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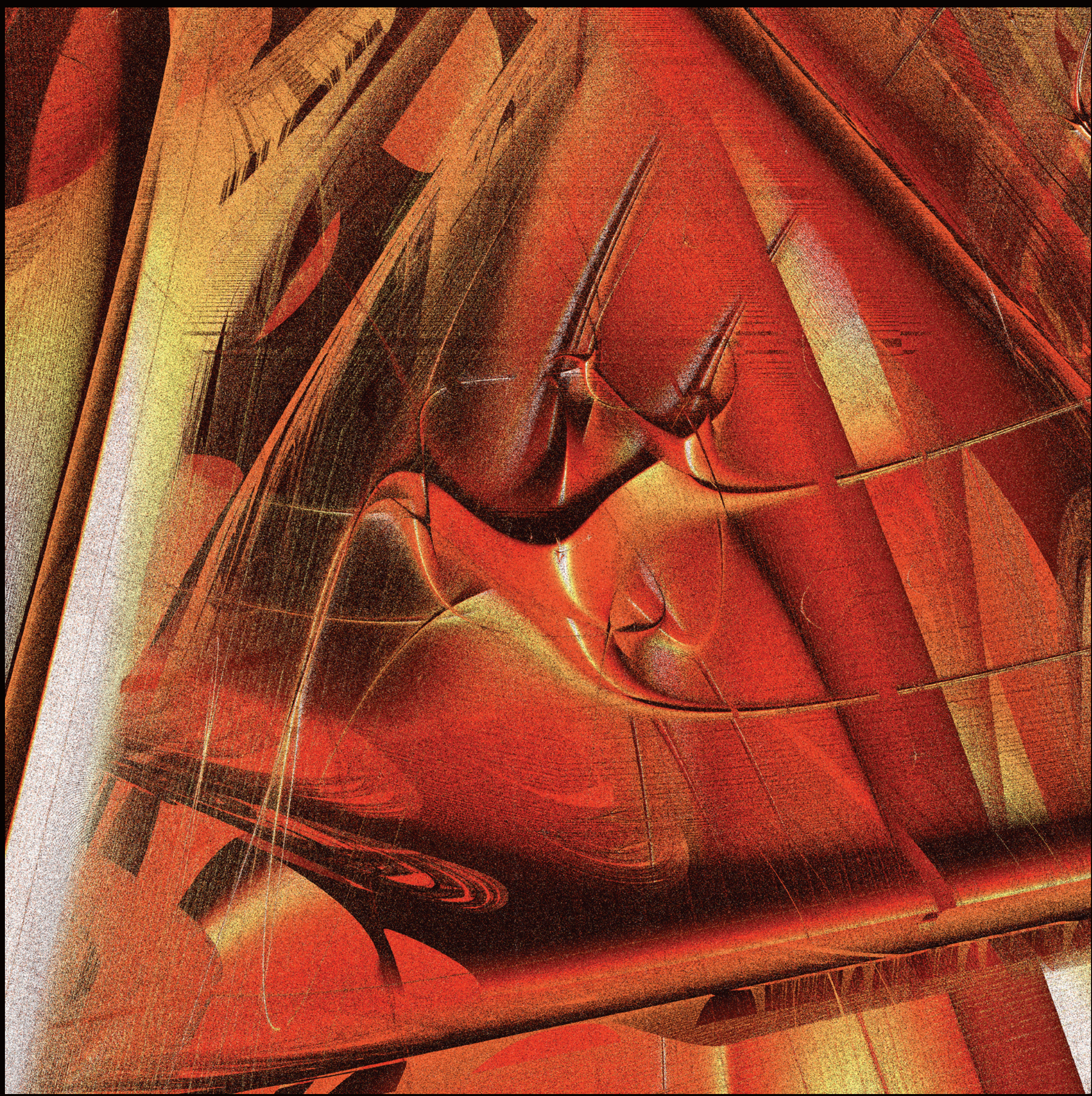

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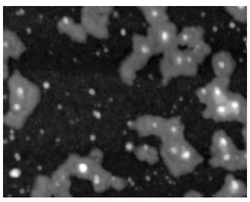

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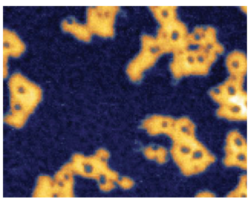

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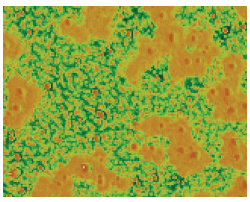

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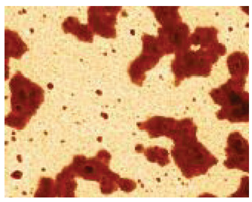

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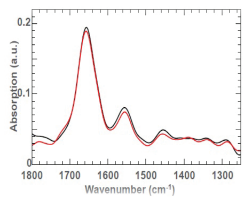

