.asml.com/students.

## You can get in contact with David via david@workingatasml.com!

# Perio Interview

## Peter Kuipers Munneke

AUTHORS: **T. TIEMENS, R. MODDERMAN**

For this edition, we visited Utrecht to interview someone you might have heard of before. His name: Peter Kuipers Munneke, glaciologist and researcher at Utrecht University, TV weather presenter at Nederlandse Omroep Stichting (NOS), RUG alumnus, former active FMF member, and even former Periodiek editor! Accompanied with some old physical copies of Periodiek of the years 2001 and 2002, we took the train to Utrecht, and after having faced all kinds of traditional Dutch weather, we finally arrived at the UU campus where we were welcomed by Peter.

**What has your study path looked like, and how did you end up where you are now?**
It all started with me not having chosen Physics as a first study: after graduating from high school, I started studying Spatial Planning and Design[1] at the University of Groningen. I quit in my first year, before Christmas: although I chose to do a technical study, I missed a beta part in my studies, and I needed some more exact challenge. A good friend of mine however did start with Physics right away, and in his first year he took me to some Special Relativity lectures, which were at that time given in room 5111.0080. I didn't take the exam, but I attended the lectures, just to try to get an overview of what studying Physics looks like.

1 At that time, this study was in Dutch only and was called 'Planologie'.

The next September I started studying Physics. Three years later, when we had to choose a track[2], I chose "Experimental Physics" because there was a lot of freedom in electives. I filled the free part with courses from UU: Meteorology, Climate, Ocean, Fluid Mechanics, et cetera. I have been travelling to Utrecht a lot, which was quite intensive but also very enjoyable. My last year I spent in Sweden writing my final thesis.

In my final two years of studying Physics, I already went into the direction of the concrete side of physics. I really enjoyed doing physics that explains real life observations. Courses I took in Utrecht involved the

2 At that time, there was no BSc-MSc construction yet. One had to choose in what flavour to graduate. There was an equivalent of master thesis, however.

atmosphere and polar ice caps, and for my final thesis I went to Sweden and studied glaciers for which I spent four magnificent weeks on Spitsbergen. After my graduation, I saw that some related PhD positions at UU opened up. I applied straight away, and obtained it! That was back in 2005. I really enjoyed my PhD research, which I finished in 2009. I have been affiliated with Utrecht University ever since.

### How did you end up being a weather presenter?

My road to becoming one was quite standard. What I enjoyed during my research was doing the research itself of course, but also explaining concepts. During my PhD research I won several prizes for best presentation at conferences, et cetera. Explaining things that look simple to explain at first sight but actually aren't. At the time a position opened up, when one of the current weather presenters was quitting, I thought, "You know what, I'm just going to fill out this application form, why not! If they invite me over, it is still not too late to say no." I got further and further through the application process, and at some point I really had to seriously consider it. Finally, I was called and asked whether I was willing to accept the position. "I think so, yes", I said, and that was the start of my career at the NOS[3].

### What aspect do you enjoy most of presenting the weather?

Well, when I look at a rainbow for instance, I can think of it as being an optimal phenomenon: I see the law of refraction, I can visualize patterns of wavelengths, along with all these physical concepts. But I can also view a rainbow as just a very beautiful phenomenon on its own I can elaborate upon during the weather part of the news. Something like, "tomorrow we will have rainfall in quite some areas but as the day advances the sky will clear itself up, so there's a high chance on all kinds of optical phenomena!" In a sense, you can view weather phenomena from two perspectives. Both are part of meteorology. The most enjoyable aspect of presenting the weather is explaining complicated phenomena as elementary and understandably as possible.

3 The "NOS" is an abbreviation of "Nederlandse Omroep Stichting", which means "Dutch Broadcasting System", as you can read on over.nos.nl/voor-de-pers/about-us.

