Australian Physics

VOLUME 58, NUMBER 1, JAN-MAR 2021

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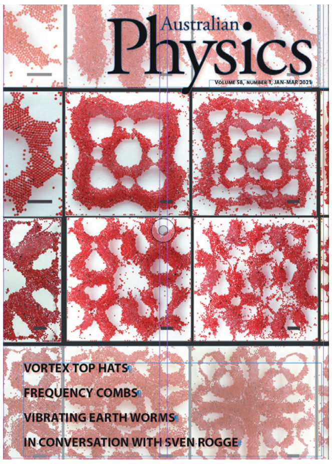

Faraday Waves visualised using small (0.2 mm) polystyrene beads. These standing waves form on the surface of liquids enclosed in a receptacle when the liquid is excited through vibration at certain frequencies.

(image: Wikimedia, Creative Commons CC-BY-SA-3.0; user Faraday Tesla)

Australian Institute of Physics

Promoting the role of physics in research, education, industry and the community

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EDITORIAL

Valuable skills for society

Physicists have valuable problem-solving skills. The various career paths open to physicists are testament to that. Sven Rogge, the new AIP President, explains in our conversation piece that clearly communicating this to the Australian community is the nut we need to crack. Hand on our hearts: could we be more active in amplifying the positive message about science and physics in society, working to make science become naturally understood part of the fabric of everyday life everywhere? That would enable the country to make decisions that positively impact STEM for meaningfully long timescales.

In *#PhysicsGotMeHere,* Sarah Midgley OAM describes how problem-solving skills link together for her with specialised knowledge about careers in STEM and technologies to help advise others in government on future workforce issues.

At the research level, Oliver Stockdale, Matthew Reeves and Matthew Davis demonstrate, in their article on vortex top hats in superfluids, how physics helps to solve tricky problems at the quantum level. Ivan Maksymov and Sergey Suslov show how microwave frequency combs could lead the way to manipulating the human brain. The latter inspired our front cover, which shows Faraday waves in small particle assemblies. In earthly endeavours of research and problem-solving, this time the Young Physicists explore what happens when you stimulate earth worms to vibrate using a subwoofer. The underlying work gained Ivan Maksymov and Andriy Pototsky an Ig Nobel Prize in 2020.

In operational matters, here a reminder that Australian Physics has now transitioned to quarterly issues. Book reviews are always welcome, and we are looking forward to hearing from you about your career story for *#PGMH.*

We close with a very warm welcome to Sven Rogge, and a profoud thank-you to Jodie Bradby, the outgoing AIP President and a most valued mentor of the editoral team.

With best wishes for 2021,
David Hoxley and Peter Kappen.

In conversation

The Editors of Australian Physics are in conversation with Sven Rogge, the new AIP President. Sven shares his thoughts on his own journey in physics, and the role of the AIP and physics in Australia.

What is physics?

AP: What is physics? Where do its boundaries lie?

SR: Oh, that's a hard question. For me, physics is the discipline, or the attempt, to understand the world around us in a rigorous manner, explaining why things behave the way they behave, making predictions, and testing these predictions. To be able to do this, we need rigorous training in the physical laws that we understand up to now, and the mathematical framework to work with these. Then, we go out and either we push forward to deepen that understanding, or we apply that understanding and our problem-solving skills to problems that are out there, not necessarily creating new physical insights, but solve current problems. And that could be going from data science and material science and artificial intelligence or any of that.

AP: It has been said by some people that 'physics is what physicists do', but that might lead to a sense of mission creep. So, the description you've just given, how does that not apply to, for example, analytical chemistry?

SR: There's always a question of scale and complexity. If you look at the spherical cow in vacuum, for example, physicists are really good at looking at a problem and driving it to the most simple form and understand how the laws of nature apply. Then, you make things more complex by adding more electrons to an atom beyond hydrogen. When you add more and more simplifications and abstractions, then you go towards chemistry, which is equally important, but it tries to do something else. It doesn't necessarily try to push the understanding of, say, how the electrons interact with each other; it wants to predict how these atoms behave. So, it's a different version of abstraction and detail. And I would say physics is the discipline that pushes the deepest into understanding the physical laws and pushing the way we understand how the world around us is governed by the laws of nature to further improve that.

I think it is important to reflect on the fact that physics, chemistry, and biology are all equally important. They just deal with different levels of complexity. For instance, if you try to understand a cell or an animal on the level on which we try to understand atoms or matter, that is just not going to work. You have to set certain boundaries and how detailed you want to go to actually achieve what you want in terms of understanding.

Inspirations and the world around us

AP: What is the thing that inspires you about physics? What inspired you to become a physicist?

SR: As a kid, I was very intrigued to find that to understand the world around us, we can do experiments, and we can formulate hypotheses and test them. As I learned more during high school, I got more interested in understanding things on a really detailed level and hence I went more in the direction of physics. I got very interested in understanding the cosmos and in high-energy physics. I thought: 'OK, this is really cool. I really want to understand what keeps everything together and what makes everything tick on the most fundamental, most microscopic level.' This also plays into the very large energy and length scales, which I found exciting. When I finished high school, I was pretty sure that I am not a theorist. While at that point I could have also gone towards engineering, I really wanted to stick with science and give physics a go and see if that worked for me. And it did work for me. I found it exciting and I enjoyed the study very much.

As I learned more about how you actually make progress in science, I got really excited about experiments that can be carried out by manageable teams; there are always teams in the modern world and it's not one person doing something somewhere in isolation. That brought me to condensed matter physics where you can design a clever experiment in the lab and, learn something about your system, and then refine your theory and bring it to the next level. High-energy physics is extremely exciting, but it needs very, very large experiments. That is why I ended up in condensed matter [physics], where we are pushing, on the one side, really fundamental physics, say in information science and mesoscopic physics, and at the same time, we are doing experiments in the lab that use our practical skills. So that really made me tick and has worked for me from the early days onwards.

The rewards from working and learning in teams

AP: You mentioned that working as a physicist is very rarely a solo effort but about working with people. Could you comment more on physics and teams?

SR: When you start, say, as a junior graduate student, you go into a lab, and that lab is a group of people with a vision of what they want to achieve. You learn from them skills and techniques, you read and learn the background theory, you have discussions with them. It is the reading by yourself and then reflecting with people that pushes the understanding and that creates new ideas and builds something that becomes bigger than what you could have built alone. So, it is always about building on something with someone else. As you become more experienced down the road and perhaps have an academic group, it's that same thing again: you work with a group of motivated people who chose to do a PhD or an Honours project or a PostDoc. This creates very stimulating environments, and I have enjoyed that a lot over the years. - The downside of all that is you have to find funding and jump through hoops and deal with uncertainty. On the plus side, you get to decide what you find interesting, what you want to work on, and you get to work with people on that. I find that very rewarding.

> *"Diversity in physics is very much linked to the image of physics. If we get out the notion that physics is a discipline that is exciting, that is not self-serving, that contributes to society, I think people would understand that physics is a very fruitful career path."*

Why the AIP exists

AP: What is the AIP for?

SR: For me, the role of the AIP is to give physicists, people interested in physics, a platform to communicate and also a voice. On the one hand, the AIP should speak on behalf of its members to society, towards politics, and we should enable interactions between physicists in Australia. That has been the role of the AIP, and I also see this as the role of the AIP going forward.

We have the Congress and the Summer Meeting where people can meet at all career stages; it is very important to have a sense of community. At the same time, we want to shape the image of physics, what physics is about, what the importance of physics is towards society and in politics. There is work to be done here, because physics is at times seen as an ivory tower discipline, which it is absolutely not. Physics provides fantastic training and skills in problem solving that push forward science and enable the development of technology, and thus physics also brings problem solving graduates into society. We are not very good at communicating that clearly. That is, I think, where the AIP enters the picture to work on changing that image.

AP: The AIP has cousins in different disciplines, like RACI, and it has overseas equivalents like IUPAP. How do you see the AIP talking to these other societies that have similar ambitions, but in different countries or different disciplines?

SR: Maybe we unpack that by starting, say, in Australia. As we talked about earlier, the role of the AIP in my vision is to create that communicative platform for people interested in physics in Australia, and to be that voice in terms of advocacy. The other societies, like the Australian Astronomical Society, Australian Optical Society and many, many more, have a similar vision. For me, this becomes about working with them, learning from them, and to be of service to our members. As an example, we are right now working on the awards in the AIP. They are very important, but we have to clean the system up a bit and then communicate more clearly what awards are out there. For example, we look to the Astronomical Society and it has done a very good job of representing its awards, and take that as a role model and talk to them.

The AIP in the international context

SR: About interacting with other societies worldwide, there are sister societies in other countries. Again, there is the learning from them, keeping friendly ties, and giving membership discounts for people. Members want to have a link to their societies. They come from the UK, they are in the German Physical Society, the American Physical Society, and so forth. Most of these societies have a national focus where they want to be that platform for their country. There are few societies, like the American Physical Society, that play an international role. They have huge international meetings that we go to. I do not see that the AIP could or would want to do that. I think by sheer size, some evolve to that and some other countries will not have that, and that's fine. For example, the AIP Congress has fantastic international speakers that really enjoy coming to Australia. But, at the end of the day, it is a platform for the people in Australia to communicate with each other and hear what is going on in physics.

Then there is the link to umbrella organisations like IUPAP. This has a formal structure, and we had the pleasure of having the presidency of IUPAP a couple of years back with Bruce McKellar. There's a chapter that looks at semiconductor physics, the field I am in, and when we organise large conferences, there are some endorsed by IUPAP, and we draw on that, which is very useful. If you go towards high-energy physics or other big science then these large organisations are very important, because they broker to some degree what is going on with those large experiments. It is very important to have a voice in that, and Australia gets its fair share in that space.

The image of physics is linked to diversity

AP: With diversity very much on the agenda for the AIP, how do you think we can achieve greater diversity? Do you have priority areas for what success would look like in the diversity space?

SR: We all agree that diversity is important. The motivation for diversity, for me, is that any monoculture in any way is not helpful. A diverse background of people and diverse trains of thought always strengthen the outcome. This is about helping people and giving them opportunities, and we will have a better physics community if it is more diverse in any direction.

For me, the issue we face with diversity in Australia, and the rest of the world, is very much linked to the image of physics. We need to communicate the notion that physics is a discipline that is exciting, that is not self-serving, that contributes to society, that has the full span of fundamental insights all the way up to applied sciences, and that provides problem solving skills relevant to the real world in environments that are not directly linked to physics. If that becomes clear, I think people would understand that physics is a very fruitful career path.

Then there is the bias we have [in] the environment we live in right now. We all have a bias, if it is conscious or not, and we really have to work to overcome that. That does not solve itself. You really need to do something and set yourself goals. For example, in the last 10 years, university departments have evolved and have increased the fraction of female academic members quite drastically; they have not changed just because we thought it was a good idea. If you set yourself goals and you track how you do with these goals, then you can move forward. If I talk to my colleagues about increasing diversity, everyone is acknowledging it is a good thing to do. We all have become better departments because of that effort.

Around the image of physics, the toughest nut to crack is projecting that image into society and, especially, into schools. The image of high school physics as an exciting topic is not out there. The career adviser is steering kids more towards engineering because why would you want to be a scientist? Again, there is that ivory tower thing. That is something that needs work, and it will take time. But I think if we all go out there and just make a point of communicating how we contribute to society wherever we can, then then we will have a chance of getting that right.

AP: When we are looking at improving the perception of physics in schools and society, would you copy some of the overseas activities, for example, the German Physical Society's National Physics Olympiad for school kids?

SR: Definitely. While we are engaged with the Olympiad, I agree that that we have to do more. This comes back to how physics societies can work together. We should look at best practice rather than trying to reinvent the wheel. I think everyone is proud of being copied if they do the right thing and see it work somewhere else as well.

Engaging with industry and building career paths for the next generation

AP: Could you share a little bit about the relationship between academia and industry? What should Australia be doing? How can we help our members in this?

SR: Thanks for bringing that up–that is important to me. The vast majority of all our physics graduates do not go into academia but rather into "the real world". Even if they do not go into an R&D environment, say, they go to a bank or consultancy to work with data; there they use those skills they have been training with as physicists. And it is often overlooked that this happens on a societal level: they are useful people, and they do not brag about where they came from; they just use their skills. We need to do better in preparing our students for the real world, and there are significant opportunities to do so. For example: having summer internships in companies, having that as an absolute norm every summer break, go out there, experience a new environment, see how people work in problem-solving environments, have industry come in and show career paths, show how people apply their skills, bring industry and academics together to learn about the problems that industry faces and see if there are common grounds and problems that can be solved.

In this space, it is very early days in Australia. We see some things working. They are more on an individual level where someone has a link somewhere and that is working well. We have to see just more of that, because then, it will become more apparent how many positive career paths there are in science and physics, how diverse that training is, how many options are out there. But, there is also an advantage for the industry or the companies out there to tap into the productivity, the knowledge, the motivation that is present in the academic sector. Now, the academic sector is very aware that just relying on government funds to carry out research is becoming harder and harder, and many academics are eager to engage. Of course, they want to engage in the way that they can drive forward the core line they are working on, but whatever synergies exist that they are happy to explore, I see definitely the AIP as an organisation that can help and drive this change. The industry is out there; the departments are on the other side and some departments have that engagement working. Some departments want it but have not really achieved that. And rather than everyone reinventing the wheel, working with the AIP to make that happen I see as a big win on all sides.

Influencing policy

AP: That brings us to a final puzzle piece in the innovation system around government and policy. How can the AIP influence or inform policy settings that enable this transition to a more recognised discipline area that can enable industry work?

SR: There is the bottom up versus the top down. The bottom up, I think, is happening in that space that we just talked about: A physics department engaging the world around them, sending their students out to work with industry, enhancing the image how the work and training we do is relevant. More globally, the AIP is a volunteer organisation, so we do not have a large body of people who can lobby. Hence, we are working with people around us, for instance from the Academy of Science and the National Committee of Physics, in showcasing examples where industry appreciates physics. Together, we work on outlining to government how physics contributes. We are filling that advocacy role by working with other institutions in Australia and to get the word out.

The importance of quality

SR: Whenever the pressure came on last year [during the pandemic], there was a strong positive focus on science. Science led to the decision-making around the pandemic. People realised that in Australia, we have to embrace our STEM community. The Job Readiness Packages came out, and the focus on STEM was good. At the same time, there is the cut to funding for students in the higher education sector, which makes it harder to educate them properly. Money needs to be saved, but education is actually a major export commodity in Australia that we should be proud of, that we should celebrate, and that we should invest in. We are generating these graduates for the world, but also for us to be competitive. We have to do that to the best level that we can. That is not the region where you want to cut corners and shave a couple of percent off. You want to really be out there to be with the best.

Vortex ordering in superfluid films

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The frictionless flow of room temperature superfluids in semiconductors potentially has applications in future quantum technologies such as ultra-low energy electronics. However, turbulent flow in superfluids may hinder the practicality of such applications. The many favourable properties of superfluidity provide a clean and efficient experimental test bed to study turbulence and address long unanswered questions. An Australian-led coalition of three laboratories have independently verified a 70-year-old prediction about the emergence of large-scale turbulence in two-dimensional systems using state of the art laser control of superfluids. Their experiments shed light on turbulent phenomena observed in geophysical and weather systems, as well as demonstrating promising candidates for quantum technologies such as ultra-precise accelerometers.