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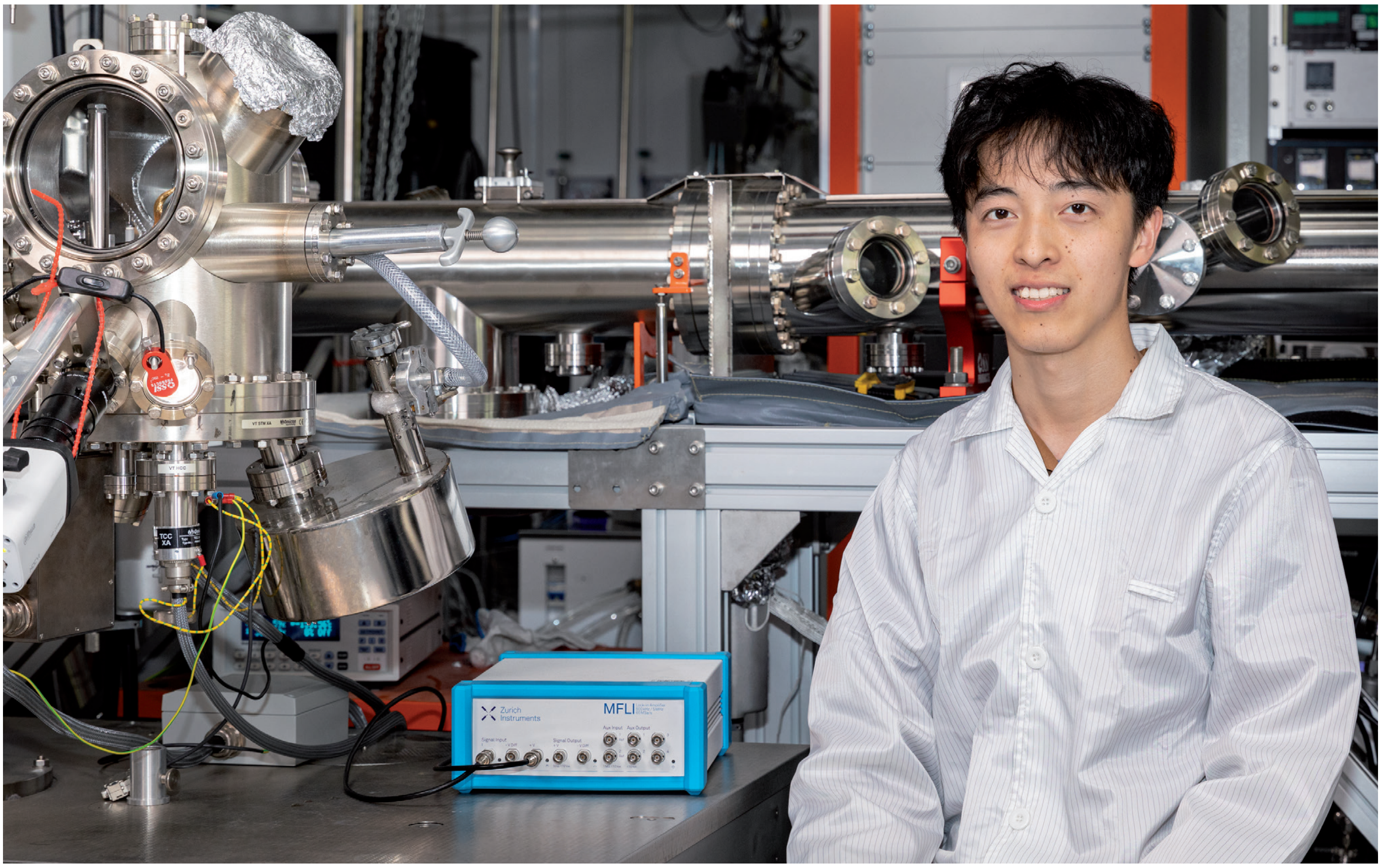

Yumeng Yang, Spin InfoTech Lab, ShanghaiTech University

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We congratulate the Spin InfoTech Lab led by Prof. Yumeng Yang at ShanghaiTech University for realizing fast and energy-efficient magnetization switching. Through charge-spin conversion based on the anomalous Hall effect in ferromagnetic materials, this result can be used in a magnetic random access memory (MRAM) bit to improve reliability, memory density, and speed. This work will greatly benefit the commercialization of next-generation MRAM technology, which is one of the most promising candidates for high-performance neuromorphic computing.

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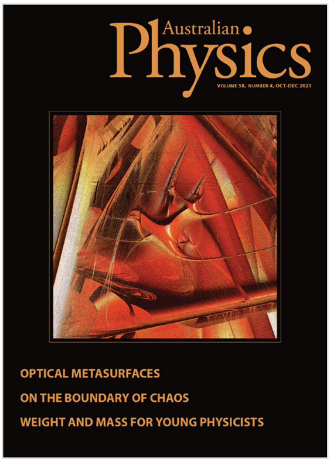

Render of a Markus–Lyapunov fractal - a boundary between chaos and stability. For points along each pixel ray, the logistic map is iterated with the 'r' parameter cycled through the sequence B,C,A,B,A of values from the 3D axes A, B and C. The resulting Lyapunov exponent determines whether that point is rendered as solid for stability, or transparent for chaos.

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Editorial

Juxtapositions

Welcome to the final issue of Australian Physics for 2021. This year, the world has been re-acquainted with the Greek alphabet with special introductions to α, κ, δ, and ο. Meanwhile, "strollout" was crowned Australian word of the year. Various other events in Australia and abroad emphasised the state of motion of things. While, on the scale of the universe, motion appears relatively orderly, humankind lives in an interesting anisotropic local minimum full of juxtapositions, always on the border between chaos and order. That contrast is reflected in this issue. Our articles feature, on the one side, a discussion of optical metasurfaces where control, order, and symmetry rule. On the other side, we feature an exploration of the Lyapunov exponent that characterises chaotic system behaviour.

It is worth noting the contributions students have made to this issue of the magazine. The article on the chaotic behaviour of the double pendulum was written by a final year student at Barker College, NSW, and an undergraduate student from University of Massachusetts, Boston, contributed the book review on topology. Both pieces deal with non-trivial matters and underscore that there is a generation of engaged physicists joining the community.