### What is your favourite weather phenomenon? What would you like to talk about to 10-year-olds? And to adults?

I really like optical phenomena, like halos and rainbows. Enjoyable to see, and really nice to explain on an elementary level how they arise. But there are always two perspectives on the weather: you can observe phenomena while standing on the ground, but also from outer space: satellite images can show very clearly how low-pressure areas and air vortexes form and evolve. Something I also really think is interesting is how all pressure gradients, forces, friction forces at the Earth's surface, et cetera all play a role in the forming process of low- and high-pressure areas. If I were to explain my favourite weather phenomenon to adults, then I would like to show them very nice satellite images. For 10-year-olds, it is much more interesting to talk about optical phenomena.

### How well do you manage to combine presenting the weather with your own research?

Doing both things in parallel is quite manageable I learned, but on a day I present the weather I have to work for a full day. I start at 1pm, and I finish around 9 pm which is right after the NOS eight o'clock news which is one of the final things of the day I'm involved in. Between 1pm and 4pm, I investigate all kinds of weather models: the current observations, satellite images, everything I can use to form a complete overview of today's weather and the weather of the coming days. After I'm finished with that, I switch to "presentation modus": I present the weather on the radio at 4.30, I write the weather forecast for Jeugdjournaal[4] and for Nieuwsuur[5], and as a last thing I present the weather in the eight o'clock news.
Combining this with my research goes as follows: on average, I work two days a week at the NOS and three days here at UU for which I chose to do only research and no teaching activities. Every now and then I'm invited to give some guest lectures, but I'm

4 A daily TV news programme the NOS broadcasts directed to 9-to-12-year-olds.
5 "Nieuwsuur" (nos.nl/nieuwsuur) is a joint news programme by NOS and NTR (ntr.nl).

not involved in teaching bachelor or master courses and hence I also don't have to correct exams. Some fellow researchers of mine sometimes envy me for not having to teach courses and having enough time for research. Just prioritize well, and you will succeed.

### Has your work as a weather presenter influenced your research somehow?

A little bit. During my time I had at the NOS so far, I learned to talk clearly and avoid all kinds of jargon to serve the purpose of conveying the message as clear as possible. The art of using language in such a way that it supports this purpose really helped me in writing scientific literature. When I was new to scientific writing I used to take looks on how other articles were written, and I used to just repeat the structure for my own writings. But now I always start from the general message I would like to convey: the new finding which really matters, and to whom I would like to communicate this finding. As soon as you know that, the rest will follow almost automatically. This is a completely different way of thinking, and it's something I learnt during my time at the NOS.

*"I always hear from other people that I've explained the message crystal clear"*

The type of communicating using images, clear pictures, and clear language I learned at the NOS I really can apply in my research. And it pays off: usually, after having sent in a draft article, the comments I usually receive first from the reviewers is almost always about how well-written the article is from a language use point of view. How well they think I did my science could be another issue from time to time of course, but I always hear from other people that I've explained the message crystal clear and in a readable way.

I've been co-author for articles many times where the actual content was written by other people, and if I have that role I often focus on improving the use of language of the text. Usually, the science that is done is completely OK: the equations are correct, the meteorology is carried out as it should be, et cetera. But the way people write and use language is often horrible. I think that the general scientific community erroneously thinks that, when writing for other scientists, it is not necessary to be clear. But being crystal clear is very important! Sometimes, data is communicated in a very fuzzy way, and many times it would have been better to communicate the data using diagrams or in another understandable way. Just make something up to serve the purpose of being clear.

### What would be your advice on living environmentally friendly?

A key point in my opinion is that the general public should be made aware of what choices precisely influence the environment in what way. For example, if you manage to, throughout a year, save 100 plastic bags, you might be proud of yourself having contributed to the environment, but if you take a flight to Australia the next day then what precisely have you been contributing to the environment with saving plastic bags? It all is about seeing things in proportion. I think that climate scientists should somehow manage to influence the legal authorities to change the legislations. Think, for example, of $CO_2$ budgets.

FIGURE 1: Peter. Photo by Stefan Heijendaal

But other than that, the general energy transition process is very important to cooperate on. For example, we need to switch to wind energy and solar energy. But we also need to invent ways to efficiently save energy into proper accu systems and to make the general flow of energy more efficient.