Introduction

Superfluidity is an emergent feature of a quantum many-body system that typically occurs at cryogenic temperatures. The first known superfluid was created approximately 80 years ago by Kapitza [1] and independently by Allen & Misener [2], where helium-4 was cooled below its transition temperature $T_c = 2.17K$ to create superfluid helium-4 (also known as He-II). Below the critical temperature, known as the lambda point of He-II, the viscosity of the helium sample was measured to be approximately 1500 times smaller than its counterpart above the lambda point. The vanishing viscosity is one of the fundamental properties of superfluidity, which allows for phenomena such as the famous superfluid creep (Figure 1), and the absence of resistance against a barrier as it moves through a superfluid below a certain critical velocity.

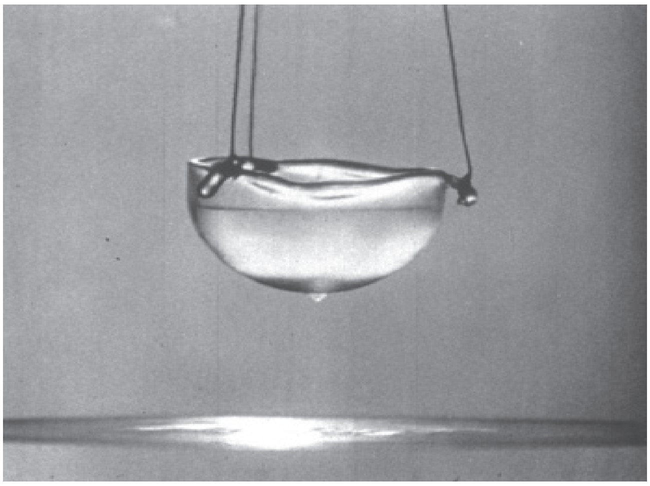

Figure 1: The famous superfluid creep. A superfluid drips from the bottom of the container despite it not being full. Due to the vanishing viscosity, the superfluid 'creeps' up the walls and falls over the edges (Wikipedia(2021), Alfred Leitner (1963); public domain).

Since the first demonstration of superfluidity in helium, significant effort has been devoted to gain both a theoretical understanding of its properties, and to develop experimental control of such systems. The topic of superfluidity has been awarded multiple Nobel Prizes, including for the discovery of superfluid helium-3, microscopic theories of superconductivity (i.e., the superfluidity of electrons), and the creation of atomic Bose-Einstein condensates (BEC). He-II is a remarkable substance as it possesses the largest known thermal conductivity and an exceptionally small index of refraction. To date, however, practical applications of superfluidity have been limited–it has mostly helped develop theory for low temperature physics. However, He-II has found applications as a technical coolant for superconducting magnets in the Large Hadron Collider, fusion reactors, and infrared astronomy telescopes [3-5].

Due to its many favourable properties, particularly its ability to flow without dissipation, superfluidity is a strong candidate for future quantum technologies. The ongoing push to develop quantum technologies in the "second quantum revolution" has seen a renewed interest in application of He-II as both a coolant and a fundamental element of devices (e.g. oscillators). While superfluids typically exist at ultralow temperatures, it has recently been demonstrated that superfluids of light can exist at room temperature [6]. Despite these remarkable properties, there do exist negative aspects to superfluidity. For instance, the lack of viscosity means it is extremely easy to excite turbulence in a superfluid.

Within Australia, two Australian Research Council (ARC) research centres are working with superfluids to gain a better understanding of how to use it for developing such technologies. One of the goals of the ARC Centre of Excellence in Future Low-Energy Electronic Technologies (FLEET) is to develop a room temperature superfluid transistor that will potentially slash the energy consumption of computing. Meanwhile, the ARC Centre of Excellence for Engineered Quantum Systems (EQUS) aims to use superfluids, in combination with optomechanics, to develop ultra-precise sensors for applications in defence and navigation.

A collaboration between these two centres offers a unique environment to study superfluids. A key focus has been on the chaotic motion of superfluids (i.e., turbulence), which is likely to be a mitigating factor in developing superfluids for technologies. In this article, we discuss the some of the results from this collaboration, which includes the verification of a 70-year-old prediction on how large-scale turbulence emerges in two-dimensional systems. These results not only provide a more thorough fundamental understanding of turbulence but have a range of applications in understanding neutron stars, weather systems, and superfluid accelerometers.

Vortices in superfluids

Superfluids are ideal systems to study quantum phenomena as they are experimentally accessible macroscopic quantum systems. One particular topic of interest in studying superfluids is their chaotic motion, known as turbulence. Turbulence is a long-studied problem, with many current outstanding questions even in classical fluids. Turbulent motion destroys laminar flow and thus eliminates the lossless property of superfluidity.

In classical physics it is believed that the Navier-Stokes equation holds the key to understanding the origins of turbulence. It is one of the Clay Mathematics Institute's Millennium Problems to "make substantial progress toward a mathematical theory which will unlock the secrets hidden in the Navier-Stokes equations." Richard Feynman went as far as saying turbulence was "the most important unsolved problem of classical physics". There are good reasons for this grand statement, as turbulence underpins several ubiquitous phenomena such as weather, flight, green energy, and transport.

Likewise, turbulence in quantum fluids has many unresolved issues. Similar to its classical counterpart, quantum turbulence is difficult to understand and describe. In general, turbulent flow arises via a complex interaction of the vorticity of the fluid. However, unlike its classical counterpart, the vorticity of a quantum fluid is *quantised*, which means it is easier to identify, and which leads to more tractable models in describing turbulence in quantum fluids.

The key to the quantisation of vorticity, defined as $\boldsymbol{\omega} = \nabla \times \mathbf{v}$ where $\mathbf{v}$ where is the superfluid velocity field, is the single-valued nature of the wave function. The circulation is quantised as

$$\Gamma = \oint \mathbf{v} \cdot \mathrm{d}l = \kappa \frac{h}{m}$$

where κ is an integer that represents the 'strength' of the vortex, h is Planck's constant, and m is the mass of the superfluid atom. That is, unlike classical vortices, quantum vortices can only rotate with one, two, or any integer amount of rotation. The consequence of the above equation is that one can feasibly describe the chaotic behaviour of superfluids entirely from a description of the vortex dynamics. It follows that to understand how turbulence manifests and behaves in superfluids, one must understand the dynamics of quantised vortices.

Onsager's negative temperature Vortices

The dimensionality of a fluid, i.e., 2D vs 3D, drastically alters its turbulent behaviour. One stark example can be seen via the behaviour of vortices over time. Under most circumstances, where the fluid is able to flow in all three dimensions, one will observe an energy cascade, where large sources of vorticity (i.e., large, powerful vortices) will break into smaller, weaker vortices. However, under some circumstances, the flow can become suppressed in one direction, yielding effectively two-dimensional (2D) flow. Remarkably, in 2D, the opposite occurs: an inverse energy cascade takes place where smaller vortices of like-charge will instead merge with one another to form larger vortices. A schematic of this process is shown in Figure 2.

Imagine a finite two-dimensional superfluid system with an equal number of singly quantised vortices and anti-vortices (i.e., vortices spinning in opposite directions). The vortices are point-like particles which never run into one another and move under the influence of the flow of all the other vortices. Energetically the vortices interact similarly to charged particles in two-dimensions, but with no inertia [7]. At low system energies, the vortices and anti-vortices tend to pair with one another. As the energy of the system is increased, the pairs break up and the vortices are essentially free. However, if even more energy can be added, then the like-signed vortices start to coalesce into two clusters (Figure 3). This state is of particular interest as it can be characterised as having a negative temperature, as first identified by Lars Onsager [8]. Temperature in statistical mechanics is defined as

$$\frac{1}{T} = \frac{\partial S}{\partial U}$$

where S is the entropy and U is the energy. As the system energy increases, the entropy of the vortices decreases with the formation of the clusters. The negative temperature state is a direct consequence of the position coordinates, x and y, being canonically conjugate variables. Unlike objects with mass, vortices have no momentum. The phase space is therefore bounded, and hence entropy can decrease as energy increases.

The existence of these Onsager vortices are not just a theoretical idea for small experimental quantum systems, but concepts thought to be important in understanding large scale turbulent systems such as weather patterns and geophysical turbulence of the Earth. For example, the Great Red Spot observed on Jupiter is believed to be an example of this physics.

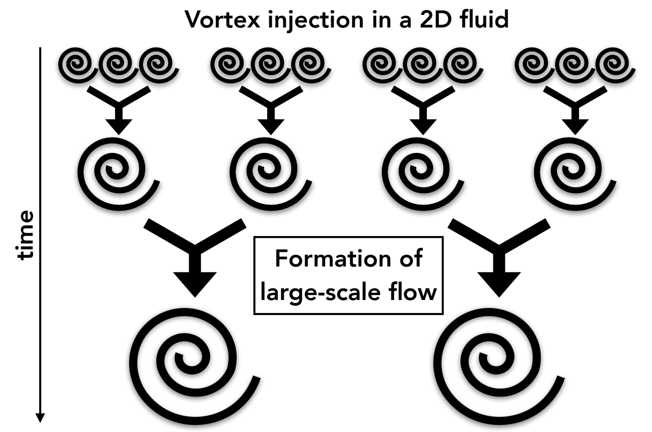

Figure 2: Vorticity dynamics for a 2D system. There is an inverse energy cascade where small vortices coalesce to form large-scale flows. In 3D, the reverse process happens (i.e., time in the above schematic would instead point in the upwards direction).

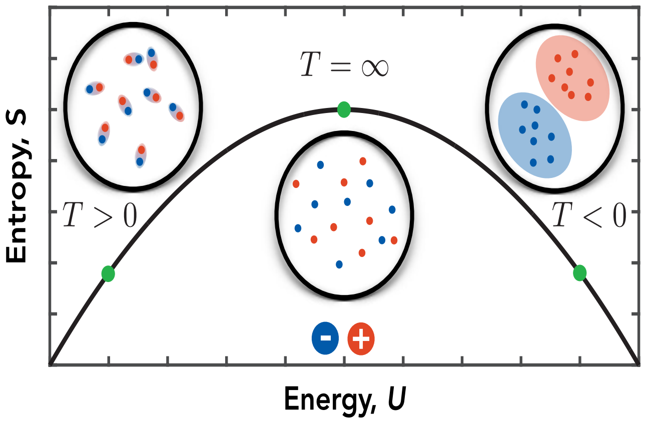

Figure 3: Phase diagram of vortices in a bounded geometry. In the low energy limit, vortices pair together and are at a positive temperature. Increasing energy yields free vortices with infinite temperature. Further increasing energy yields Onsager vortices with a negative absolute temperature [Eq. (1)].

So far, we have described an idealised vortex system at equilibrium. However, in realistic superfluids the vortices have a finite extent–and when oppositely charged vortices run into one another they annihilate, releasing a burst of sound energy into the superfluid. A recent theoretical paper studied what happens in a more realistic model when starting with a random arrangement of vortices and antivortices at infinitemperature [9]. Interestingly, they found that while many of the vortices annihilated, the ones that were left formed Onsager vortex clusters at a negative temperature. While the system may first appear to have become more ordered, and hence have a smaller entropy, in actual fact much of the entropy is carried away by the bursts of sound, and so the second law of thermodynamics is safe. The dynamical process of Onsager vortex formation was called "evaporative heating", as the vortex pairs that annihilate can only remove a small amount of energy. This leaves behind a higher energy per vortex for those that remain, and thus results in negative vortex clusters. Other studies have probed these Onsager vortices theoretically [10-12], but it was only in 2019, 70 years after Onsager's original prediction, that this phenomenon was experimentally observed for the first time in a superfluid [13, 14].

Experimental verification of Onsager's theory

The experimental observation of these 'Onsager clusters' proved to be a significant step in understanding the emergence of turbulence in two-dimensional quantum systems. Two experiments independently observed the clusters: one at the University of Queensland (UQ) [13], and the other at Monash University [14]. Both experiments created a superfluid not with helium, but with an atomic Bose-Einstein condensate. This is known as the fifth state of matter, which occurs when a system of bosons is cooled such that they all condense into the quantum mechanical ground state. In this regime the system can become a superfluid.

Both UQ and Monash experiments cooled gases of rubidium-87 atoms to nanokelvin temperatures, and

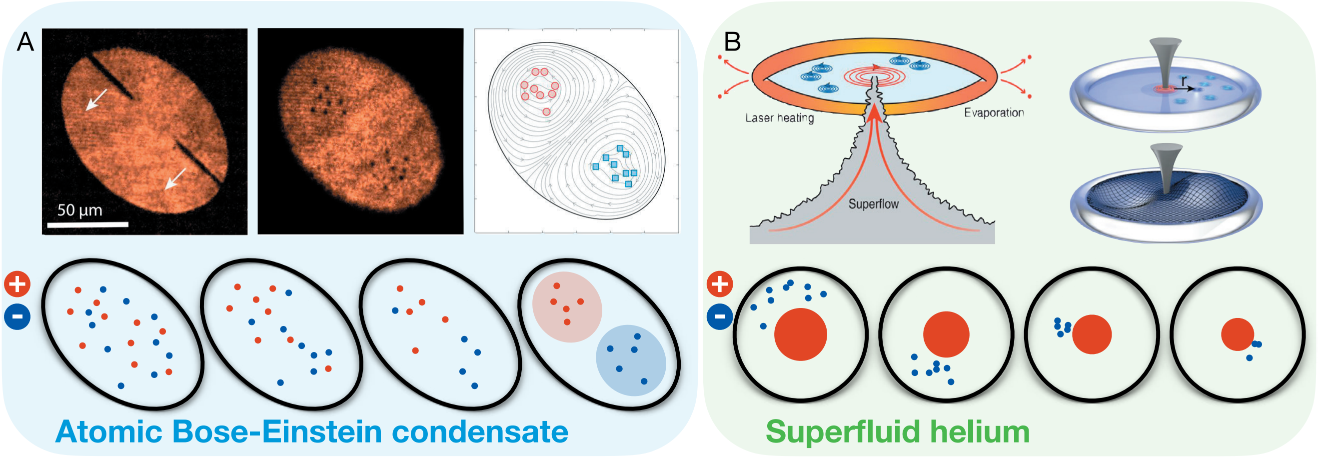

Figure 4: Experimental realisation of Onsager vortices. (A) The upper row is from the UQ BEC experiment, where the high-energy Onsager vortices are injected into the superfluid via laser sweeps. The first two pictures are images of the superfluid during and after the sweep, and the right image represents the velocity field of the superfluid created by the vortices (red and blue points) [13]. The bottom row is an illustration of how the Onsager vortices form from a random distribution of vortices, as was observed in the Monash University experiment [14]. (B) The UQ superfluid helium experiment. The upper left is a sketch of the experimental system, where the vortices are on the lower surface. The upper right shows the vortices and the sound wave, whose interactions are exploited to infer the vortex distribution [16]. The lower row is an illustration of the dynamics. Negative vortices spiral inwards and annihilate with the central pinned vortex, reducing its strength in quantised amounts.

trapped the condensate using sculpted laser beams such that it formed a flat pancake shape, i.e., approximately they were two-dimensional. Vortices were introduced into the superfluid via laser beams that swept through the superfluid faster than the critical velocity, leaving vortices behind in their wake.