Our Young Physicists' column digs into the distinctions between weight and mass, and the considerable effort physicists invest in precision in both language and measurement. This precision is valuable to the wider community, as #PhysicsGotMeHere demonstrates. It prepares for other careers when combined with passion, be it for making connections through communication or supporting the animals who are such an important part of our lives.

So now with holidays approaching, we wish you a very happy Festive Season and all the best for 2022. And as always, if you fancy a little physics writing, you know how to contact us.

Best wishes,

David Hoxley and Peter Kappen.

From the Executive

Advocacy on the ARC "no-preprint rule"

Of all the activities the AIP undertakes to promote the role of physics in Australia, one of the most important is advocating on behalf of the profession and our members. In the last few months, the issue that has most occupied our thoughts in the advocacy space has been the "no-preprint rule", and the ramifications of that rule for our members.

This issue first came to light in August, when we learnt that a number of Future Fellowship and Discovery Early Career Researcher Award (DECRA) applications had been ruled ineligible by the Australian Research Council (ARC). This was due to a violation of a new and poorly understood ARC rule that forbid reference to preprints anywhere in a grant application, including the project description.

Fellowship applicants, caught unaware by the rule change, were dismayed and distressed to discover that their chance of a fellowship had been dashed. Physics was hard-hit. In fact, all 32 applications ruled ineligible were from physics or astronomy. The AIP email box was soon full of personal stories of lost opportunity.

It is perhaps no surprise that physics was strongly impacted by this unexpected rule change. We routinely use preprints for rapid dissemination of the latest developments. It is a standard way of doing business. Physicists pioneered the arXiv electronic preprint repository over 30 years ago and were using paper preprints long before that. These days, preprint servers are used to house all manner of scientific documents including PhD theses, software manuals, technical design reports, and the like. Indeed, for many of us, it is difficult to imagine how to fairly and accurately cite the relevant literature without referring to an arXiv document!

The AIP acted swiftly to prepare a submission to the ARC, together with other stakeholders, and to get the message out in the media. We coordinated an open letter to the ARC in conjunction with the professional societies in astronomy (ASA), chemistry (RACI) mathematics (AustMS), which was co-signed by over 50 leaders in physical sciences in Australia. It was pleasing to see the relevant professional bodies join forces to address this issue of mutual concern.

Our letter urged the ARC to rescind their rule in future funding rounds. We advocated that the ARC explore avenues to support the fellowship applicants affected, and recommended that future changes be subject to wider consultation with researchers and peak scientific bodies.

We were pleased to see that the ARC listened to the community and removed the "no-preprint" rule for future funding rounds. However, we remain concerned about the fate of the 32 fellowship applications ruled ineligible. Formal appeals have been submitted to the ARC by many of those applicants, with outcomes that are as yet unknown. In a follow up letter to the ARC in October, again co-signed by the AIP, RACI, ASA and AustMS, we stressed the need for fair resolutions, and transparency around process.

It was particularly unfortunate that those caught out by the "no-preprint" rule were DECRA and Future Fellowship candidates. These grants are designed to attract and retain some of our brightest and most promising young researchers at critical career points. For the health of the physics profession, this is precisely the point where we can't afford to lose talented young people.

The AIP will continue to monitor this issue and will speak out again if necessary. The results of the appeals process is clearly on our radar, together with possible impacts on the Discovery Project funding outcomes that are yet to be announced.

The preprint saga highlights the importance of professional societies like the AIP. Providing a voice for physics in Australia, we are in unique position to advocate on behalf of the profession, without worrying about stepping on anyone's toes. When we can collaborate with fellow professional societies on issues of common interest or concern, it makes our message to government and policy makers all the stronger.

[1] See www.aip.org.au/advocacy for the AIP open letters to the ARC on the "no-preprint" rule, and the response received from the ARC.

Nicole Bell, AIP Vice President

Optical metasurfaces

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During the past decade we observed the rapid development of the field of optical metasurfaces, two-dimensional planar structures composed of optical resonators of different shapes and types. Metasurfaces have become a highly demanding field of research due to their exceptional abilities to manipulate light and versatility in applications of ultrathin optical devices. Metasurfaces have been suggested for a complete control of light–matter interaction with subwavelength structures, and they have been explored widely for various applications such as bending of light, metalenses, metaholograms, and nonlinear optics. Here we provide a general insight into the field and discuss some functionalities of metasurfaces highlighting their biomedical, computational, and quantum applications.

Metasurfaces are made of artificial subwavelength elements with small thickness which provides novel capability to manipulate electromagnetic waves [1]. Well before the exploration of metasurfaces, tailoring the light scattering with planar optical structures has been pursued with diffractive optical elements, such as dielectric gratings [2]. The concept of metasurfaces provides much broader and deeper insights and many more degrees of freedom to play with for complete control of light. Metasurfaces are characterised by generally planar geometry and reduced dimensionality, and usually consist of arrays of optical resonators with spatially varying geometric parameters and subwavelength separation (see two examples in Figure 1). Upon interaction with light, engineering of the spatially varying optical response allows one to mould the optical wavefronts at will. In contrast to conventional optical components that achieve wavefront engineering by phase accumulation through light propagation in a medium, metasurfaces provide new degrees of freedom to control the phase, amplitude, and polarisation of light waves with subwavelength resolution, as well as to accomplish wavefront shaping within a distance much less than the wavelength of light [3]. The outstanding optical properties of dielectric metasurfaces drive the development of ultrathin optical elements and devices, whether showing novel optical phenomena or new functionalities outperforming their traditional bulky counterparts. As the field of metasurfaces is rapidly growing, many review articles focusing on different areas can be found in the literature [4-7].