### What if you get to choose between a crystal ball you can use for looking 48 hours into the future, and a crystal ball which shows you once what the world will look like in 100 years. Which one would you choose?

I would choose the second crystal ball, definitely. You can use it as a sort of compass, to see what you can still change before the time is near. You could use the first crystal ball for weather forecasts, but when presenting the weather, you can always blame yourself if in the end it turns out that you were wrong in your forecast. For climate research, however, you can't. My research is about polar climatology, and when I retire there is no way in which I can check if the forecasts I have made during my research will turn out to be correct – if only I had that second crystal ball to verify my scientific life.

I wouldn't only use the 100-years crystal ball to see how the climate will have changed over the coming 100 years, though. I definitely would also want to see how artificial intelligence will have evolved. Whether we are all wearing implant chips that we use for every practical matter. Or maybe I'll see myself in the crystal ball, 140 years old – imagine!

*"We have ordered quite an amount of pizzas during our Periodiek sessions"*

### What did the FMF look like back in your days?

In our time, we certainly had more active members than you have now[6], but in that time the FMF still covered computing science. But my times hanging around at the FMF certainly were not functional only. Regularly, after having had a day of lectures in Utrecht, I used to visit the campus after I got back in Groningen just to see others and to be there because other people were there.

Looking back, I also remember the way we started working with computers. In my first year, back in 1998, I had my first ever email address. Before my first year, I can remember to have been on the internet once or twice. Those were the times, when all we had was an analogue dial-up modem. I visited the NS website a few times then. Yes, these new developments were brand new back then. Do you guys still have this oval-shaped PC room in the NB building? When I was studying there we had these enormous screens.

### Has your time at FMF and Periodiek contributed something to you?

My time at the FMF has been, first of all, a great time. I co-organized a KBE, I participated as an editor in Periodiek, but it's not that I participated in activities worth mentioning on a CV like doing a board year. Most of all, I just had a great time and made lots of friends and some of them I still see regularly. And regarding Periodiek, I really liked to write about science - or about less serious subjects. At that time, there was a course called "Scientific Writing", and I was one of the few from my year who really enjoyed this course.

To be honest, I have more memories from our KBE to Sweden than from my time at Periodiek. But one of the things about Periodiek I'll never forget is us working full nights through, just to get things done before our deadline. We have ordered quite an amount of pizzas during our Periodiek sessions.

6 We told Peter some current statistics from FMF.

# Science and Scientology

## Exchange Article

AUTHOR: **K. GLIMMERVEEN**

This article is a crossover between the Periodiek and Dei Facto, the faculty magazine of the faculty of Theology and Religious Sciences. We tried to find a commonground between religion and science. In the last edition of Dei Facto, you can find an article about numbers and Christianity.

"Science and religion": perhaps not a combination of words that you have read often in your time at university. After all, it doesn't exactly sound relevant to natural sciences or mathematics. However, as a Religious Studies student, I have discovered that those two words are at times pretty intimately connected. Perhaps this is unexpected; after all, religions don't have to follow scientific norms. Religions don't have to verify, falsify, or conduct experiments to convince their believers. Religion isn't science, right?

I would be inclined to agree with you. However, there is one religion that famously claims to be based on pure scientific fact: the *Church of Scientology*. If you have heard of this group, it's probably because of their cult-like appearance, their famous members such as Tom Cruise and John Travolta or the nightmarish stories of ex-members who frantically try to escape Scientology's watchful eye. The Church of Scientology is infamous for harassing people who try to leave and for bothering those who are critical of their movement – so if I suddenly disappear after publishing this article, you know what happened to me. But for those who don't know what Scientology is: it is a church founded in the 1950s by Ron L. Hubbard, based on the idea that people are spiritual beings who have lived many lives and need to learn to get in touch with their inner selves. To reach this goal, Scientology has a collection of processes and practices that are meant to remove negative emotions and help you achieve your higher potential.