The UQ and Monash experiments differed in how they generated the Onsager clusters. In the Monash experiment, vortices were injected so that vortices and antivortices were randomly distributed, similar to the initial theoretical proposal in Ref. [9]. Through the process of evaporative heating, the Onsager vortices formed. This process is sketched in the lower row of Figure 4A. Despite the low number of vortices in the initial state, and the vortices subsequently lost via evaporative heating, distinct formations of like-sign clusters were observed in the final images of the cluster.

Unlike the Monash experiment, the UQ experiment initialised the vortices directly into an Onsager vortex state. By sweeping two lasers through either side of the superfluid, two large clusters of opposite sign vortices were created, as indicated by the snapshots of the superfluid in the upper part of Figure 4A. Here, we see direct images of the condensate, where the black dots are holes in the condensate which are the quantum vortices.

The UQ experiment focused on studying the stability of this negative temperature state, which is far from the global equilibrium of the whole superfluid and would not incorporate any vortices. The clusters were observed to persist for the entire lifetime of the superfluid in the experiment, suggesting these far from equilibrium states are incredibly stable, even with dissipation due to the sound waves that exist at finite temperature.

A superfluid helium detour

A third experiment that studied quantum vortices in a nanoscale film of superfluid helium-4 soon followed. This experiment consisted of a microscopic disk on a pedestal that was embedded within a cryogenic fridge filled with helium-4 gas [16]. As the fridge cooled, the helium formed a thin superfluid film over the disk. A sketch is shown in Figure 4B. Unlike the previous two experiments, vortices were created here by tuning the lasers so that a fast flow of superfluid was generated up the pedestal (Figure 4B). This technique was the first in the world to demonstrate the use of laser control of superfluid helium.

In superfluid helium, vortices cannot be directly imaged as (i) the refractive index of helium is comparable to that of air and (ii) the vortex cores are only angstroms in diameter, far too small for direct optical imaging. To combat this issue, this experiment exploited the interaction between vortices and the sound waves of the superfluid.

The rotational superfluid flow generated from the

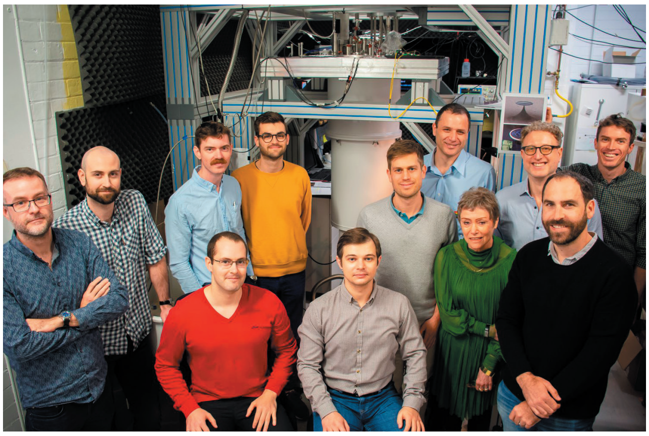

Figure 5: The University of Queensland members of the Australian Quantum Vortex Team, who were finalists in the Scientific Research category of the Australian Museum Eureka Prizes in 2020.

vortices alters the frequency of the sound modes running clockwise and anticlockwise about the disk due to the Doppler effect. Harnessing the optomechanical interactions, i.e., the interaction between the mechanical motion of the superfluid (sound modes) and the coupled light (lasers), allowed one to infer the distribution of the vortices from the spectra of the emitted laser light.

Unlike the first two experiments, antivortices and vortices were not freely moving within the superfluid. In the helium experiment, a large multi-charged vortex was trapped on the central pedestal, while a cluster of singly charged antivortices was free to circulate in the superfluid (Figure 4B). Despite this qualitative difference, the evaporative heating of vortices and their coalescence into a like-sign vortex cluster were nevertheless inferred from the data. Over time, the free antivortices would spiral inwards and annihilate with the pinned central vortex cluster. This would reduce the strength of the pinned vortex and increase the overall energy per vortex of the system.

A surprising finding of the study was that the vortex dynamics were dominated by coherent motion. This contrasts with previous studies of thin-film He-II where substrate defects caused large pinning forces on the vortices, strongly limiting their dynamics. The nanofabrication techniques used to produce the microscopic disk resulted in a near atomically smooth surface; the ability to produce coherent flows in similar setups may prove favourable in measurement applications harnessing thin-film helium flows.

The combined research team that performed these three independent studies of Onsager vortices were together a finalist for the Scientific Research category for the Eureka Prizes awarded by the Australian Museum in 2020.

Vortex fluids

In the modelling of the superfluid helium experiment, many different scenarios of vortex dynamics were initially considered to try to reproduce the experimental data. One scenario that turned out not to be relevant to the experiment, but later became of interest was that of an expanding cluster of like-sign vortices. This phenomenon exhibited interesting properties related to turbulence in both its long-time dynamics, and in its stark deviation from classical vortex behaviour.

Many turbulent phenomena observed in classical fluids have quantum analogues. For example, both von Kármán vortex streets [15] and negative temperature equilibrium states (as mentioned above [13, 14]) exist in both classical and quantum fluids and have each been demonstrated experimentally. In contrast, there are some turbulent quantum phenomena which possess no classical analogue.

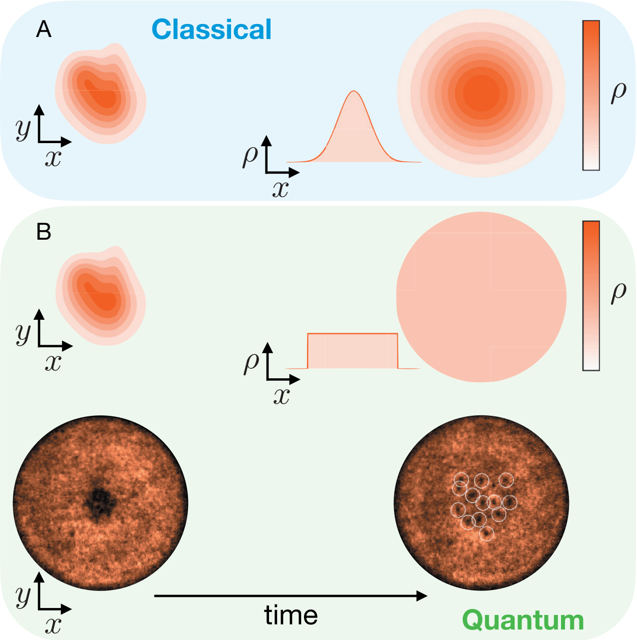

Figure 6: Dissipation via vorticity. (A) A vortex in a classical fluid: a vortex expands to form a Lamb-Oseen vortex (Gaussian density). We also show a 1D slice of the 2D distribution on the right. (B) The expansion of vorticity in a quantum fluid. Due to the quantisation of vortices, the distribution expands to form a Rankine vortex (uniform distribution). The bottom row illustrates the experimental emergence of the Rankine vortex, where vortices are the black dots (highlighted by the white circles on the right).

In this subsequent study, the collective dynamics of many like-sign vortices were considered in a finite temperature 2D superfluid. The finite temperature led to the expansion of the vortex cluster over time, and a decrease in the overall energy of the cluster.

Often, the dynamics of many vortices are chaotic and impossible to describe exactly. As opposed to describing the dynamics of each vortex, a method known as the vortex fluid theory was used, which describes a collection of vortices as a fluid in their own right [17, 18]. That is, the collection of vortices has their own hydrodynamic equations separate from the superfluid equations. The core assumption is that the quantised vortices are so densely packed that one can approximate their distribution with a continuous vorticity field.

The remarkable property discovered was that any initial condition, regardless of the arrangement of vortices, eventually expanded to form a Rankine vortex [19]. A Rankine vortex, which behaves like a 'super vortex', has uniform density and rotates as a rigid body. The Rankine vortex was an analytic solution to the vortex fluid theory, and furthermore was found to be an attractor. This means that as any system of like-sign vortices expand, the distribution will always tend towards this solution.

This is the point where there exists no classical analogue of the quantum phenomena we observe. The Rankine vortex is forbidden in classical fluids due to the existence of viscosity. A Rankine vortex has a 'top-hat' configuration–uniform density right to its edge, and then zero density outside–which is not possible in a viscous fluid. This is illustrated in Figure 6, where we show three examples of an expanding cluster.

The first row of Figure 6 represents a classical fluid, which has some continuous vorticity distribution represented in the contour plot. Over time (from left to right), this system dissipates energy, and the vorticity tends towards a distribution known as a Lamb-Oseen vortex, which has a Gaussian shape. This is shown on right side of Figure 6A, where a 1D slice through the 2D distribution is also shown.

The second row shows the same case but for a quantum fluid. Of course, the vortices are still quantised, but the vortex fluid theory approximates the distribution as continuous. As can be seen on the right side, the distribution expands to form a Rankine vortex, where the distribution is uniform within, and the 1D slice resembles a 'top-hat' in shape. The emergence of the top-hat arises due to the additional stresses a quantum vortex fluid experiences as a consequence of the quantisation of vortices.

In addition to providing the analytical solution to the vortex fluid theory that shows the formation of a Rankine vortex, we also analysed experimental data from the expansion of a small vortex cluster in a quasi-2D atomic BEC. In the third row of Figure 6, we show some of these experimental snapshots of the superfluid. On the left side, the cluster is tightly packed at the centre of the superfluid. After expansion, one can see they have expanded to form a quasi-uniform distribution as predicted by the vortex fluid theory.

While the vortex fluid theory is in principle only valid for large collections of vortices, the BEC experiment was performed with only 11 vortices. It is quite remarkable that the results of the vortex fluid appear to be applicable to systems containing so few vortices, suggesting that other properties of the theory could be probed in atomic gas BEC experiments [19].

Conclusions and future directions

The study of superfluid vortices in Australia has produced some significant advances in our understanding of the formation, subsequent evolution, and dissipation of large-scale turbulent quantum systems. By using pioneering laser techniques to control quantum fluids, a 70-year-old prediction about how turbulent systems evolve has been verified. The results have applications not just in advancing our fundamental understanding of turbulence, but direct uses in understanding how turbulence may be avoided or exploited for future quantum technologies. The experimental techniques used in these studies have applications in other quantum technologies such as ultra-precise inertial sensors.

Despite these advances, there still remains much to be understood about the manifestation of turbulence in quantum fluids, such as energy cascades. One key challenge to overcome is the number of vortices an experiment can host. While the atomic BEC can realistically contain approximately 50-100 vortices, the superfluid helium experiment can host several thousand. This would allow much more rigorous tests of the vortex fluid theory to be explored. Superfluid helium films could also provide a platform in which to investigate turbulent energy cascades or build a quantum simulator of the rotating superfluid core that is believed to exist in neutron stars to investigate the role vortices play in their dynamics.

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About the authors

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Prof. Matthew Davis is the Deputy Head of the School of Mathematics and Physics at the University of Queensland and a Chief Investigator with both FLEET and the ARC Centre of Excellence for Engineered Quantum Systems. He is an expert in the dynamics of finite temperature Bose gases, and has pioneered the development of theoretical models to describe such systems.

New Fellows of the AIP in 2020

The AIP community congratulates everyone who became a Fellow of the AIP and celebrates their continuing contributions to physics in Australia:

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Acoustic frequency combs, gas bubble oscillations and brain-computer interfaces

Ivan Maksymov, ARC Future Fellow, Optical Sciences Centre, Swinburne University – imaksymov@swin.edu.au
Sergey Suslov, Professor, Department of Mathematics, Swinburne University – ssuslov@swin.edu.au

We present the results of our experimental work on the generation of acoustic frequency combs using nonlinear oscillations of gas bubbles in liquids. We elaborate the main motivation of this work–preparation of tests of a safe link between the brain and computers that uses ultrasound waves instead of invasive needle electrodes. Whereas we are still far from doing something this complex, we also discuss a less distant applications of the so-generated combs in precision underwater measurements and biomedical imaging. Readers interested in our results may also like to read the Young Physicists' Page article in this issue.

Brain-computer interfaces

Can you imagine what your life would be if you could transfer information from computers and Artificial Intelligence systems directly into your brain? This would make you, and people around you, better car drivers, higher school achievers and more diversely skilled workers.

Although much of this remains a theme for science fiction, scientists already work on this idea. For example, high-tech companies, including Elon Musk's Neuralink [1], implant needle electrodes into animal brains to test their Brain-Computer Interface (BCI) technologies ultimately intended to enable the transmission of large amounts of information from a computer directly to a human.

However, inserting needle electrodes into a living brain is very invasive and poses significant health risks such as inflammation of the brain tissue or even its damage [2]. Thus, to create safer BCIs, we need new non-invasive techniques that do not harm live tissues.

Recently, biophysicists put forward a hypothesis that, if proven correct, could unlock novel opportunities for avoiding invasive and dangerous brain implants. In particular, scientists came across intriguing experimental observations indicating that electric nerve signals that transfer information between the brain and other parts of our body may also have an acoustic wave component [3-6].

The proposed acoustic model of nerve signalling does not necessarily contradict the accepted model of electric nerve signal communication but rather extends it by deepening our understanding of biophysical processes in the nerve. In fact, similarly to the potential ability of the nerve fibres to guide light and even hypothetically transmit quantum information [7-9], the acoustic channel may be an alternative means of nerve communication that Nature does not use. Moreover, whereas the electric nerve signalling may be the optimal means of communication inside a living body, using it for communication with the nervous system from the outside environment may have its limitations. That is where the alternative communication channels can help.

If the nerve signals can indeed propagate as acoustic waves, then we may imagine a novel technology that would enable us to transmit information to the brain by sending acoustic impulses—for example, ultrasound (US) waves—from a mobile device held near the head. Acoustic waves can safely pass through the skin, bones and brain tissues, which is a property that underpins medical US imaging procedures. Hence, using US waves could enable us to create safer and more reliable non-invasive BCIs that do not require needle electrodes.

Acoustic solitons in nerve fibres

However, using US waves to access the brain is not straightforward because there can be other unexplored mechanisms of acoustic nerve signalling. For example, acoustic waves must remain well-confined inside nerve fibres to enable efficient transmission of signals across the nervous system. To guide an ordinary sound wave over a long distance one needs an acoustic waveguide. An efficient acoustic waveguide has to satisfy a number of physical criteria, including having a regular shape along its whole length and an acoustic impedance matching at both ends. Unfortunately, according to these criteria, a nerve fibre appears to be a poor acoustic waveguide [6].