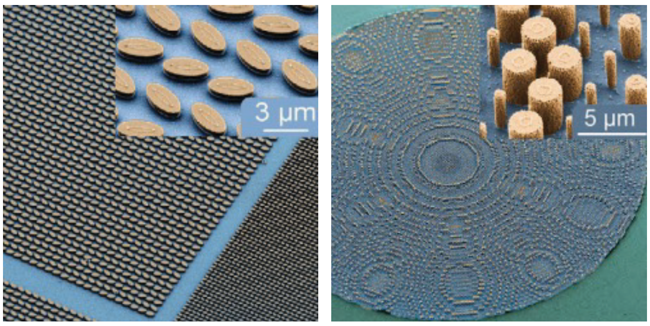

Figure 1: Examples of two mid-infrared metasurfaces designed and fabricated for optical biosensing (above) and flat-lens focusing (below). Metasurfaces are composed of Ge resonators on Al_2O_3 membranes [8].

Metasurfaces consist of carefully arranged "unit cells" or "meta-atoms" with subwavelength structures. The optical response (phase, amplitude, and polarisation) of the meta-atom changes with its geometry (height, width, material, etc). The meta-atoms are arranged into arrays to provide specific variations of parameters, depending on required functionalities. Meta-atoms can operate as subwavelength resonators supporting multipolar Mie resonances [3], or they can contribute to averaged parameters like metamaterials [4].

The concept of optical metasurfaces have been applied to demonstrate many exotic optical phenomena and various useful planar optical devices. Many of these metasurface-based applications look like very promising alternatives to replace conventional optical elements and devices, as they largely benefit from ultrathin, lightweight, and ultracompact properties, providing the possibility of overcoming several limitations suffered by their traditional counterparts, and can demonstrate versatile novel functionalities. Figure 2 summarises some metasurface-based functionalities aimed at polarisation control and wavefront control. For example, conventional polarisation control employs birefringence of crystals, where the required phase retardation between two orthogonally polarised wave components can be accumulated through light propagation. As a result, the conventional setups for polarisation control are usually bulky and suffer from several limitations such as narrow operating bandwidth and limited choice of materials. Motivation to replace bulky optical components boosts the development of metasurface-based wave plates, vortex converters, lenses and holograms operating in different frequency regimes.

Wavefront engineering for conventional refractive lenses is based on the surface topography or the spatial refractive-index variation of the optical transparent media. Under such a framework, the beam profiles are altered according to the phase accumulation along the optical path through these lensing devices. A possibility to control polarisation with metasurfaces motivates the implementation of polarimetry flat-optics devices for sensing the polarisation state or determination of the Stokes parameters of an arbitrary light source.

Another interesting platform for metasurfaces is computer-generated holograms, which requires careful engineering of local phase, amplitude, and polarisation response to obtain high-quality images. Metasurface-based devices applied to vortex-beam generation have recently received tremendous interest due to their various promising applications in high-

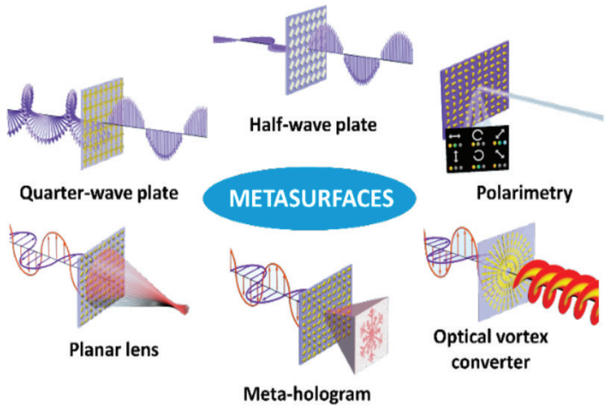

Figure 2: Metasurface-empowered applications of flat optics for various functionalities: polarisation control, wavefront shaping, lensing, and holography (adopted with permissions from [4]).

resolution microscopy, optical tweezers, and classical and quantum communication technology. Thanks to the advances in nanofabrication technologies, these low-cost, large-area, and mass productive techniques have sped up the development of static metadevices and are gradually becoming mature. It is expected that flat optical components based on dielectric metasurfaces will appear in our daily life soon bringing complexity of optical components and new functionalities [9]. Recent perspective [7] suggests four major promising paths for the future development of the field of metasurfaces