This sounds fairly standard for a spiritual movement. However, Scientology claims to be different from any other churches or religions; they argue that they are based on science and have developed concrete technologies to help you live your life. "There are no tenets in Scientology which cannot be demonstrated with entirely scientific procedures," Rob Hubbard boasted.[1] Scientology will not ask you to blindly believe; your experiences will give you certainty about the effectivity of their practices. In this way, Scientology rejects other religions as dogmatic and presents itself as a unique Church where you, as a modern person living in a scientific age, will be allowed to think for yourself. Pretty attractive for people who want to believe in something or improve their lives, but reject mainstream religions as being outdated. However, I think you can probably sense the question coming: how scientific is Scientology, really? Are they more scientific than other religions, or are their claims completely fictional?

Firstly, Scientology does have some practices that they describe as scientific or technological, such as their E-Meter sessions. The E-Meter is a device which is supposed to measure spiritual changes in the brain to determine whether someone is experiencing psychological pain. What it actually seems to measure is the resistance between two electrodes that the client is holding, but this is supposed to be influenced by certain mental processes. I don't think there has ever been an attempt by the Church of Scientology to actually show exactly how this device works, and it's been ruled by a U.S. court long ago that it cannot diagnose or ease any mental or physical health problems.[2] Inside this E-Meter, there's a lot of wiring going on inside that I will not even pretend to understand; in fact, it's a really well-built machine of great quality if measuring resistance of the human body is what you want.[3] However, to claim that it also somehow measures psychological processes is comparable to liedetector levels of science.

Another example of Scientology trying to mix with science are their drug rehabilitation programs (something you can reasonably expect to have a medical basis), the largest project being Narconon. Unfortunately, this program has been criticized for being unscientific and even dangerous.[4] The criticism mostly focuses on the fact that the program effectively makes clients go cold-turkey and doesn't give any medication to counter withdrawal effects. It also uses sauna sessions of up to five hours, whereas it is usually recommended to not stay in a sauna for longer than 30 minutes. Lastly, clients are given 'vitamin bombs' far beyond the recommended amount, which can have adverse effects on your health. The fact that multiple patients have died under suspicious circumstances during the program doesn't help much to prove the scientific basis of Narconon.[5]

It's worth noting that Ron Hubbard, the founder himself, always did regard Scientology more as a science than as a religion. It's widely assumed that he took the religion angle later because evidence started to show that his techniques were just not supported by scientific fact. As a religion, you have the upper hand in e.g. legal scenarios, because U.S. courts cannot rule whether religious doctrine is true or false. At this point Scientology embraced some beliefs like reincarnation, in order to strengthen their position as a religion. However, this of course weakened the claim that Scientology really was a science, and it became a strange mixture of the two – with neither part having worldwide support. So not only is it highly questionable whether Scientology is scientific, but it's also in many countries, such as Belgium, not officially recognized as a religion either.[6] It therefore has a very unusual position across the world, living in the twilight between religion and science, and the organization itself seems to be unsure which route they really want to take.

I want to make a final note about this: it is not my intention to bash Scientology just because it's different and rejects the status quo. As a student of religion, I know what positive psychological and physical effects different religions can have and how they can genuinely help people. I also think it's great when religious institutions show interest in societal problems such as drug abuse, so props to them for trying to raise awareness. However, Scientology's claims of having a scientific basis seem to be questionable, misleading, and even dangerous. Even though it may seem on the surface like a perfect fit for our modern age, there is only one possible conclusion: Scientology might be a religion, but it sure isn't science.

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[2] Fiske, Edward. "Scientologists and F.D.A. Clash in Court." The New York Times, 1971. www.nytimes.com/1971/06/08/archives/scientologists-and-fda-clash-in-court-html.
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[6] "Erkende Erediensten." Erkende erediensten | Federale Overheidsdienst Justitie. Accessed February 3, 2020. https://justitie.belgium.be/nl/themas_en_dossiers/erediensten_en_vrijzinnigheid/erkende_erediensten.