Consequently, it has been suggested that the formation of acoustic solitons—non-dissipative waves that propagate

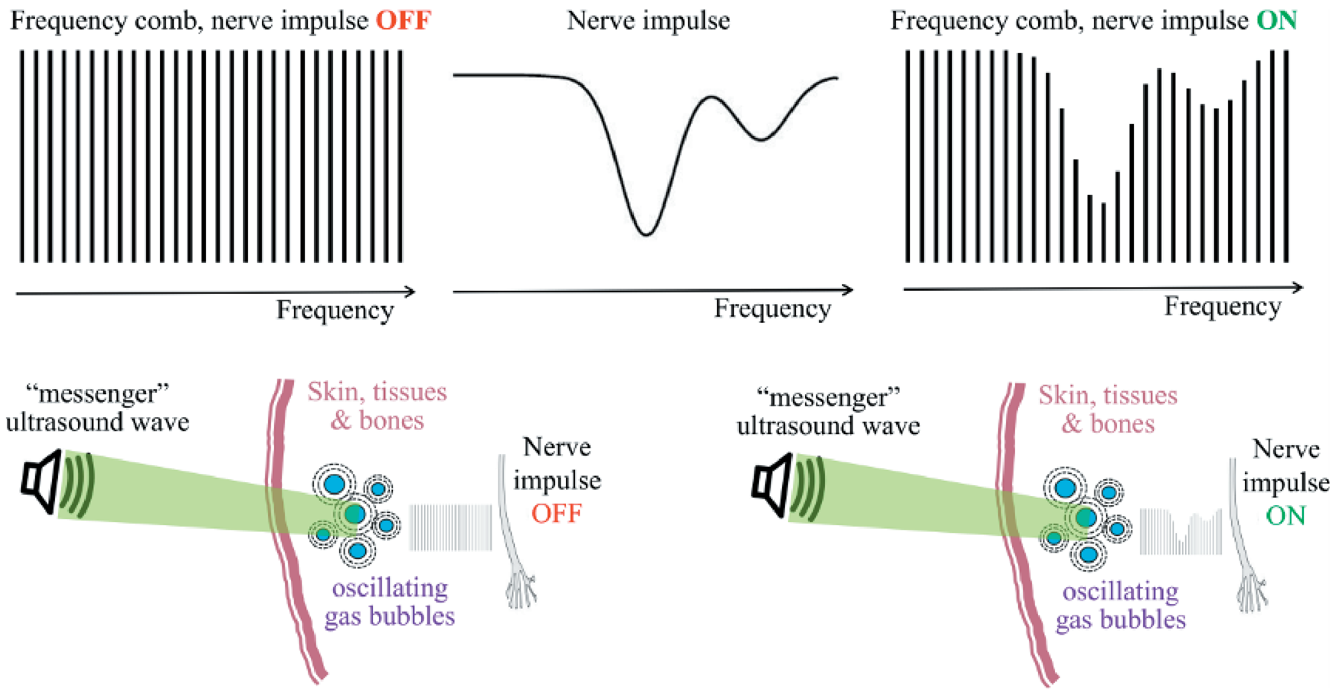

Figure 1: Potential application of the AFC in non-invasive BCIs. Irradiation of gas bubbles in the brain tissues with US wave results in the generation of an AFC. When there is no nerve impulse in the nerve, the 'picket fence' structure of the AFC remains unchanged (top left). However, when the nerve impulse is present, its acoustic component modifies the structure of the AFC such that its 'picket fence' structure repeats the shape of the nerve signal (top right).

over long distances and pass through each other without changing shape—could be one of the mechanisms that enables proper confinement and guidance of acoustic waves in the nerve [3-6]. Solitons are localised waves formed when a nonlinear process in the propagation medium compensates for dispersion of the wave [11]. Outside the field of acoustics, solitons are also known in the context of water waves in canals and of a laser light in optical fibres [11]. Significantly, natural irregularities in the shape of the nerve fibre such as the nodes of Ranvier—periodic gaps in the insulating sheath on the axon—should not be an obstacle for the propagation of solitons [6]. In fact, it has been shown that optical waves, which have a much shorter wavelength compared with sound, can pass through these gaps without significant power loss [7].

Although thus far there has been no conclusive confirmation of solitons in the human brain, mounting experimental evidence speaks in favour of their existence in animals' nerves [3-6]. Thus, it is plausible that a US beam could be used to non-invasively create and control nerve impulses in the brain.

However, there are several other physical limitations that could restrict our ability of doing this. Firstly, it is challenging to focus a US wave beyond a certain beam diameter due to the diffraction limit of acoustic waves. Secondly, a nonlinear interaction is required for the creation of acoustic solitons in the nerve and this could be physically possible only using a high-pressure driving US wave.

Although such waves can be created inside a living body for medical treatments such as lithotripsy (kidney stone removal) [12], they can damage the brain tissues. Therefore, they cannot be used for establishing a safe link with the brain. Scientists believe that the interaction of the pressure waves with gas bubbles trapped in the tissues around nerves [13, 14] may be partly responsible for such a damage. When intense acoustic waves impact them, gas bubbles first slowly expand and then collapse [15] so rapidly and violently that nearby nerve cells are likely to endure a stronger damage than tissues not containing bubbles.

This does not mean that we cannot use gas bubbles in the brain tissues to our advantage. Indeed, artificial gas bubbles have been already used to safely deliver drugs through the blood-brain barrier [16]. Hence, we could use similar technologies to exploit the potential of the natural gas bubbles in the brain. In particular, we suggest [17, 18] that the natural ability of a gas bubble to oscillate and emit acoustic waves, and thus effectively focus acoustic radiation into a very small volume, can be used to create local acoustic pressure 'hotspots' sufficient for the interaction with the solitons in the nerve (Figure 1).

In the following, we present our experimental and theoretical results that represent the first step towards a practical verification of the approach depicted in Figure 1. Before testing our ideas on a living organism, we investigate nonlinear oscillations of gas bubbles in water. We also demonstrate a Frequency Comb (FC) generated using nonlinear oscillations of gas bubbles in liquids.

Whereas we believe that the results of the tests in water will be useful for the development of new types of BCIs (recall that a living body consists mostly of water), they should find applications in the fields of precision underwater distance measurements, positioning and communication, where the use of FCs is an emergent research topic [19].

Results and discussion

A Frequency Comb is a signal with the spectrum consisting of equally spaced frequency components that form a 'picket fence' structure [20, 21]. In optical physics, an FC is essentially a 'rainbow' consisting of light of many different colours, each with its own frequency. By analogy, acoustic FCs (AFCs) can be regarded as a 'chord' consisting of several musical notes of different pitches played simultaneously. However, whereas optical FCs can readily be generated on demand using lasers and nonlinear photonic resonators [20, 21], techniques of a reliable AFC generation have not yet been developed.

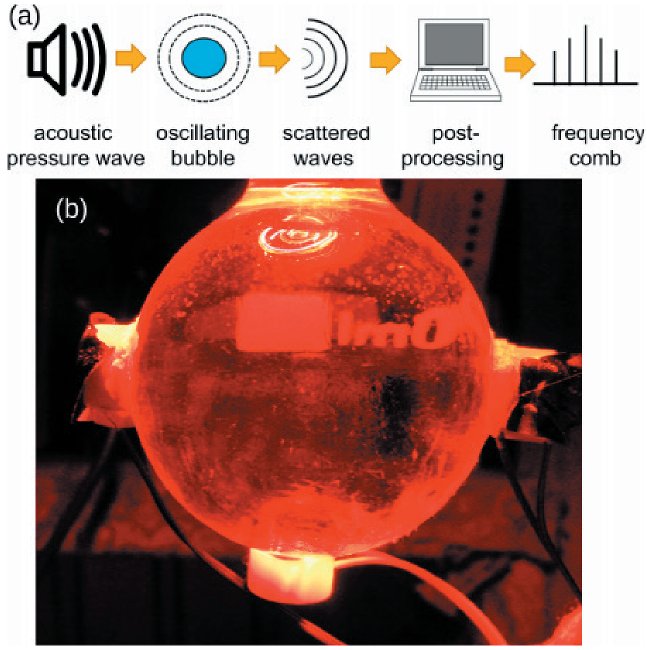

Figure 2: (a) Schematic diagram of the suggested AFC generation. (b) Photograph of one of the experimental setups created and tested by us. The red light was used to increase the visibility of the gas bubbles that can be seen in the upper part of the flask.

Figure 2(a) shows a schematic diagram of the proposed AFC generation. Random pulse-like perturbations that are caused by external noise always present in physical systems leads to weak bubble oscillations at their natural, also referred to as Minaert, frequency [15]. This frequency defines the pitch of a sound heard, for example, from running water or ocean waves. In addition, the application of finite-pressure harmonic US signals triggers a nonlinear response of the bubble cluster that results in the generation of multiple ultraharmonic frequency peaks [15]. The frequency of US waves is typically much higher than the natural bubble frequency. Therefore, the interaction of such nonlinear oscillations with noise-induced natural bubble cluster oscillations results in the amplitude modulation of the bubble cluster response and the appearance of sidebands around the main peaks in its frequency spectrum. We demonstrate that these equidistant sideband peaks form an AFC.

In our paper [22], a cluster of gas bubbles in water was created in a stainless steel tank using a bubble generator. The driving pressure wave was emitted by a US transducer. Waves scattered by the bubbles were detected by a hydrophone.

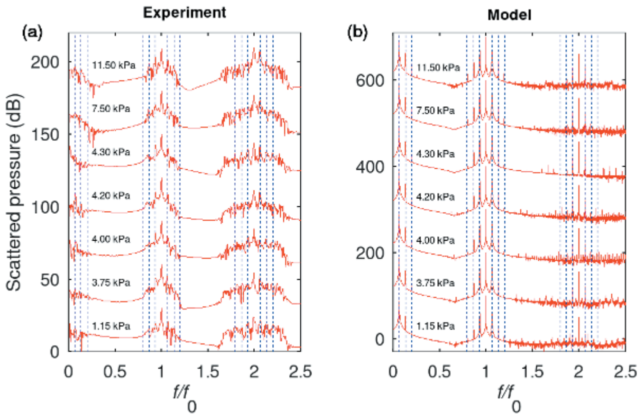

Figure 3: (a) Experimental and (b) calculated AFC signals. The vertical dashed lines mark the peaks at the natural frequency and its ultraharmonics (the left parts of the spectra) as well as the frequencies of the sideband peaks around the fundamental and second harmonic frequency of the driving signal.

In biology labs transparent glassware is usually used. We showed that the material of a vessel (steel or glass) does not influence the AFC generation. Essentially the same result was obtained when we used a round glass flask (Figure 2(b)), where gas bubbles were created by adding a drop of glycerol into water [23]. Glycerol is a viscous liquid that has a low vapour pressure, but its surface tension is comparable with that of water [23]. In aqueous solutions, it forms hydrogen bonds with surrounding water molecules, which suppresses the evaporation of water into the bubbles and, subsequently, improves their mechanical stability.

Figure 3(a) shows the measured AFC signals at the increasing pressure of the driving US at the frequency

f_0 = 24.6 kHz. We observe the main features of an FC—a number of equidistant sideband peaks around the fundamental harmonic frequency $f/f_0 = 1$ marked by the dashed lines. The frequency difference between all sideband peaks is 1.67 kHz, which corresponds to the natural frequency of the bubble cluster. Similar sidebands can also be seen around the ultraharmonic frequency $f/f_0 = 2$.

Figure 3(b) shows the calculated AFC signals. Consistent with the size of the bubble cluster inferred from the experiment, in our calculations we assumed that the radius of a single equivalent gas bubble is 1.95 mm. Our further theoretical analysis employing Poincaré–Lindstedt method provided a detailed explanation of the origin of the sidebands and ultraharmonics in the AFC spectra.

Future work

Our plan is to develop models of nonlinear gas bubble oscillations in a brain, which will require considering elastic properties of the brain tissues. We also plan new experiments using a phantom mimicking the elastic properties of the brain tissue. In such a phantom, we should be able to create gas bubbles of controllable sizes, which is important for the analysis of raw experimental data.

We have accumulated a significant expertise in experimentation with earthworms, including measurements of nerve signals in their nerve fibres. In this context, the reader may be interested in our Young Physicist article elsewhere in this issue. In our further studies we are going to investigate gas bubbles in the tissues of earthworms. Thanks to the ability of earthworms to survive in various water conditions [24] and withstand minor injuries, we should be able to introduce gas bubbles in their bodies using a syringe without causing them any harm. We also plan to improve the technique of the AFC generation using nonlinear oscillations of gas bubbles in liquids. In our experiments and models, we have thus far considered gas bubbles of predominantly the same sizes. However, according to our model proposed in Ref. [11], there should be many more sideband peaks in the spectrum of the AFC when gas bubbles are polydisperse, i.e. the population of bubbles is characterised by different sizes.

Overall, we expect a wider application of so-generated AFCs in the areas of biology and medicine, where there is a need for novel types of sensors. For example, it should be possible to use them for obtaining information about pathogens (e.g. bacteria) contaminating water [25].