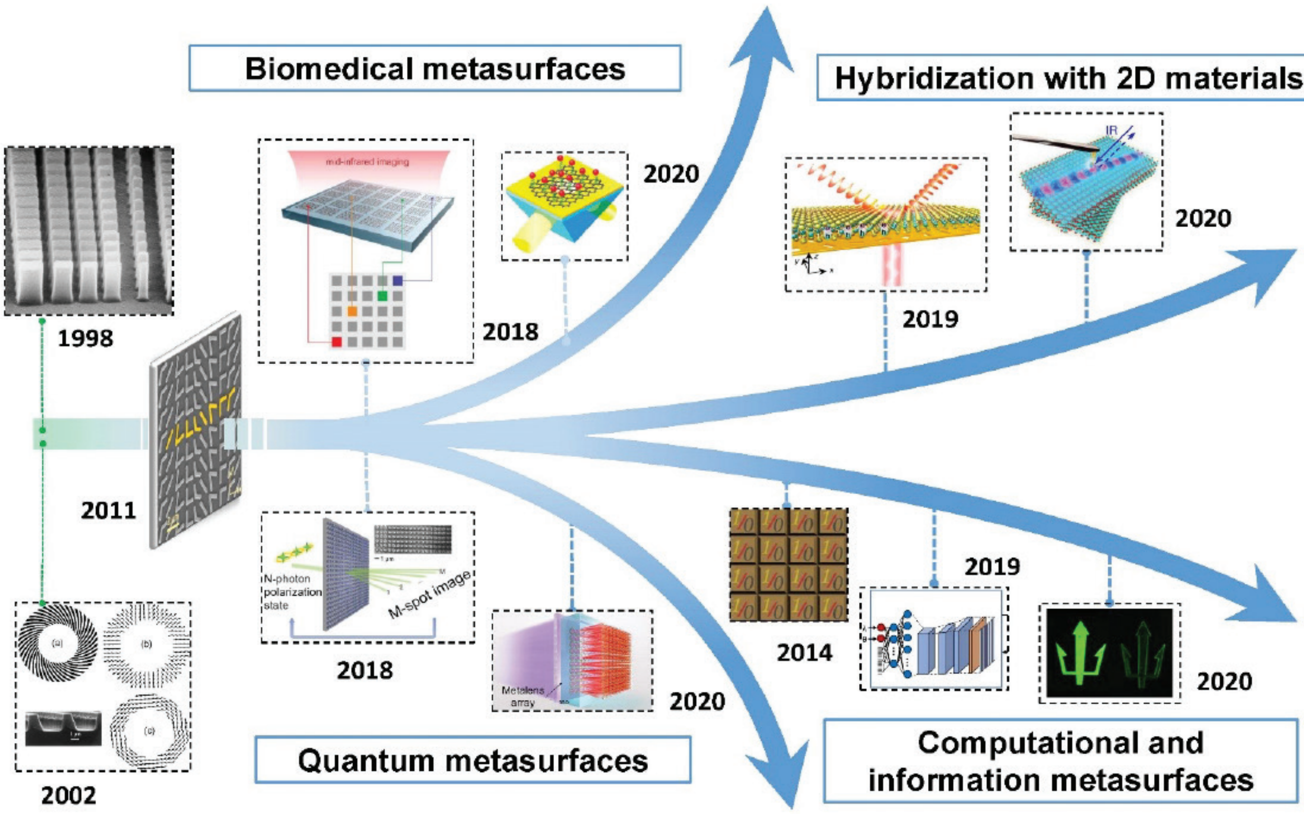

Figure 3: Major milestones and selected directions for the research on optical metasurfaces and their applications to other fields (for more details and the extended diagram, see [7]).

(see Fig. 3). Specifically, this includes metasurfaces integrated with low-dimensional materials, and also metasurfaces for biomedical, computational, and quantum applications. Hybridising metasurfaces with two-dimensional materials, such as transition metal dichalcogenides (TMDCs) can realise advanced active manipulations of light–matter interactions at the nanoscale in a designer manner, offering a new platform for next-generation photonics. For new applications such as in biological systems, metasurfaces can largely enhance sensitivity of biomolecular detection, selectively distinguish chiral biomolecules, and achieve high-resolution bioimaging. Most recent application of metasurfaces can be found in quantum technologies [10]. Meditated quantum entanglement and a new platform for integrated quantum devices may become possible with emerging metasurfaces. Finally, novel applications may emerge from advanced computer algorithms (machine learning, neural networks), topological physics, time-variant metasurfaces which would allow enriching dimensionality, as well as combining metasurfaces with microelectro-mechanical systems (MEMS), and many other continuously emerging advances.

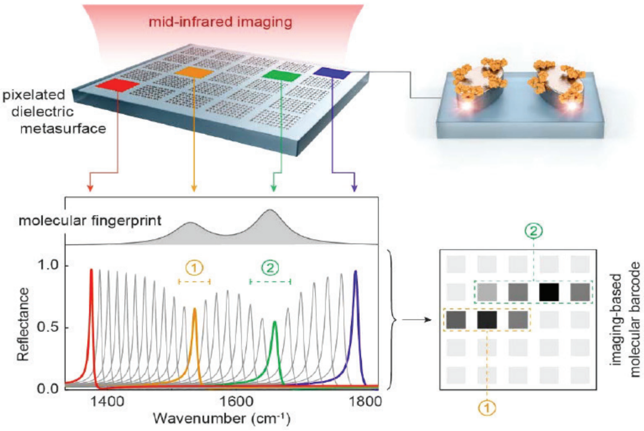

Figure 4: Pixelated dielectric metasurfaces based on the bound states in the continuum for encoding molecular absorption signatures into barcodes suitable for imaging-based detection.

One of the promising new directions for metasurfaces is biosensing and surface-enhanced spectroscopies (see Figure 4, adopted from [11]). Recently, we have suggested and demonstrated a novel approach for mid-IR spectroscopy that leverages pixelated dielectric metasurfaces to spatially encode molecular absorption signatures into chemically specific two-dimensional barcodes [12,13]. The method is based on high-Q resonances created by using symmetry-broken resonator arrays supporting bound states in the continuum [14,15]. By assigning different resonance frequencies to different pixels, one-to-one mapping between spectral and spatial information is obtained. Reflectance signal variations for different pixels are correlated with the strength of the molecular absorption signatures, which are read out in an imaging-based set-up to yield molecular barcodes. Crucially, such molecular imaging can be performed using broadband light sources and detectors, enabling spectrometer-less operation in a miniaturised platform for on-site applications. Multi-component samples containing biomolecules, environmental pollutants, and polymers can be analysed by comparing the barcode of the unknown mixture with a library of reference barcodes, aided by advanced pattern recognition and machine learning techniques.

Finally, metasurfaces provide novel opportunities for nonlinear optics expanding it into new directions with novel phenomena and functionalities. Nonlinear effects in thin, artificially structured materials such as metasurfaces do not rely on phase-matching conditions and symmetry-related selection rules of natural materials, and they may be substantially enhanced by strong local fields and collective resonances inside the metasurface nanostructures [16].