# Understanding Refraction and Sunglasses Conceptually

AUTHOR: **A. DONGELMANS**

As a physicist I often ask "how" or "why" questions. There was one particular question that, after a couple of years of studying, still wasn't answered. For the people who took optics, this might be especially interesting. The simple question I asked is: "Why is light refracted, for example from air to water?"[1] This question then led to: "Why is it that all the light that reflects from water is horizontally polarized, causing glare?" Even though physics mostly concerns itself with "how", I still wanted a "why" answer deep enough to be satisfactory.

## Wrong explanations

To find out, I will first explain which three methods taught in kindergarten optics fail to explain why light is refracted:

1. Fermat's principle: light always has the shortest optical path length. This is true but is only an empirical explanation. The EM field does not "know" which path is shortest in advance and there is no answer as to why refraction happens.

[1] *Source of figure 1a, 3, 4, 5, 6: [Ref. 1].*

2. The marching band/soldiers analogy: the band represents photons hitting another material and supposedly change direction. This is false. The photons merely "slow down" in the material and do not change direction. If they would, the wavefront (shown by a rod in Figure 3) of photons entering would have to be rigid; the photons entering last (high circle on the bar) would experience a torque with velocity $v_{photon} > c$. **Unfortunately, this wrong analogy is still taught at many middle schools and universities...**

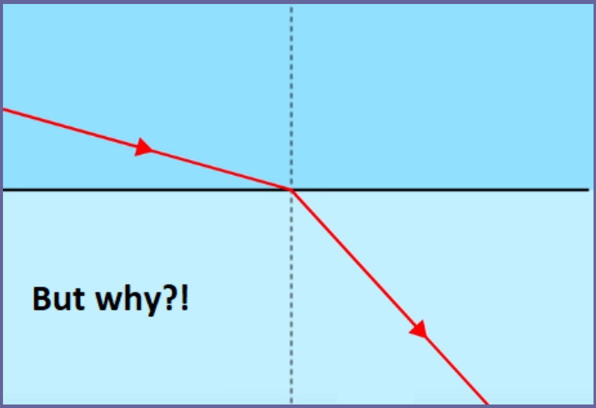


FIGURE 1: (a) Why is light refracted?

FIGURE 1: (b) What is the link between refraction and this annoying glare?

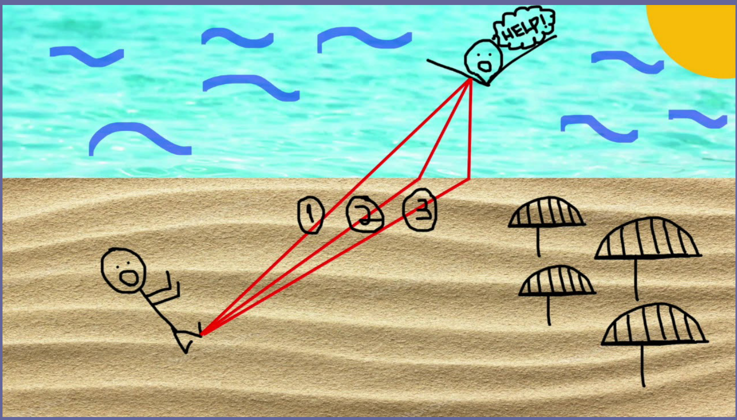


**FIGURE 2: Fermat's principle, you'll want to pick path 2 which takes the least amount of time. Source: [Ref. 2]**

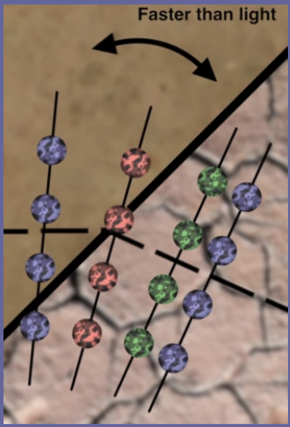


**FIGURE 3: The old-fashioned run-of-the-mill explanation for refraction.**

3. Huygens' principle: this approach does not give a unique solution. It basically says that at the boundary between two surfaces, at every point the incoming photon hits acts as an origin as if you would throw a stone in a pond: a ripple occurs. This ripple propagates into the other material. If many photons strike the material, many ripples form. This creates multiple wavefronts. One of these is in the direction of what we observe to be refraction. But this is *just one* wavefront and so this explanation does not work.