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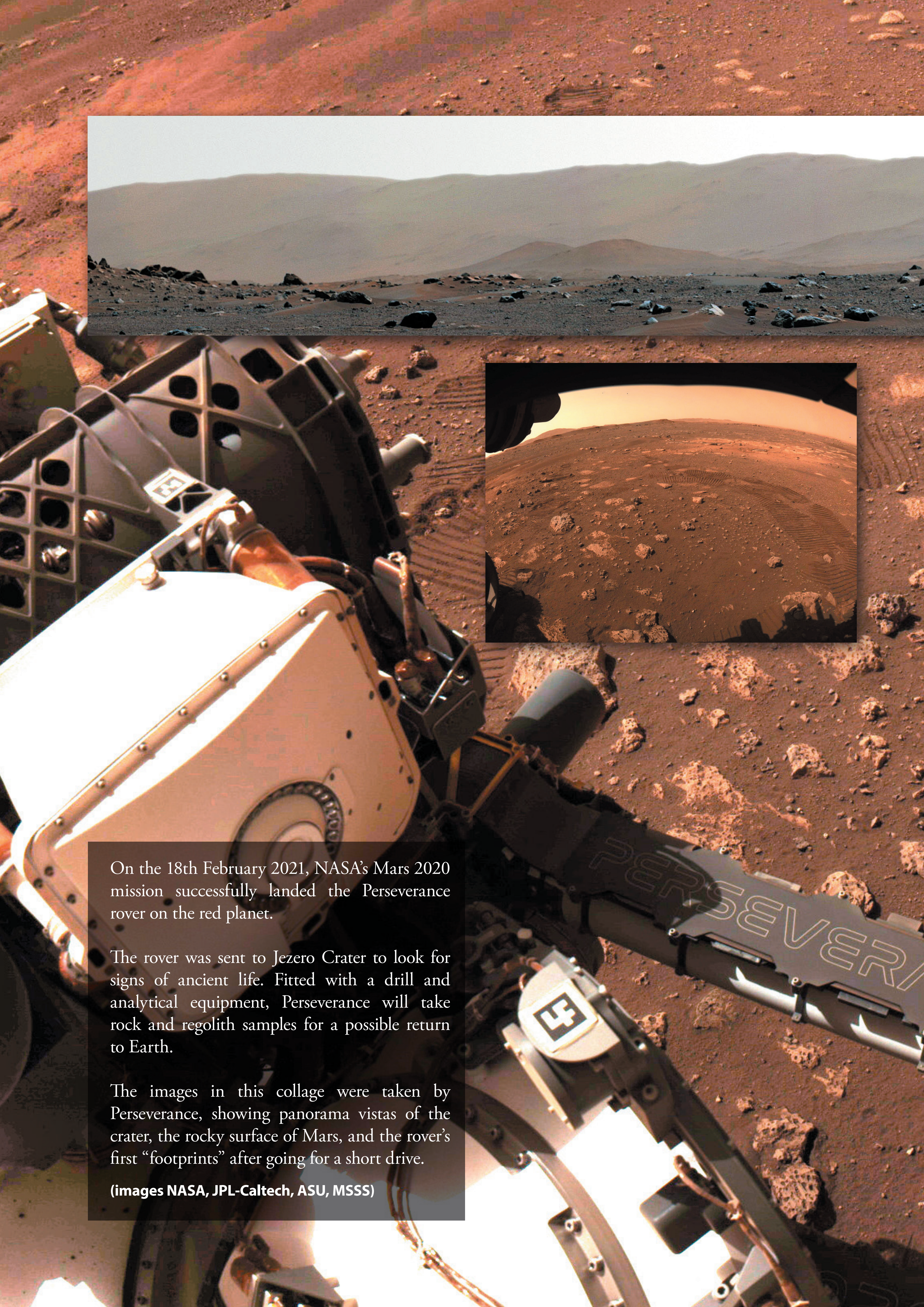
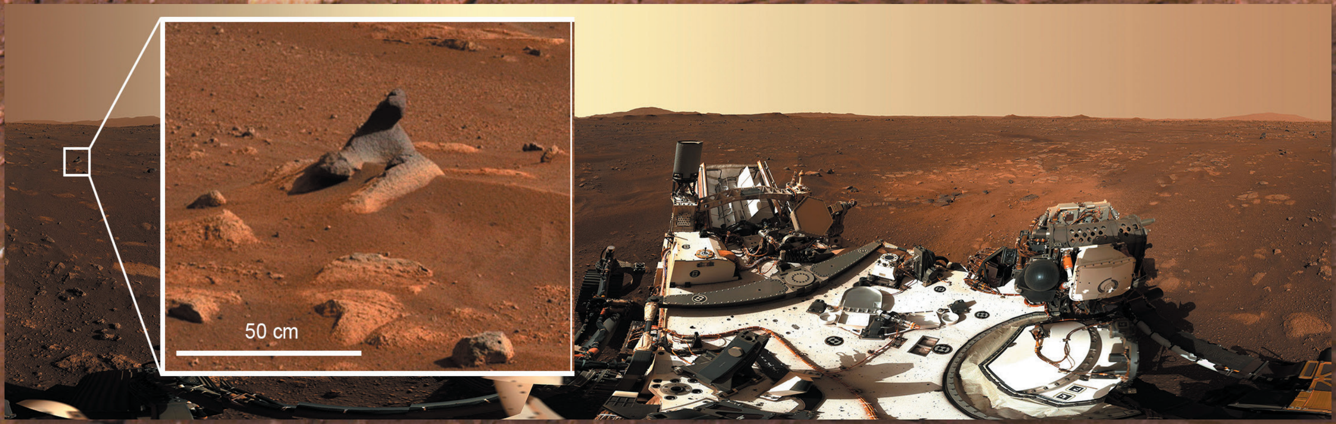


On the 18th February 2021, NASA's Mars 2020 mission successfully landed the Perseverance rover on the red planet.

The rover was sent to Jezero Crater to look for signs of ancient life. Fitted with a drill and analytical equipment, Perseverance will take rock and regolith samples for a possible return to Earth.

The images in this collage were taken by Perseverance, showing panorama vistas of the crater, the rocky surface of Mars, and the rover's first "footprints" after going for a short drive.

(images NASA, JPL-Caltech, ASU, MSSS)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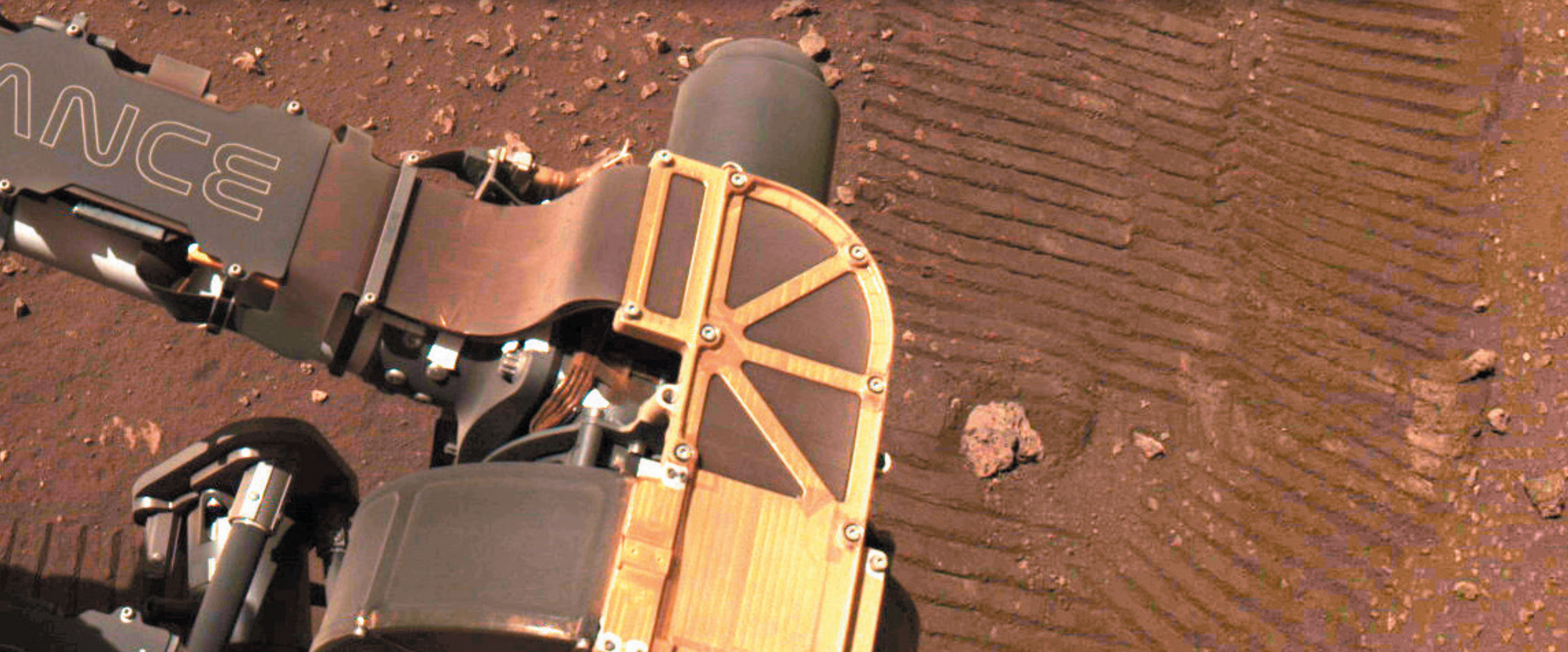
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Young physicists and vibrating earth worms

Ivan Maksymov, ARC Future Fellow, Optical Sciences Centre, Swinburne University – imaksymov@swin.edu.au
Andrey Pototsky, Senior Lecturer, Department of Mathematics, Swinburne University –apototskyy@swin.edu.au

If you place a glass of water near a playing loudspeaker, you will see the water 'dancing' to the music by developing small ripples on its surface. Have you ever wondered how these ripples form and what would be their favourite music genre? Because up to 60% of the human body consists of water, perhaps very similar ripples can exist on our own skin? To answer these questions, and also reveal an intriguing and sometimes counter-intuitive nonlinear and chaotic motion of vibrated liquids, we propose and describe a technically simple experiment using liquids from your kitchen such as water, oil and soybean sauce. By adding a handful of living earthworms that you can find in your garden or buy from your local Bunnings, you can reproduce our IgNobel-winning experiment as well as learn about a novel approach to non-invasive brain-computer interfaces.

Experimental setup

The experimental setup consists of the following technically simple equipment (Fig. 1, left). You need a low frequency loudspeaker connected, via a power amplifier, to the headphone output of your laptop. A Petri dish needs to be glued to the top of the loudspeaker. You also need a tone generator program to create audio signals.

Use a pipette to create a pancake-like water or oil drop occupying the area of approximately 5×5 cm. Set the volume to zero and turn the power amplifier on. In the tone generator, select a 60 Hz sinusoidal waveform. Then gradually increase the volume. First, you will see that the entire drop wobbles by moving up and down with the same frequency of 60 Hz. However, when you increase the volume to above a certain level, the vibrations will become intense enough to make the drop's surface unstable. You will observe the famous Faraday waves [1] on the surface of the drop. Discovered in 1831 by Michael Faraday in vibrated water tanks, Faraday waves are essentially standing waves, or ripples, that appear on the surface of a fluid under the action of vertical vibration. The frequency of the ripples is usually half the vibration frequency. This feature is called the subharmonic response. If you continue increasing the volume, the amplitude of the Faraday waves will gradually increase until the drop enters a chaotic dynamical regime characterised by irregularly pulsating ripples. If you have difficulties in reproducing these results, try a simpler experiment by adding more liquid so that it fills the Petri dish almost to the rim (Fig. 1, right).

You can make the following improvements to precisely detect the onset of Faraday waves and measure their spectra (Fig. 1, left). Use an LED lamp to illuminate the drop.

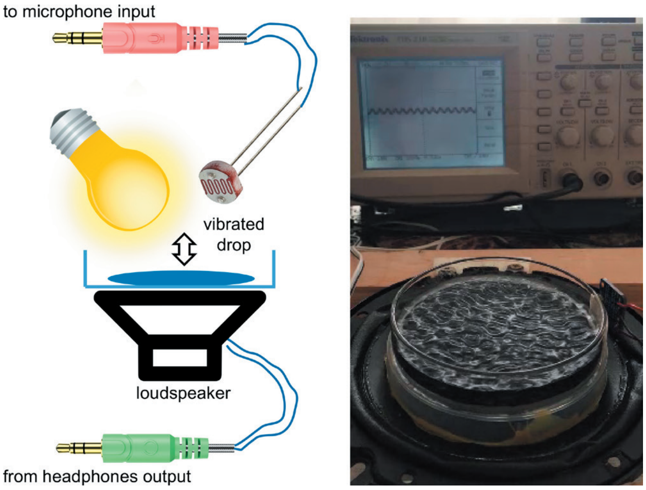

Figure 1: (Left) Schematic of the experimental setup. (Right) Photograph of the Faraday waves on the surface of water contained in a Petri dish glued to a vibrating loudspeaker.

Extract the photoresistor from an old night light (a new photoresistor costs $4 in Jaycar). Solder the contacts of the photoresistor to one end of an old 3.5 mm jack audio cable and plug the other cable end into the microphone input of your laptop. Place the photoresistor above the drop. The intensity of the LED lamp light reflected from the vibrating liquid drop will be modulated by the Faraday waves and then converted into electric signals by the photoresistor and the pre-amplifier of the microphone input of the laptop.

You can use the free Audacity software to record microphone signals and convert them into frequency spectra. For example, at a low vibration amplitude with a $f = 60$ Hz sinusoidal input signal you will observe just one peak at 60 Hz. However, above the onset of Faraday waves at a higher vibration amplitude you will see several peaks at the multiples of the subharmonic frequency $f/2 = 30$ Hz [2]. You might also see parasitic mains hum signals at 50 Hz and its harmonics, which you can remove using a hum eliminator readily available from acoustic equipment stores. The quality of your experiment will be improved further by using a low-power laser pointer and a faster and more sensitive photodetector. However, you must follow safety rules when using lasers such as never point their beams at human face.

Choreography of dancing drops

The dynamics of a vibrated liquid drop becomes even more spectacular, and sometimes unpredictable, when it swims in a more viscous fluid that does not mix with the drop. Suitable candidates for this experiment would be water or soybean sauce that are denser and less viscous than vegetable or olive oil.

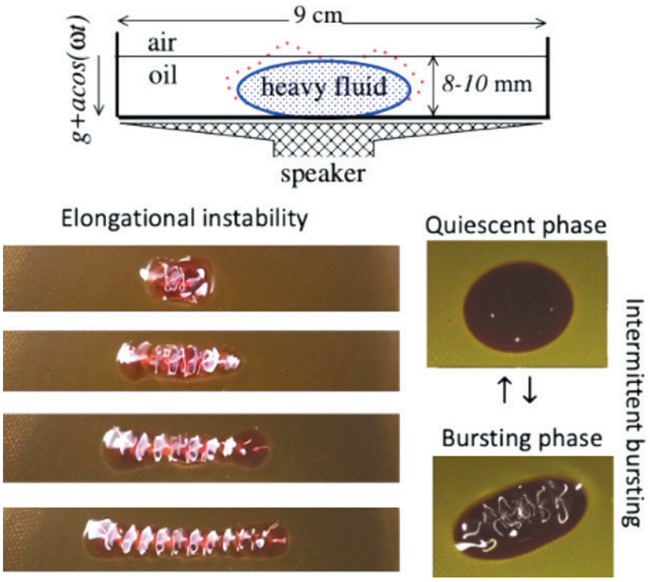

Figure 2: (Top) A drop of a heavy fluid (water or soybean sauce) in a Petri dish filled with less dense and more viscous oil. Worm-like elongational instability driven by Faraday waves (left) and intermittent dynamic bursting — random switching between quiescent and bursting phases (right) .

Fill the Petri dish with oil to a depth of 5-10 mm and add 1-2 millilitres of water or soybean sauce in the middle (Fig. 2, top). If the oil bath is relatively shallow, the water (or soybean sauce) would make a puddle with its upper surface not completely covered by oil. In this case, the puddle spontaneously stretches under the action of vertical vibration that is sufficiently strong to create a worm-like elongated structure (Fig. 2, left). This artificial worm is created due to the Faraday waves that develop on the surface of less viscous puddle and make it unstable while more viscous oil surface remains almost flat. Stretching the puddle into a worm is known as elongational instability that was first observed in ethanol drops floating on silicon oil [3].

However, when the oil bath is sufficiently deep, the drop becomes completely submerged in oil. By choosing the right amount of water (or soybean sauce), we can create a special kind of a submerged drop with its upper surface covered by a very thin (about 1-2 mm) layer of oil. When vibrated, such a drop exhibits a spectacular behaviour called intermittency [4]. In this regime, the drop spends several seconds in the so-called inactive or quiescent state (Fig. 2, right), where it maintains a circular shape as if the vibration were absent. Then, the drop spontaneously elongates driven by the Faraday waves and enters the so-called bursting phase (Fig. 2, right). However, the bursting phase is unstable, which means that after a few seconds the drop restores its circular shape and returns to the inactive phase. This cycle, known as type III intermittent bursting, repeats over and indefinitely as long as the vibration amplitude remains constant.

Vibrated earthworms

The same experimental setup can be used to investigate the shape of vibrated living earthworms. Earthworms have a hydrostatic skeleton—a flexible skeleton supported by fluid pressure and skin, which is common among simple invertebrate organisms. Hence, when the worm's muscles are relaxed, from the physical viewpoint they should vibrate similarly to a liquid drop enclosed by a thin elastic skin. However, unlike liquid drops, living earthworms try to escape from the loudspeaker. Therefore, sedating them in a 20% alcohol solution for 30 seconds not only relaxes their muscles but also immobilises them for up to 5 minutes (Fig. 3). Note that although using earthworms in scientific research does not require ethics approval, they should be treated as humane as possible and the above procedure does not harm them in any way.