Conclusions

As widely accepted, photonics plays an important role in our everyday life, and it is closely connected with the progress of technology and many scientific discoveries. The recently emerged field of flat optics based on metasurfaces helps to advance many grand challenges in photonics. One of those challenges is to realise tunable and switchable optical ultrathin and ultralight devices with dynamic and active control of light including its amplitude, phase, and polarisation. Metasurfaces emerged first as simple beam-steering structures, but they provide important novel functionalities, open new applications, and drive new discoveries. Integration of metasurfaces with quantum emitters and creation of multifunctional modulators for light would naturally follow those initial steps. We believe that further advances in fundamental research in optical metasurfaces and technological innovations in flat optics will uncover their tremendous potential making a rapid impact on science, technology, and society. In addition, there are many other areas in physics and photonics which will benefit from metasurfaces and undergo rapid developments.

Acknowledgements

The author acknowledges useful collaborations with the groups of Hatice Altug and Cheng-Wei Qiu and thanks his research teams at Nonlinear Physics Center in Canberra and the ITMO University in St. Petersburg for continuous support and help. This research was supported by the Strategic Fund of the Australian National University, the Australian Research Council, and the US Army International Office.

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About the author

Professor Yuri Kivshar received PhD degree from Ukraine in 1984. From 1988 to 1993 he worked in Europe and USA, and in 1993 he moved to Australia where later he founded Nonlinear Physics Center at the Australian National University. His research interests include nonlinear photonics, metamaterials, and nanophotonics. He received many prestigious awards for his research, including Lyle Medal of the Australian Academy of Science, The State Prize in Science and Technology (Ukraine), Lebedev Medal (Russia), Harrie Massey Medal (UK), Humboldt Award (Germany), and more recently SPIE Mozi Award (USA).

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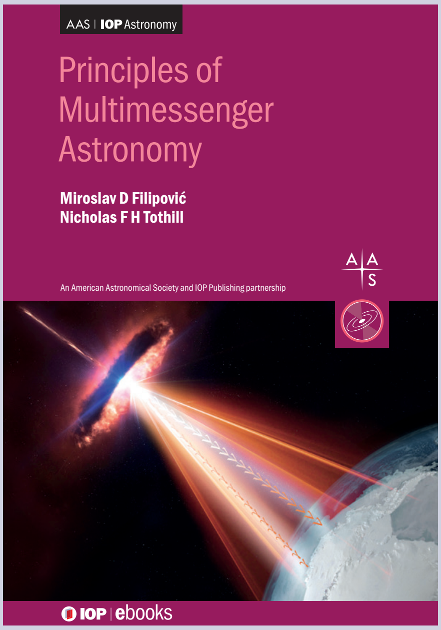

Principles of Multimessenger Astronomy

PUBLISHED SEPTEMBER 2021

Miroslav D Filipović and Nicholas F H Tothill

ABOUT THE BOOK

Astronomy has traditionally relied on capturing photons from cosmic sources to be able to understand the universe. During the 20th and 21st centuries, different messengers have been added to the astronomer's toolset: cosmic rays, neutrinos, and most recently gravitational waves. The goal of this book is to provide a broad understanding of these messengers and their relationship to each other. The unique physics of each messenger is introduced, as well as the physics of their detection and interpretation. Part of AAS-IOP Astronomy Series.

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- Provides a general reference for all astronomers interested in multimessenger observational astronomy and astrophysics, as well as a teaching resource
- Explores foundation topics that are useful across messenger and waveband boundaries
- Includes scientific history, and the operation and use of modern astronomical instrumentation
- Introduces the use of data from multiple messengers

ABOUT THE AUTHORS

Prof Miroslav Filipović is a scientist, philosopher and philanthropist with over 30 years of experience in astronomy. Since May 2002, Professor Filipović is affiliated with the Western Sydney University (WSU), and has been responsible for the development of Astronomy at WSU. He is Chair of the largest public Observatory in Australia (the WSU's Penrith Observatory), and has over 200 refereed publications. His research interests centre on supernovae, high-energy astrophysics, planetary nebulae, Milky Way structure and mass extinctions, H II regions, X-ray binaries, active galactic nuclei, deep fields, and stellar content in nearby galaxies.

Dr Nick Tothill joined Western Sydney University in 2011, where he is now Senior Lecturer in the School of Science and Director of the Penrith Observatory. He is a member of the Astronomical Society of Australia and the International Astronomical Union. His research centres on the interstellar medium of the Milky Way, but includes topics as diverse as high-redshift galaxy surveys, Antarctic astronomy, and cosmic-ray astrophysics.

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The boundary of chaos: an investigation into the length ratio dependent chaotic dynamics of a planar double pendulum

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Matthew Hill, Director of the Barker Institute, Barker College – MHill@barker.nsw.edu.au

A planar double pendulum is constructed by attaching two point masses together, with one of the point masses connected to a pivot point. It is an interesting dynamic system because of its tendency to exhibit chaotic motion, which can be quantified using the Lyapunov exponent. If the Lyapunov exponent is positive, the system is considered chaotic. If the Lyapunov exponent is negative, instead of being chaotic, the system produces periodic motion. Previous research has determined that at a 1:1 length ratio (between the two arms), the pendulum's motion is periodic, while if the length ratio is increased to 1:3, the pendulum's motion is chaotic. The work presented here aims to increase the precision of the measured length ratio representing the transitional point between periodic and chaotic motion. A computational simulation that provided a numerical solution to the Euler-Lagrange equations of the pendulum was used to determine the Lyapunov exponent for differing length ratios. The results demonstrate that the transitional length ratio lies between 1:2.34375 and 1:2.375.