### Actual answer

Instead, we have to involve some math. Don't worry, the explanation will still remain intuitive. Below are Maxwell's 3rd and 4th equation.

$$\Delta \times E = -\frac{\delta B}{\delta t}$$

$$\varepsilon \Delta \cdot E = \rho$$

What is important here is $\varepsilon$, the permittivity, the interaction of incoming light with specic matter. Conceptually, this is because charges affected by the external electric field will align with it, but also counter it because there will be an additional electric field due to the charges rearranging. So the higher $\varepsilon$, the higher this counter E-field generation! This lowers the perpendicular electric field in matter (see Figure 5).

We shall treat the same problem mathematically for photons coming from air and entering water. At the surface, each side has its own set of Maxwell equations. We can therefore equate them:

$$\Delta \times E_{air} = -\frac{\delta B}{\delta t} = \Delta \times E_{water}$$

$$\varepsilon \Delta \cdot E_{air} = \rho = \varepsilon \Delta \cdot E_{water}$$

Now we apply some calculus and arrive at:

$$E_{\parallel}^{air} = E_{\parallel}^{water}$$

$$\varepsilon^{air} E_{\perp}^{air} = \varepsilon^{water} E_{\perp}^{water}$$

The variables are shown in Figure 6. $\varepsilon$ is different for each material and depends on its molecular composition: $\varepsilon^{air} \approx 1$ and $\varepsilon^{water} > 1$. Because the electric permittivity in water is bigger than in air, the perpendicular electric field has to be smaller than it is in air: $E_{\perp}^{water} = \frac{\varepsilon^{air}}{\varepsilon^{water}} E_{\perp}^{air}$. By adding the parallel and perpendicular components, we get the E-field vector. As the direction of light is always perpendicular to the E-field, we can see its new direction. Voila, refraction.

### Why you wear polaroids

As to answer "Why is light from water mostly horizontally polarized, causing bright reflections?", we now know the only relevant physical variable for refraction is, the electric permittivity. For an incoming angle higher than the so-called "Brewster angle", the electron inside the material no longer oscillates strongly enough to radiate another electric field, see Figure 7. Why specifically this angle? That has to do with the dipole moment of the individual molecule and each one's contribution inside the total electric field of that material [3], usually modeled as many springs connected together. Brewster angles can thus be used to find out what the material is you are looking at by varying angles!

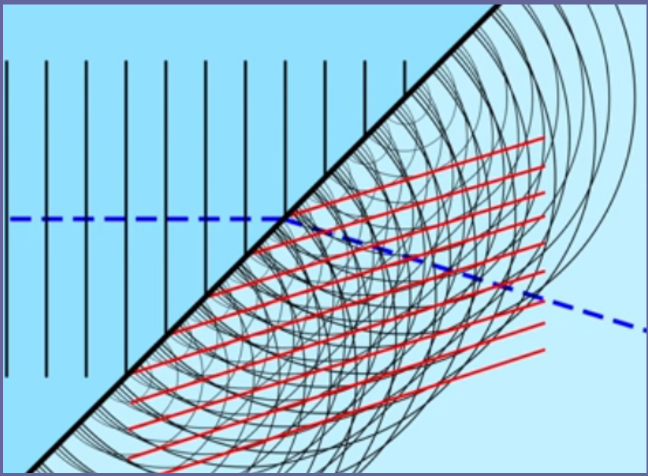

FIGURE 4: One of the many wavefronts (in red). Another wavefront would go in the same direction as the blue-dashed line meaning there is no unique solution.