To detect Faraday waves, vibrate one sedated earthworm on the loudspeaker. Unlike in liquid drops, to see the shape of Faraday waves on worms you will need a good slow motion camera. The camera of your smartphone can suffice. Results of computer modelling presented in our paper [5] explain what kind of shapes you should expect to see. Do not vibrate the same earthworm for more than 2 minutes. Afterwards, rehydrate it in water for 30 seconds and return it to the box or release to a garden.

Figure 3: A sedated earthworm prepared for the experimentation.

Brain-computer interfaces

Our experiments involving living earthworms mostly aimed at addressing research questions pertinent to the field of nonlinear dynamics [5]. However, we also vibrated earthworms because this could help us to verify the hypothesis claiming that nerve impulses propagate not only as electric signals, but also as acoustic waves that can form solitons, waves that can propagate over long distances keeping their shape [6]. For example, water waves in canals can propagate as solitons. However, it is more challenging to detect solitons in human nerves than in the nerves of much simpler organisms of earthworms.

If future research confirms that nerve impulses indeed propagate as solitons, our finding of Faraday waves in vibrating worms can become important for the field of brain-computer interfaces (BCIs). As with ultrasound waves used in medical imaging procedures, vibrations can propagate through human skin, skull bones and brain tissue without causing damage. Thus, by externally generating vibrations at different frequencies using a mobile device, we may be able to trigger Faraday waves in the brain tissues, which in turn should enable us to access nerve impulses ('human thoughts') in the brain.

Of course, we are still very far from knowing how to actually do something this complex. However, we believe that our ideas may be used by hi-tech companies that try to implant needle electrodes into human brains to link them with computers [7]. This approach is very invasive and poses significant health risks such as inflammation of the brain tissue or brain damage. Pending further detailed research, using vibrations may help create a safer BCI—one that works without unsafe needle electrodes [5, 8, 9].

About the authors

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Notes

a. When it comes to speakers, low-frequency means 'bass'–the wider the cone on the speaker, the better. Sub-woofers are ideal, if you can persuade the owner to let you…

b. Most classic stereo hi-fis have the amplifier separate to the turntable and/or CD player. It takes a small voltage signal from the computer and makes it powerful enough to mechanically move the speaker.

c. It doesn't have to be glued–the speaker owner may not be happy about this bit! If so try without gluing.

d. A really fun software tone generator can be found at https://www.szynalski.com/tone-generator- well worth a play (it's free).

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#PhysicsGotMeHere

This occasional column highlights people who have a qualification in physics but are in roles we might not traditionally associate with physicists. The information is drawn from the 'Hidden Physicists' section of the AIP e-bulletin.

Dr Sarah Midgley OAM, Manager – Skills Research and Analysis, NSW Department of Education

I currently lead a team of analysts and researchers in economic and skills analysis. We use a range of data sources and industry insights to explore labour market trends and how the world of work is changing, identify jobs and skills in demand and determine the future outlook for education and training. I am deeply passionate about the power of education in transforming people's lives and reducing the skills divide and social inequality.

My physics background provided me with analytical and problem-solving skills that I use in my current role. I also use my specialist knowledge about STEM careers and emerging technologies when providing advice on future jobs in demand or systemic workforce challenges (e.g., how to increase diversity and women in STEM).

Alongside my career, I have also had the privilege to volunteer with a number of community organisations, including Australian Marriage Equality. In 2020 I was recognised with an Order of Australia medal (OAM) for my service to the LGBTIQ (Lesbian, Gay, Bisexual, Transgender, Intersex and Queer) community.

Some takeaways: While immersed in academic life, it can be hard to see the full range of career pathways open to you as a physicist. Your technical and transferrable skills can be applied in so my exciting careers. Enjoy the journey – expand your experiences as much as possible and support your peers and junior physicists along the way.

My career story so far:

After graduating from a Bachelor's degree in Physics with Honours at Western Sydney University, I went straight to the Australian National University to complete a Graduate Diploma of Science (Physics). I moved again, this time to the University of Queensland, to earn my PhD in Theoretical Quantum Physics, graduating in 2011. I became a Postdoctoral Research Associate in Physics at the University College London the next year, but have since moved back to New South Wales to take up various roles within the Department of Education in vocational education and training with TAFE NSW. These roles included Analyst, Senior Analyst, and now Manager in the Strategic Research and Analysis Unit within the Strategy and Policy area.

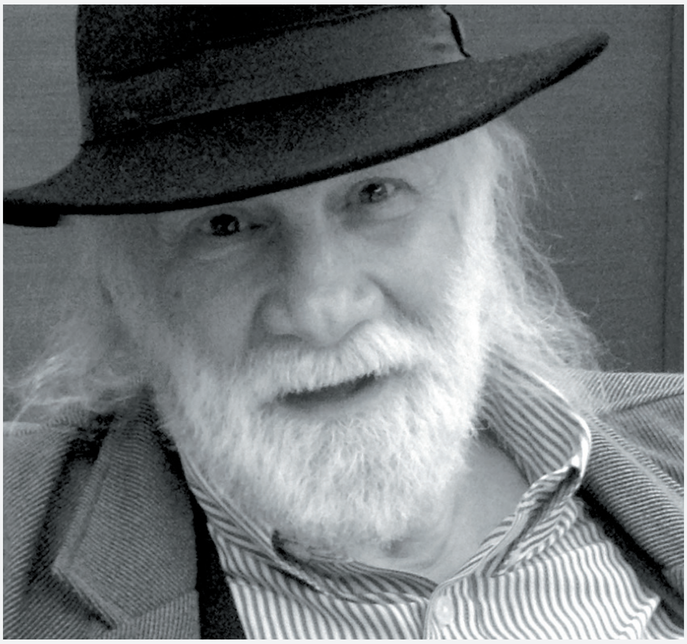
Norman “Norm” Edward Frankel

(22 March 1939 – 14 July 2020)

Australia has lost a charismatic and influential mathematician and physicist with the passing of Norm Frankel, who succumbed to heart disease after having endured multiple myeloma for some years.

Norm arrived in Australia on Anzac Day 1963 with $10, a very strong undergraduate degree from MIT, and a couple of years of work experience. He enrolled in a PhD degree in theoretical physics at Melbourne University, and fairly soon was made a lecturer while he worked toward his degree.

His infectious personality, gregarious manner and love of science made his lectures both engaging and memorable, and many students (including me) were attracted to work with him. He became known for lecturing without notes, deriving all results in real time on the board. Most students found this instructive and his style inspirational. As more lecturers provided printed notes, some students were frustrated at having to take their own. Student assessments of Norm’s classes were therefore distinctly bimodal.



Norm was officially working on plasma physics under the supervision of Ken Hines, but, in fact, he had many collaborators and wrote papers on plasma physics, superconductivity, statistical mechanics and crystal structures until he eventually submitted his thesis in the early 1970s.

Norm, together with Ken Hines and Ken Amos, established the Thursday Club, a lunch at various restaurants for physicists, the occasional mathematician, visiting academics and any graduate students brave enough to attend. These extended lunches frequently lasted the whole afternoon, and while a number of problems in physics and mathematics were discussed, by the end of the lunch most of the world’s problems had been solved.

Norm’s interests became increasingly mathematical, enhanced by a long and occasionally fractious collaboration with Larry Glasser of Clarkson University. Together with Vic Kowalenko (a student of Norm’s) they wrote a book based on the analogue of Euler and Jacobi’s development of $\sum_0^\infty e^{-an^2}$ for $\sum_0^\infty e^{-an^s}$. Norm became fascinated by Euler’s many results in number theory, and in the second half of his career, his greatest love was number theory of the Eulerian style.

He had a long-standing friendship with Freeman Dyson, which included the occasional collaboration. In 2013, Norm published a joint paper with Dyson and Glasser on an interesting series discussed by D. H. Lehmer in the American Mathematical Monthly. His last paper was also with Dyson, a paper I had the privilege to co-author, on a subset of the primes. This paper appears in the Journal of Integer Sequences and is the last paper of both Norm and Freeman Dyson, who also died this year.

In his plasma physics days, Norm had a fierce exchange with Bob May, then at Sydney University. Both had strong egos, which perhaps got in the way of realising that they were in fact not at loggerheads, as one was discussing dominant terms and the other non-dominant terms in the properties of some plasma.

At the time of his death, Norm was working on aspects of the Riemann hypothesis. I was supposedly his collaborator but was kept in the dark as to the nature of the problem we were working on. My contribution was to evaluate isolated integrals and sums that Norm sent me from time to time, and to set results in LaTeX.

This singular approach to collaboration was typical of Norm, who did everything his own way, including his retirement. He negotiated this around 1995, along with a contract to keep lecturing for many years.

His long-time friend and collaborator Barry Ninham describes him thus: *"Norm was somebody out of Damon Runyon, but more Tom Wolfe and The Bonfire of the Vanities and The Right Stuff. Like Wolfe he caricatured trends and pretensions but more gently so everyone laughed to tears, and with a trace of Dylan Thomas' wistfulness. You loved him or hated him. His students were legion and loved him. We tried to get him to UNSW, and left the offer open for nine months. He could not bring himself to leave Melbourne. We asked him to move to ANU in theoretical physics. He nearly did, but he would not come."*

Norm married Annette Barrette in 1963 and they had a daughter Elizabeth in 1965. After their divorce, Norm partnered with Robyn, whom he lost to cancer after a couple of years. This hit him very hard. But in 1985, he partnered with Karen Lee, and they had a daughter Peri together in 1990. Peri looked after Norm towards the end of his life, and deeply misses him. He is also survived by a younger sister, Ellen, who lives in North Carolina.

Norm was a unique, electrifying presence in the Australian mathematical physics scene. He still gave hugely entertaining, yet informative talks at conferences toward the end of his life, including an invited talk at Freeman Dyson's 90th birthday conference. Many of his graduate students have gone on to stellar careers around the world, and many more have Norm to thank for sparking their love of physics and mathematics. We have lost a unique member of our community, and we may not see his like again. Vale Norm.

Tony Guttmann AM,

Emeritus Professor of Mathematics

The Dangers of Too Much Quantum Mechanics

by Michael Hall

Schroedinger's cat had got quite fat,
And booked a quantum diet
(Heisenberg's hound had come around
To tell him he should try it):

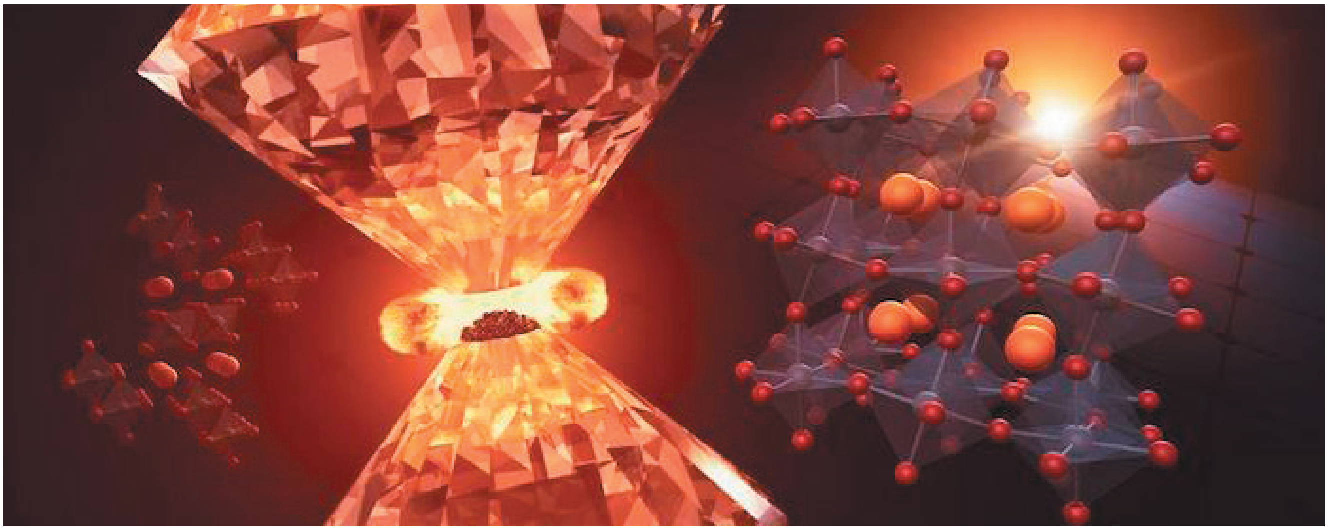
Each day his bowl was half filled whole
And half filled not one jot.
He thus both ate nowt off the plate
And yet could scoff the lot.

Well, all was good while no-one could
See in his box to state
If he had waned or more weight gained–
On average he felt great!

But then, by chance, a passing glance
Led to an awful fate:
A choice, between him far too lean
Or much too much oblate....

And so my dear, the moral's clear–
Yet worth writing perhaps:
Don't complicate your quantum state
Or you may well collapse!

Physics around the world



Stable enough for solar power applications. Courtesy: Greg Stewart/ SLAC National Accelerator Laboratory

Solar-cell perovskites turn stable under pressure

Solar cells made from lead halide perovskites are good at converting solar power into electricity and relatively straightforward to manufacture. Unfortunately, they're also unstable at room temperature and ambient humidity, which is something of a drawback for devices that tend to be located outside. Now, however, researchers at the US Department of Energy's SLAC National Accelerator Laboratory and Stanford University may have found a solution. Their new technique involves pre-treating the material at high pressures and temperatures, and its developers say it could be scaled up for industrial production.

Perovskites are crystalline materials with an ABX3 structure, where A is caesium, methylammonium (MA) or formamidinium (FA); B is lead or tin; and X is chlorine, bromine or iodine. They are promising candidates for thin-film solar cells because they can absorb light over a broad range of solar spectrum wavelengths thanks to their tuneable bandgaps. Charge carriers (electrons and holes) can also diffuse through them quickly and over long distances. These excellent properties give perovskite solar cells a power conversion efficiency (PCE) of more than 18%, placing them on a par with established solar-cell materials such as silicon, gallium arsenide and cadmium telluride.

One of the most efficient perovskites for solar cell applications is composed of caesium, lead and iodine. This material, $CsPbI_3$, has four possible phases: a yellow room-temperature non-perovskite phase (δ), plus three black high-temperature perovskite-related phases in which the crystal takes on a cubic (α), tetragonal (β) or orthorhombic (γ) structure. While the black phases are efficient at converting sunlight into electricity, heat and humidity quickly make them revert to the yellow phase, which is useless for photovoltaic applications.

High pressure squeeze

The SLAC-Stanford researchers have now shown that it is possible to nudge this yellow phase into an efficient and stable black configuration. Led by Yu Lin, Wendy Mao, Hemamala Karunadasa and Feng Ke, they did this by placing crystals of the yellow phase between the tips of a diamond anvil cell (DAC) and subjecting it to pressures of 0.1 to 0.6 GPa at a temperature of up to 450 °C. They then rapidly cooled the material down and removed the sample from the DAC.