The planar double pendulum system

A planar double pendulum is defined by attaching twopoint masses with a rigid, weightless rod, with the top point mass connected to a pivot point with a second rigid, weightless rod as seen in Figure 1 [1]. The length ratio of a pendulum is expressed as L_1:L_2. A pendulum is a Hamiltonian system, meaning its gravitational potential energy and kinetic energy is constantly exchanged and conserved throughout its motion [2]. Most importantly, the system has tendencies to produce chaotic motion [3, 4].

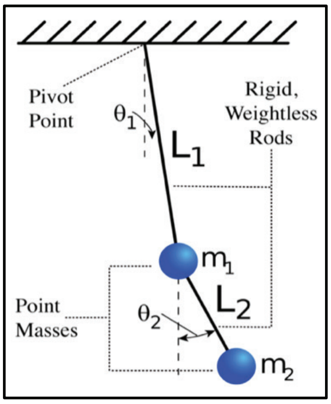

Figure 1: The planar double pendulum system. Adapted from [18].

Chaotic motion and the Lyapunov exponent

The Lyapunov exponent, λ, as defined in Equation 1, has proven to be the most useful quantification of chaos [5], and as such was used to quantify chaos in this study. A system is chaotic when λ is > 0, and it is periodic when λ is < 0 [6]. Qualitatively, chaos is the physical phenomenon where a dynamic system is highly dependent on its initial conditions and its motion is seemingly random [7]. λ is defined as the average exponential rate of divergence of infinitesimally close orbits in phase space [6]. Infinitesimally close orbits within phase space correspond to nearly identical physical states, hence an exponential divergence of these orbits implies a rapid loss of predictability of the system.

$$\lambda = \lim_{t\to\infty}\left[\lim_{\|\delta Z_0\|\to 0}\left[\frac{1}{t}\ln\frac{\|\delta Z_0(t)\|}{\|\delta Z_0\|}\right]\right] \qquad (1)$$

Danforth's algorithm which determines λ (summarised by Equation 2) has been used to quantify the chaos of a pendulum [1, 7]. Despite the use of Danforth's algorithm, none of these studies presented a complete and easily repeatable method for the algorithm. Therefore, this study includes a repeatable summary of Danforth's algorithm for calculating λ of a pendulum in Part 3 of the methodology.

$$\lambda_i(t) = \frac{1}{t}\sum_{n=1}^{t} \ln\|\vec{y}_n^i\| \quad (2)$$

As per the details of Danforth's algorithm, Galloway and Macaskill [8] suggest that in order for λ of a pendulum to be calculated, $\alpha = \theta_1, \theta_2, \dot{\theta}_1, \dot{\theta}_2$, with the set $\left\{\overrightarrow{\epsilon y_0^{\alpha}}\right\}$ being the set of column vectors in Equation 3.

$$\lim_{\epsilon \to 0}\left\{\begin{bmatrix}\epsilon\\0\\0\\0\end{bmatrix}, \begin{bmatrix}0\\\epsilon\\0\\0\end{bmatrix}, \begin{bmatrix}0\\0\\\epsilon\\0\end{bmatrix}, \begin{bmatrix}0\\0\\0\\\epsilon\end{bmatrix}\right\} \quad (3)$$

The importance of Gram-Schmidt orthonormalisation is to ensure that the displacement vectors do not collapse onto the dominant eigenvectors of the system, which increases the uncertainty of the λ calculation [8, 9].

The principle of least action

Rather than utilising Newton's second law of motion, the principle of least action was used to formulate the pendulum's simulation and Euler-Lagrange equations [10]. Feynman's definition of the principle of least action is "the average kinetic energy less the average potential energy is as little as possible for the path of an object going from one point to another" [11]. The action functional S_i of a pendulum is given by:

$$S_i = \int_{t_0}^{t_1} \frac{1}{2} m\dot{\theta}_i^{\,2} - mg\theta_i dt \quad (4)$$

This functional is relatively simple to compute numerically compared to the forces and acceleration of the masses. The actual path that is taken by the masses is that which minimises the action integral [10, 11]. One consequence of this is the Euler-Lagrange equation:

$$\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{\theta}_i} - \frac{\partial \mathcal{L}}{\partial \theta_i} = 0 \quad (5)$$

Testing the chaos of the planar double pendulum

Extant research into the pendulum has predominantly been through the use of a computational simulation. This is due to the pendulum's sensitivity to its initial conditions, hence making it very challenging for a built model to undergo a valid testing method that can be reliably repeated.

The Kolmogorov–Arnold–Moser theorem must be considered as it suggests that for certain initial conditions, the system may exhibit quasi-periodic motion, which is neither periodic nor chaotic [2]. The theorem states that at low energies (in the region of length ratio 1:1 to 1:3), the pendulum system's Euler-Lagrange equations may be integrable, meaning that if the phase space trajectory is subjected to a weak nonlinear perturbation, a portion of the invariant torus survives. This torus is the topological surface on which the phase space trajectory is bounded. Hence in this investigation, the motion of the pendulum near the transition point was investigated for possible quasi-periodicity, which can be seen if λ falls within the approximate range of 0 ± 0.05.

Another study into the pendulum system analysed the chaos of the system through the Lyapunov exponent [12]. This study chose to investigate the dynamics of a pendulum in regard to its total energy, *E*, and provided the knowledge that there is a clear boundary between periodic and chaotic motion at $E \approx 4.46$. This suggests that there are specific characteristics of a pendulum that makes it chaotic.