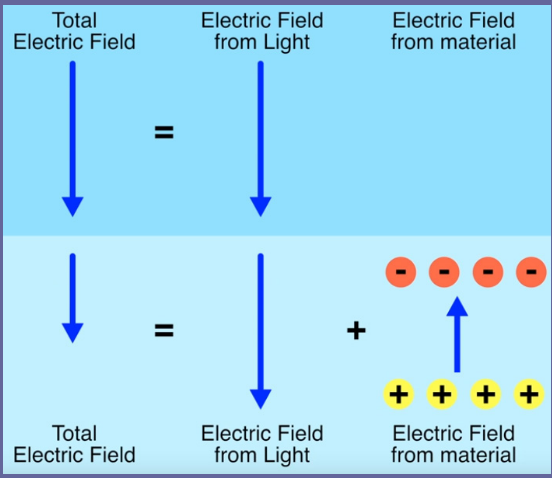


FIGURE 5: How the perpendicular electric field decreases.

The sum of highly polarized reflected light, along with unpolarized directly from the sun, causes glare and is unhealthy to look at, e.g. looking at a lake's surface. Simple sunglasses with a horizontal filter alleviate that problem like in Figure 8.

And that is why light is refracted, polarized and annoying you in summers.

## References


[1] Lincoln, D. *Why does light bend when it enters glass?* May 2019.
[2] Sayginel, H. *Fermat's Principle & Snell's Law* Oct. 2018.
[3] 22, M. L. *Interaction of Atoms and Electromagnetic Waves* 2011.
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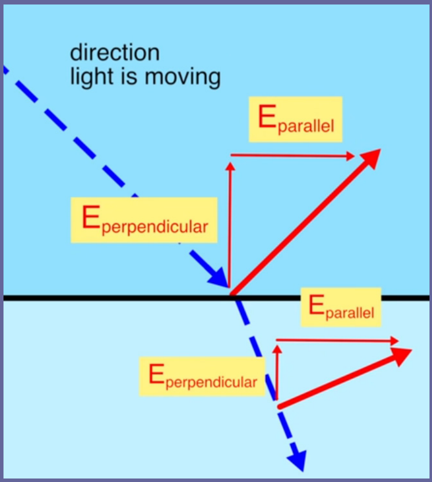


FIGURE 6: The changed electric field's vector components.

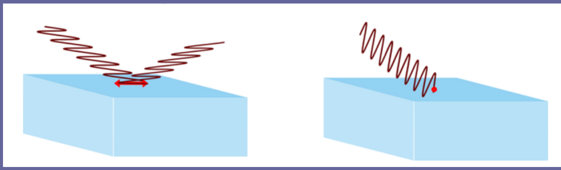

FIGURE 7: At the surface, the electrons cannot oscillate outside the water medium, restricting their degrees of freedom [Ref. 4].

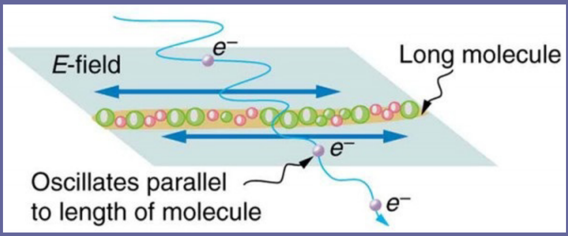


FIGURE 8: An incoming horizontally polarized E-field sets electrons in motion, having a preference of motion in the horizontal direction. The horizontal E-field has a reduced amplitude after the many interactions with the electrons [Ref. 5].

# Recipe

## Rhubarb crumble

AUTHOR: **R. MOL**

Materials:

4 souffle-/ovendishes

A bowl

A pan

Ingredients:

500 grams of rhubarb

1 bag of vanilla sugar

150 grams of sugar

2 tablespoon of orange juice

The zest *(Dutch: rasp)* of 1 orange

150 grams of flour

100 gram butter + some butter to grease up the souffledish / ovendish

Preparation:

Preheat the oven to 200 degrees. Wash the rhubarb and cut them in pieces of approximately 3 cm. Put the rhubarb with the orange zest, orange juice, vanilla sugar, and 75 grams of sugar in a pan. Boil the rhubarb for 5 minutes over a medium flame. Put the remaining 75 grams of sugar and the flour in a bowl. Cut up the butter and add this as well. Rub through the dough with your hands until crumbs have formed. Grease the soufle-/ovendish with butter and fill ¾rds with rhubarb. Sprinke it with the crumble(dough) and put it in the oven for half an hour.