Synchrotron X-ray diffraction and Raman spectroscopy measurements showed that this treatment yielded a version of orthorhombic γ-$CsPbI_3$ that was stable in the presence of moisture (at a relative humidity of 20-30%) and remained efficient at room temperature for 10 to 30 days. This is a significant improvement over earlier efforts to stabilize the bulk black phase at room temperature using, for example, applied strain, surface treatments and changes to the material's chemical composition–all of which produced good results only when the environment remained moisture-free.

(extracted with permission from an item by Isabelle Dumé at physicsworld.com)

Singing plays a key role in thyroid cancer test

A novel non-invasive test for thyroid cancer works by asking the patient to sing at the same time. Developed by researchers in France, the ultrasound-based procedure could determine the health of a patient's thyroid and help detect any cancerous nodules.

Thyroid nodules are common, but only a small percentage of such nodules are cancerous. Typically, fine needle aspiration is to detect malignant tumours, but only about 5% of thyroid cancers are detected in this way. As the majority of thyroid cancers are hard, the presence of cancerous tissue in the thyroid will increase its stiffness. This makes elastography–a technique that measures tissue stiffness–an ideal candidate for detecting cancerous nodules.

Vocal passive elastography uses ultrasound imaging to measure the speed of shear waves created in the thyroid by singing. (Courtesy: Steve Beuve)

In this study, the researchers designed an experiment based on passive elastography, which extracts elasticity from the natural vibrations in living tissues. Specifically, they exploit the shear waves generated naturally by the human voice to measure the elasticity of thyroid tissue–a technique they call vocal passive elastography (V-PE). They report their findings in Applied Physics Letters.

The researchers–from Université de Tours, CHU Dijon-Bourgogne and Université Bourgogne Franche-Comté – asked a volunteer to sing and maintain amonotonous tone at 150 Hz (roughly the frequency of the note D3), with a loudspeaker playing the same note to guide them. As the participant sings, vibrations in their trachea will induce shear waves in the surrounding thyroid gland.

The team tracked these waves using an ultrafast ultrasound probe placed horizontally against the surface of the neck. They then used correlation algorithms, based on time reversal methods initially employed in seismology, to compute the speed of the shear waves propagating through the thyroid.

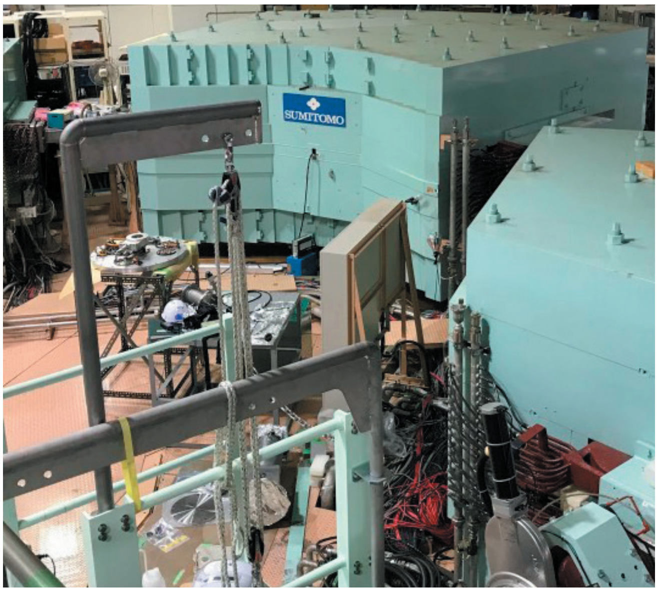
If a tumour is present in the thyroid, the resulting increase in elasticity will cause the shear waves to accelerate.

(extracted with permission from an item by Tami Freeman at physicsworld.com)

Alpha clusters found on neutron-rich surfaces of nuclei

"Alpha clusters" resembling helium-4 nuclei have been spotted on the neutron-rich surfaces of heavy atomic nuclei by an international team of physicists led by Junki Tanaka at TU Darmstadt in Germany and Yang Zaihong at Japan's Osaka University. The physicists used a high-energy proton beam to knock the clusters off the surfaces of several of tin isotopes and their findings could provide a better understanding of radioactive decay in heavy nuclei and give us important insights into the compositions of neutron stars.

Heavy atomic nuclei tend to contain significantly more neutrons than protons and as a result, nuclear physicists believe that these nuclei have neutron-rich "skins" on their surfaces. An understanding of these skins could provide important guidance to astrophysicists developing models of neutron stars–objects about 20 km in diameter with densities on par with nuclei. While neutron stars are made mostly of neutrons, about 5% of their mass comprises protons.



Alpha spotter the study was done using the Grand Raiden spectrometer at Osaka's Research Centre for Nuclear Physics. (Courtesy: Thomas Aumann/TU Darmstadt)

One of the challenges of calculating the properties of neutron stars is understanding how the protons interact with the neutrons. Although neutron stars are much bigger than nuclei, both objects should obey the same physical laws governing how neutrons and protons interact. As a result, studying the neutron-rich skins of nuclei could shed light on the equation of state of neutron stars–a physical model that links the radius of a neutron star with its mass.

Quantum tunnelling

One way that protons and neutrons could interact in a nucleus is to bind together to form an alpha particle (essentially a helium-4 nucleus). In 1928 George Gamow showed that alpha particles can quantum mechanically tunnel out of a nucleus to become free particles–explaining a common radioactive process called alpha decay. While alpha decay is a much-studied effect, it has never been shown conclusively that alpha particles exist in nuclei.

Darmstadt team member Stefan Typel has calculated that alpha particles should form in the neutron-rich skins of heavy nuclei. Now, his prediction has been confirmed by his colleagues who used the 392 MeV proton beam at the Research Centre for Nuclear Physics (RCNP) at Osaka University to knock away alpha clusters from the surfaces of a variety of tin isotopes, containing between 62 and 74 neutrons.

The team found that probability of alpha clusters being knocked away from the isotopes decreases gradually as their neutron numbers increase. Conversely, the thickness of the neutron skin is expected to increase with neutron number–confirming an interplay between alpha clusters and the thickness of neutron skins.

(extracted with permission from an item by Sam Jarman at physicsworld.com)

International Space Station sheds light on blue jets from thunderstorms

Intense "blue jets" that form during thunderstorms and extend into the stratosphere have been studied in detail by researchers in Denmark, Norway and Spain. Led by Torsten Neubert at the Technical University of Denmark, the team used thunderstorm observations taken aboard the International Space Station (ISS) to work out how the jets form, and how they influence processes higher up in the atmosphere.

Blue jets are short-lived, lightning-like electrical discharges that can appear in the upper reaches of storm clouds. They occur when the potential difference between positively-charged upper cloud regions and negatively-charged boundary layers between the cloud and the stratosphere, exceeds a certain breakdown voltage. At this point, previously insulating air will conduct intense electrical currents.

Within these environments, the jets begin their lives as channels of ionized air called "leaders". These channels have two propagating tips, which travel in opposite directions due to their opposing charges. As the positive tip propagates upwards towards the negatively charged boundary layer, it transitions into branching discharges called "streamers", which fan out to form cone-shaped structures that are blue jets.

Electric field pulses

Previous studies have associated blue jets with strong electric field pulses that last between 10-30 μs, and are accompanied by intense bursts of radio waves. Until now, however, researchers had not fully characterized how this behaviour unfolds.

View from above: photograph of blue jets taken by ESA astronaut Andreas Mogensen on board the International Space Station in 2015. (Courtesy: ESA/NASA)

Neubert's team studied this phenomenon using observations from the ISS, which offers an unimpeded view of the tops of thunderclouds. Measurements were made using the ISS's Atmosphere-Space Interactions Monitor (ASIM) instrument, which contains three photometers, that measure the intensity of electromagnetic radiation emitted by different atmospheric gases during lightning flashes. In addition, ASIM has two cameras that take images of flashes.

(extracted with permission from an item by Sam Jarman at physicsworld.com)

Relativistic quasiparticles tunnel through barrier with 100% transmission, verifying century-old prediction

A curious effect called "Klein tunnelling" has been observed for the first time in an experiment involving sound waves in a phononic crystal. As well as confirming the century-old prediction that relativistic particles (those travelling at speeds approaching the speed of light) can pass through an energy barrier with 100% transmission, the research done in China and the US could lead to better sonar and ultrasound imaging.

Quantum tunnelling refers to the ability of a particle to pass through a potential-energy barrier, despite having insufficient energy to cross if the system is described by classical physics. Tunnelling is a result of wave–particle duality in quantum mechanics, whereby the wave function of a particle extends into and beyond a barrier.

Phononic crystal: the barrier was created using two different lattices that comprised acrylic cylinders. (Courtesy: University of Hong Kong)

Normally, the probability that tunnelling will occur is less than 100% and decreases exponentially as the height and width of the barrier increase. However, in 1929 the Swedish physicist Oskar Klein calculated that an electron travelling at near the speed of light will tunnel through a barrier with 100% certainty–regardless of the height and width of the barrier.

Relativistic quasiparticles

Testing this remarkable prediction has proven difficult because of the challenges of accelerating electrons to the required velocity and creating an appropriate barrier for tunnelling. More recently, physicists have discovered that the collective behaviour of electrons in graphene creates massless quasiparticles moving at near to the speed of light. While some indirect features of Klein tunnelling have been seen in graphene, conclusive evidence for 100% transmission has remained elusive.

In this latest work, Xiang Zhang at the University of Hong Kong and colleagues have built an experimental system that uses sound waves to simulate the behaviour of relativistic quasiparticles in graphene.

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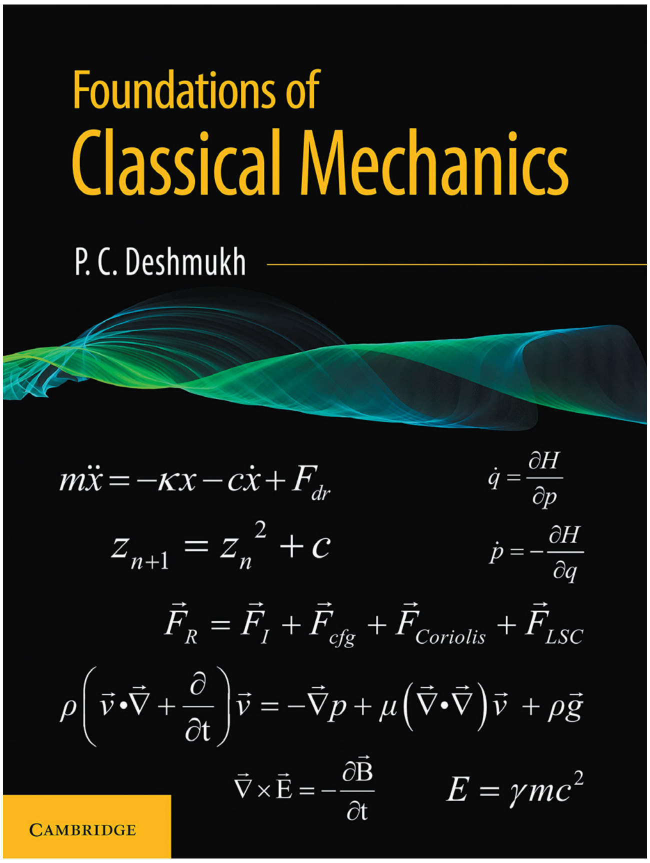
Book Review

Foundations of Classical Mechanics



By P.C. Deshmuhk, Cambridge University Press (2019), 450 pages, eBook ISBN 9781108658942, hardcover ISBN 9781108480567, paperback ISBN 9781108727754

eBook reviewed by Jim Williams, Emeritus Professor, Snr Hon Res Fellow, University of Western Australia, Perth WA 6009. – jim.williams@uwa.edu.au

An eBook version was chosen in anticipation of most readers having a preference for a computer-style search facility with adjustable magnification on a mobile or laptop for use anywhere. The instant prompt for personal memory or mathematical detail may encourage modern interaction and learning methods, particularly anywhere that colleagues and lecturers (or assistants in learning) may choose the time and place. While acquiring some proficiency with eBook technicalities imposed by Cambridge University Press, my joy with the style and abilities of the author kept me reading for days and coming back for more!

The numerous worked exercises of both text and maths, plus intriguing, well-chosen figures, would add meaning and application to classical mechanics for most readers. For example, Figure 3.4, shows the fairground 'Superman Ultimate Flight' roller coaster in Atlanta's 'Six Flags over Georgia'. It provides an unforgettable physical experience (even for this writer) of both linear and rotational accelerations with respect to the earth to identify the concepts of physics-in-motion at each twist and turn of the ride. There is real meaning to the associated maths methods to describe the phenomena.

The author, Pranama C. Deshmukh, is a Professor of Physics, Indian Institute of Technology Tirupati, India, and an Adjunct Faculty at the Indian Institute of Technology Madras, India. He conveys insights and concepts from decades of international experiences and achievements to underpin over 500 pages aimed at anyone wanting to learn 'at a leading edge' with depth, breadth, precision and clarity. His teaching strengths, with deep and broad knowledge and experience, are evident throughout this book, and are combined to provide a modern perspective of classical mechanics.

The first ten chapters bring out the links between information and concepts and show how to start with basics and to move forward to advanced levels with applications of science and engineering. A modern view of the purpose of physics evolves with strong phenomenological aspects that can be understood intuitively. The interplay between concepts of mathematics and physics is revealed consistently with worked examples, figures and maths techniques with an emphasis on elegance and rigor as is rarely achieved in a book; for example, Figures 9.18, 9.20 and 14.6. Topics include symmetry, conservation laws, linear and rotating frames of reference, anharmonic oscillators, frequency degeneracy, chaos, and the relationships of Newtonian, Lagrangian and Hamiltonian formulations. It is clear that the competition for excellence in teaching and learning within the author's sphere of influence has been very strong. The success of this book is reflected in the reader's understanding of the fundamentals, then progressing through the increasingly varied applications of theoretical and experimental models of classical mechanics. It is well suited to those with varied maths and physics backgrounds who are willing to enquire, learn and apply their knowledge.

The last four chapters (11-14) deal with modern applications. Chapter 11 discusses setting up and solving systems of coupled partial differential equations widely used in science and engineering. With that mathematics, a student should feel equipped to tackle and model most situations, with applications ranging from analysis of water flow, ocean water current, and particle movement in the atmosphere; a working basis for modelling climate change.

In chapter 12, the author excites and challenges the reader with the concepts of earlier chapters leading to the basic principles of electrodynamics, Maxwell's equations for the laws of electricity and magnetism, and history of foundations of physics and the universe!

By chapter 13, the fascination continues with the eloquent development of how to describe electromagnetic waves and the medium through which they pass, and basic descriptions in energy and momentum. Lorentz transformations are presented with discussions of simultaneity, time dilation and length contraction. The reader is challenged by the concepts and the meaning of allowing particles and anti-particles to be created and destroyed in extremely short times in and out of 'the vacuum'. The link of permittivity and permeability of 'the vacuum', with its basis in polarisation and magnetisation of the created particle and antiparticles pairs and leading to greater ideas, is well presented.

In the final chapter 14, the author's motivation to express the beauty of the powers of mathematics and experiments continues with the predictions of general relativity to provide a description of gravity as a geometric property of space and time. Questions such as "Why are gravitational forces not distinguishable from the effects of an accelerated frame of reference?" are discussed clearly. For the mathematically inclined reader, the system of partial differential equations shows how the curvature of space-time is related directly to the energy and momentum of matter and radiation. The expected topics of gravity, black holes and gravitational waves are to the fore in discussions of the passage of time, the geometry of space and the propagation of light. At this stage of the text, the basis has also been laid for reading the history of how Einstein developed his ideas on gravity, the principle of equivalence, and the general theory of relativity.

The author is particularly successful in capturing the imagination and acquired capabilities of the reader by using illustrations of maths and physics in action. An occasional reader seeking relaxation may enjoy also the following three examples: (i) Consider two astronauts in a satellite orbiting the Earth, or other planet, within a scenario with contrasting expectations of angular momentum movement on earth. (ii) A laboratory (brachistochrone) experiment to measure the time taken by a mass to travel under gravity between two points and to determine a time interval. Enough information with a photo and plots of observed data will enable students to repeat the experiment and check their model and maths. (iii) The first experiment to observe light bending coming from behind the sun (!) was achieved by Eddington in May 1919 during a solar-moon eclipse (see Figure 14.4 in eBook). It is a challenge to reproduce the mathematics, indicating feasibility of the observation.

Browsing through the 200 well-chosen figures and over 550 pages of text captures the mind to seek the association of fundamental physics and maths with science and engineering applications for the modern world. The advance of technology is rapidly changing applications involving speed, time and acceleration. For example, Figure 14.6 shows suspended mirrors of an equal arm Michelson interferometer, whose relative motions indicate gravitational wave interference. The measurement of time differences and stress pattern (inset) is linked with applicable maths modelling.

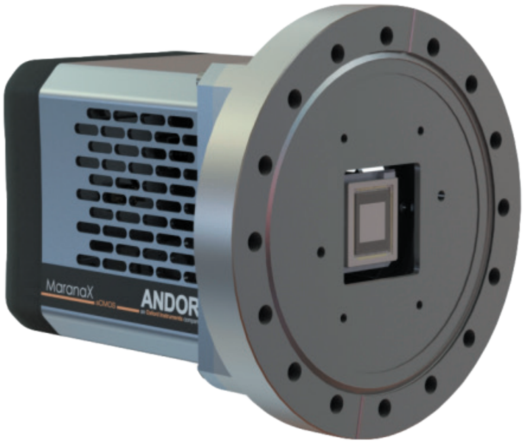
This text book prepares the modern student with an outlook and the skills to solve problems and enhance employment prospects. The book is written in a conversational style with historical sketches and accompanying figures. After using the eBook for nearly a month, every aspect of the book remained challenging and enjoyable, from learning and practicing eBook manoeuvring, to modelling fluid flows for climate control and exploring gravitational studies of interstellar space. Further encouragement to read more about using modern maths and physics is deeply installed. The book is an excellent presentation of modern classical mechanics into the space age. I strongly recommended it.

Product News

Coherent

Fastest sCMOS for direct EUV detection

Marana-X is Andor's new ground breaking sCMOS camera for direction detection of EUV and soft X-ray. The Marana-X reads out a 4.2 megapixel high resolution array in less than 50 milliseconds while maintaining very low read noise; hundreds of times faster than similar resolution CCD detectors.



The new Marana-X sCMOS boasts superior quantum efficiency in the EUV-1 keV energy range, compared to existing CCD's. The excellent quantum efficiency of the Marana-X complements its high end scientific CMOS technology allowing the minimisation of experimental time and maximum data throughput with a rapid 4fps full frame.

Chemical Imaging Microscope

Spero QT is the next breakthrough in label-free chemical imaging. Spero QT builds on the original Spero platform, delivering high-resolution, wide-field imaging driven by Daylight Solutions' quantum cascade laser technology, but what's new ? The ability to produce twice as much data in a tenth of the time with unprecedented signal-to-noise

The Spero QT has been designed specifically for mid-IR spectral imaging of biological and material samples by utilising Daylight Solutions' proven expertise in mid-IR QCL's, offering spectral coverage across the entire "fingerprint region". It is now possible to perform rapid acquisition of hyperspectral data cubes in both transmission and reflection modes and our large format focal plane array (FPA) does not require any liquid nitrogen to operate, which is typical of traditional IR imaging systems. Spero QT now also comes in a more compact footprint and with increased stage travel to accommodate up to three slides.

Features & Benefits

- Real-time, high-throughput spectral imaging enabled by ultra-high brightness QCL technology
- No stains or molecular tags required for bio imaging
- Label free IR spectroscopy displays pure chemistry of samples
- No cryogenic cooling needed
- Quick setup means more time for analysis

For further information please contact:
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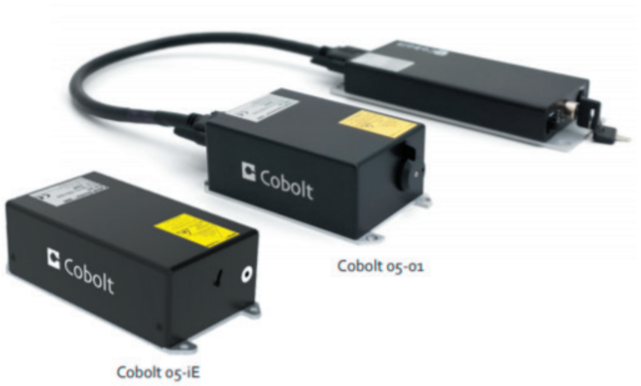
Warsash

Cobolt 05-iE: all-in-one compact single frequency laser

HÜBNER Photonics proudly introduces the Cobolt 05-iE, an all-integrated model of compact and powerful single frequency lasers across the wavelength range 457 nm – 1064 nm. In the Cobolt 05-iE lasers all control electronics are contained in the laser head eliminating the need for an external controller and bringing the trusted laser performance of the Cobolt 05-01 Series into a compact, self-contained device. The all-in-one Cobolt 05-iE (intergrated Electronics) means less complexity, fewer parts and an overall significantly reduced system footprint, thus simplifying the use and integration of the laser both for system integrators and researchers. The Cobolt Rogue 640 nm 1 W is also available as a Cobolt Rogue iE.



All Cobolt lasers are manufactured using proprietary HTCure™ technology and the resulting compact hermetically sealed package provides a very high level of immunity to varying environmental conditions along with exceptional reliability. With demonstrated lifetime capability of >60 000 hours and several thousand units installed in the field, Cobolt lasers have proven to deliver unmatched reliability and performance both in laboratory and industrial environments and are offered with market leading warranty terms.

Air cooled 355 and 532nm ns pulsed lasers

Photonics Industries, the pioneer of intracavity solid-state harmonic lasers, has introduced the new DX series air cooled lasers at 355 and 532nm.

The monolithic all-in-one design with integrated heatsink and "no contact/no touch" remote service capability ensures that the DX air cooled lasers have 20 – 50% more efficiency than comparable lasers. With a range of powers from 2 – 14W at 532nm and 1 – 7W at 355nm as well as a repetition rate of single shot to 300kHz the DX lasers are ideally suited to applications in precision laser micromachining.

New 3D printing material for high refractive index microoptics

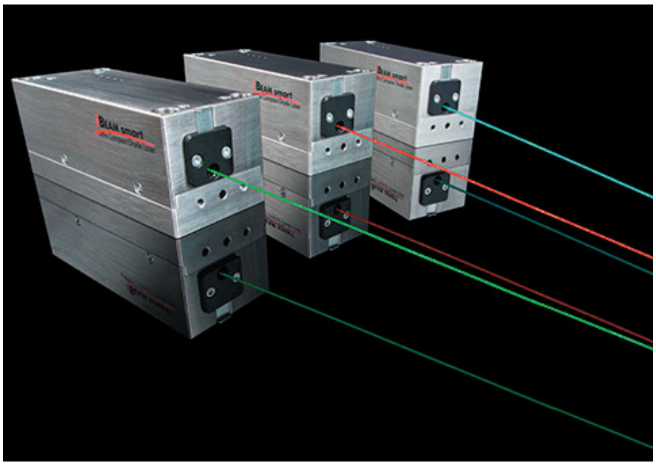
Nanoscribe introduces the new IP-n162 photoresin, a printing material with special properties for microoptical elements such as microlenses, prisms or complex freeform optics. The photoresin features a high refractive index in combination with a high dispersion, which corresponds to a low Abbe number. These properties are particularly beneficial for the 3D microfabrication of innovative microoptical designs, even without rotational symmetry and compound three-dimensional optical systems. With a low absorption in the infrared region, the photoresin is the best choice for infrared microoptics, but also for applications where low absorption losses are critical such as optical communication, quantum technology and photonic packaging.

Thanks to their optical properties, high refractive index polymers facilitate a variety of applications related to disruptive technologies. For example, in optoelectronic applications they enhance the visual properties of display devices or camera and projector lenses. Moreover, the availability of these materials for 3D microfabrication can establish a new class of complex 3D microoptical elements in much smaller sizes than possible with today's classical technologies. Examples are microlenses in miniaturized imaging systems, endomicroscopy and 3D sensing for AR/VR applications.

For more information, contact Warsash Scientific on +61 2 9319 0122 or sales@warsash.com.au.

Lastek

Toptica iBeam smart: high-performance single mode diode laser



The Toptica iBeam smart is the ultimate choice when looking for a high-performance, ultra-reliable OEM single mode diode laser system. Record values at output power, combined with excellent power and beam pointing stability are setting the standard in the class of compact diode lasers. Its flexible, µ-processor based electronics will make system integration a snap. Features such as FINE, SKILL and AUTOPULSE are capable of solving common problems in your application.

- True one box solution, no control box necessary
- Single mode, TEM00 laser from 375 to 1060 nm
- FINE and SKILL to eliminate noise and speckle
- Analog and Digital Modulation up to 250 MHz
- Clean-Up filters available

Quantum Composers: Jewel DPSS Nd:YAG Lasers

The Quantum Composers Jewel Laser is a rugged, Q-switched, Nd:YAG, DPSS laser with a compact, monolithic design. Reliable, light-weight, with easy to swap components, the Jewel is ideal for commercial and OEM applications. The Jewel is just 180mm long and weighs only 1.14kg which will reduce the space and weight limits on laser systems and dramatically decrease downtime and production costs.

Laser Features

- Energy Max: 10mJ @1064nm
- Rep Rate: 1 to 20Hz* Rep Rate
- Wavelengths: 1064nm, 532, 355 & 266
- Beam Divergence: ≤ 6.0mr
- Beam Divergence: (mrad) ≤ 6.0
- Beam Diameter: (mm) 2.0 ± 0.5mm
- Pulsewidth: 12.0 ± 2.0 ns at 1064
- Dimensions: 82mm x 180mm x 60m
- Weight: 1.5kg
- Power supply: 36-50VDC
- Efficient, reliable diode pump
- Remote Interlock, Input Trigger

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Ocean Insight is the global Leader in optical sensing technology, offering a wide range of spectrometers and optical spectroscopy tools for virtually every application.

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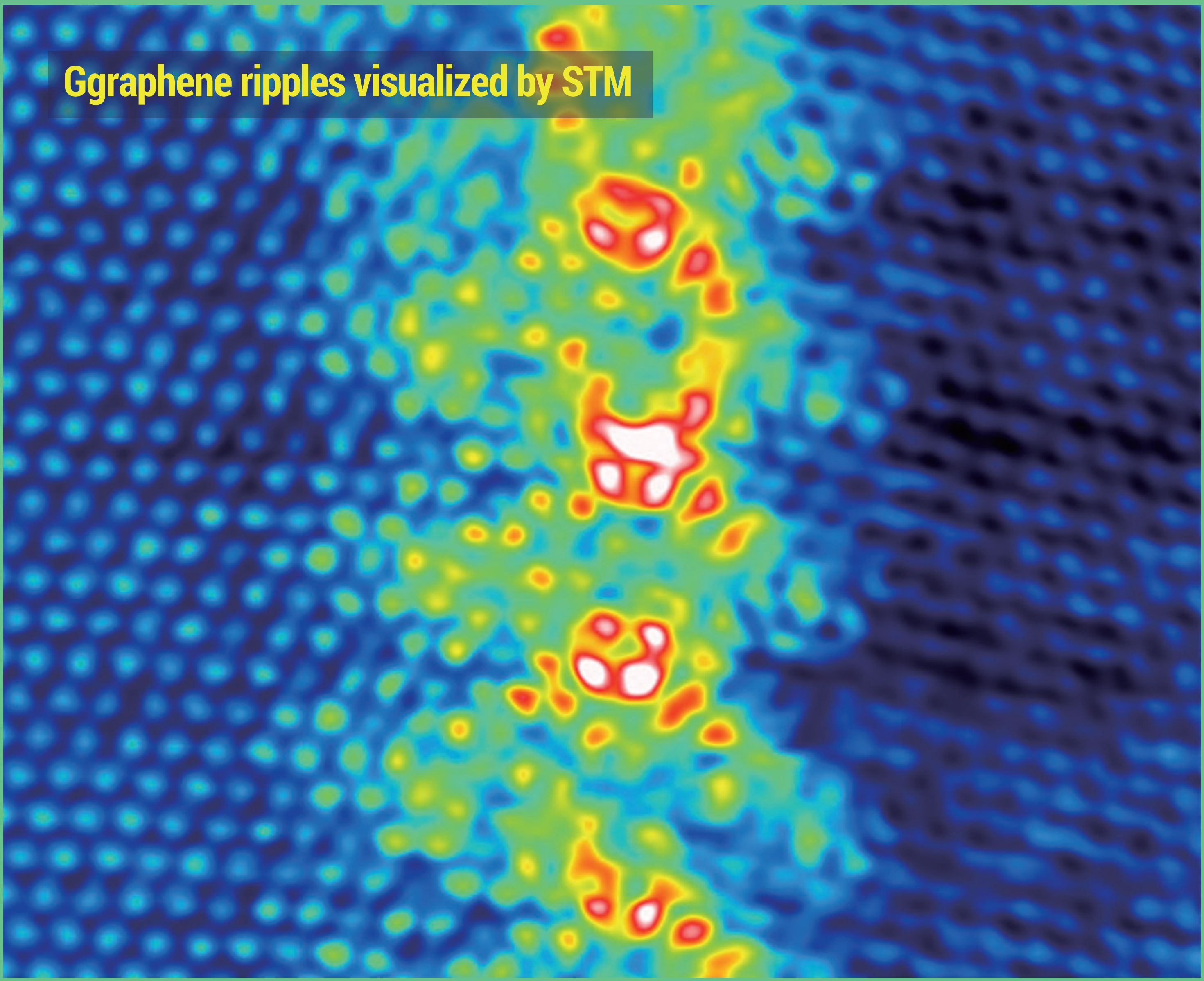

Ggraphene ripples visualized by STM

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- J/Ψ Suppression in Nuclear Collisions: a Unique Signal of Quark-Gluon-Plasma (QGP)
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- Erratum and Editor's Note

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Review and Research

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