Tips:

- The rhubarb doesn't necessarily have to be peeled. Hard pieces can be removed with a vegetable peeler.

- For variation, you can also add a handful of nuts to the crumble dough.

- The best time for rhubarb is between April and July, you can keep it the fridge for up to four days wrapped in plastic foil.

# Brainwork

## 36 copies of Schrödinger's cat in a box

AUTHOR: **R. MODDERMAN**

Last week, the Perio redaction time-travelled to Oxford University, 1935, where we succesfully managed to abduct (read: 'free') Schrödinger's cat[1] which was still captured in Schödinger's (opaque) box with a deadly substance that might or might not have leaked from its container. We came back intact, but Schrödinger's cat didn't: during the time-travel, the cat was split into 36 copies! The 36 cats now are contained in the same opaque cage, all happily accompanied with the deadly substance, and some of them could have died and some of them may still be alive - we don't know which, so to us being observers the 36-cat state is now a superposition of tensored cat states.


1 You can read about Schrödinger's cat on en.wikipedia.org/wiki/Schr%C3%B6dinger's_cat

We intend to give the cat back to Schrödinger, but there is one problem. If we open the box (which will be interpreted by the Law of Quantum Mechanics as a projective measurement on *all* cats), then the 36-cat state might collapse to the classical state in which all cats have died! Then, there would be no way back (in your Quantum Mechanics courses you have learned that the only reversible operation you can perform on a quantum state is a unitary operation; in particular, measurements are *not* invertible. For the mathematicians: just think of a measurement as a projective operation on a Hilbert space; now, use your mathematical skills to prove that such operation is invertible if and only if it does nothing - i.e., equals the identity operator).

Fortunately, in the box, we found a note written by Schrödinger himself. The note contains an attachment (figure of the grid of cats) describing how the cats are positioned, and the message explains that not all cats will be lost! So, all is fine in the end, we're just going to open up the box and send at least one cat back to Schrödinger. We want to know, however, the *color* we are certainly going to see back among the living cats.

*To the abductors of my cat,*

*Here are some instructions to undo what you FOOLS have done to my cat.*

*Some cats (indicated gray) are not entangled. Some cats are entangled (and are grouped by color). Any such entanglement is uniform: each partial measurement outcome on that group will have the same probability of being measured. To some of the cats, I have assigned the probability that the cat will be alive if that cat is measured.*

*If you measure a column, then the expected number of dead cats equals the expected number of living cats.*

*Similarly, if you measure a row, then the expected number of death cats equals the expected number of living cats. Also, if you measure 3 aligned cats (horizontally or vertically) then the probability of 3 dead cats equals the probability of 3 living cats.*

*Since the cats are in the box, you can't just perform any partial measurement. The only way to measure is to open up the box, and this will be a 36-cat measurement. But no worries: I assure you that there will always be cats that are alive if the box is opened!*

*QUESTION: when opening the box, what color will you see back for sure among the living cats?*

You can send a solution to perio@fmf.nl *before* February 1st!

## Previous Brainwork: 'The Seven Neighbours'

In the previous edition of the Periodiek, the puzzle 'The Seven Neighbours' could be found. To solve the puzzle, one was asked to deduce which of the neighbours did not study this year. Using the first 24 hints, the table below can be formed. The 25th hint states: "The neighbour that does not study does not have a girlfriend." From this last hint, the only solution is the Swedish guy in the yellow house with his Alcatel phone drinking Grolsch beer.

| | | | | | | |
|---|---|---|---|---|---|---|
| - | British | Norwegian | Chinese | **Swedish** | Finnish | German |
| Orange | Blue | Purple | Green | **Yellow** | White | Red |
| Xiaomi | - | Samsung | Nokia | **Alcatel** | - | Cat |
| Heineken | Hertog Jan | Palm | Amstel | **Grolsch** | Bavaria | - |
| - | Physics | Astronomy | Math | **-** | - | Chemistry |
| Silvia | Julia | Sandra | Janice | **-** | Deborah | - |

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