Levien and Tan's research provides valuable information on λ as the initial angle increases [1]. It was found that the system is chaotic if $\theta_1(0)$ is $> \pi/3$. This again showcases a specific characteristic of the pendulum system that makes it chaotic.

Gupta *et al.* explored the chaotic behaviour of a pendulum numerically [7]. The simulation used by Gupta *et al.* was a MATLAB simulation, allowing them to measure how the mass and length ratios influenced the chaos of the system. It found that λ increases when the mass ratio is increased. It was also found that λ increases when the length ratio is increased, with the system being periodic at length ratio 1:1 and chaotic at 1:3 [7]. However, the researchers did not find a more precise length ratio at which the system transitions from periodic to chaotic motion.

This study is designed to follow on from Gupta *et al.*'s paper, with the goal being to increase the precision of the measured length ratio representing the transitional point between periodic and chaotic motion, referred to as the 'transitional length ratio' in the work presented here. This is important for controlling and improving dynamic systems that are derived from pendulums, such as double-armed robots [13]. With the increase in robotics in industry, double pendulums have become a critical facet of manufacturing. Knowing when a double pendulum can produce chaotic motion will prove to be important in understanding and optimising pendulum-based robotic manufacturing systems.

Part 1: Modelling the dynamics of a pendulum

The reasoning for this modelling was to determine the Euler-Lagrange equations of a pendulum system. These two equations (one for each mass) govern the dynamics of the masses and formed the basis of the computational simulation. Some simplification steps have been omitted in the modelling for the sake of brevity, but all equations are accurate to the dynamics of the pendulum system.

The key initial conditions that must be defined for this system are the length of the pendulums' arm, L_i, the point mass, m_i, and the angular displacement from the vertical of the two masses (θ_i in radians), where $i = 1, 2$ indexing the two point masses.

The Lagrangian $\mathcal{L}$ for a system is known to be equal to:

$$\mathcal{L} = K_1 + K_2 - U_1 - U_2$$

$$\begin{aligned}\therefore\ \mathcal{L} = \frac{1}{2}(m_1 + m_2)L_1{}^2\dot{\theta}_1{}^2 + \frac{1}{2}m_2L_2{}^2\dot{\theta}_2{}^2 \\ + m_2L_1L_2\dot{\theta}_1\dot{\theta}_2\cos(\theta_1 + \theta_2) \\ + g(m_1 + m_2)L_1\cos\theta_1 + gm_2L_2\cos\theta_2\end{aligned}$$

Using the Euler-Lagrange equation (Equation 5), the equations of motion of the two masses can be obtained:

$$\begin{aligned}S_1 = L_1\Big[\ddot{\theta}_2L_2m_2\cos(\theta_1 - \theta_2) \\ + (\dot{\theta}_2)^2L_2m_2\sin(\theta_1 - \theta_2) \\ + (m_1 + m_2)(g\sin\theta_1 + L_1\ddot{\theta}_1)\Big] = 0\end{aligned}$$

$$\begin{aligned}S_2 = L_2m_2\Big[-(\dot{\theta}_1)^2L_1\sin(\theta_1 - \theta_2) \\ + \ddot{\theta}_1L_1\cos(\theta_1 - \theta_2) + \ddot{\theta}_2L_2 + g(\sin\theta_2)\Big] \\ = 0\end{aligned}$$

Due to their non-linear nature, there is no known method that solves the Euler-Lagrange equations analytically. However, they can be computed numerically using a computational program, one example being the *dsolve*{ } function in the Maplesoft computational simulator [14], which was used in this study. This method, however, can provide some uncertainty within the Lyapunov exponent calculation as a numerical solution is not an exact solution to the differential equations.

Part 2: Computing the transitional length ratio using the bisection method

In order to find precisely the transitional length ratio (where the pendulum transitions from periodic to chaotic motion), the bisection method was used. This method has not been used previously in research into a pendulum's dynamics but is a common method for finding the zeros of polynomials. For this work, this method can be thought of as trying to find the length ratio that makes λ as close to 0 as possible, i.e., the length ratio's zero. During Test 1, the known transitional length ratio bound is between 1:1 and 1:3 as established from extant research [7]. The length ratio halfway between this bound (i.e., 1:2) will be tested and determined to be either chaotic or periodic. This will set a new bound for the transitional length ratio. The length ratio halfway between the new bound will then be tested, 'telescoping' the transitional length ratio to its precise value after repeating multiple times.

Part 3: Steps taken to calculate the Lyapunov exponent for differing length ratios using Danforth's algorithm

A Maplesoft computational program was generated to simulate the motion of a double pendulum system, using the Euler-Lagrange equations for S_1 and S_2, the initial conditions in Table 1 and the *dsolve*{ } function. $\overrightarrow{v_0}$ was defined as the vector representing the initial conditions of the pendulum in the phase space of the pendulum system. $\overrightarrow{\varepsilon y_n^\alpha}$ ($\alpha = \theta_1, \theta_2, \dot{\theta}_1, \dot{\theta}_2$) was defined as the basis displacement vectors of the four dimensions of the phase space at the limit as $\epsilon \to 0$. The five conditions ($\overrightarrow{v_n}$, $\overrightarrow{\varepsilon y_n^\alpha}$) were iterated for a small time-step (0.01 seconds), generating $\overrightarrow{v_{n+1}}$ and the four $\overrightarrow{k_{n+1}^\alpha}$. The largest magnitude of the difference between the vectors $\overrightarrow{v_{n+1}}$ and $\overrightarrow{k_{n+1}^\alpha}$ was recorded, i.e. $\left\|\overrightarrow{v_{n+1}} - \overrightarrow{k_{n+1}^\alpha}\right\| = \left\|\overrightarrow{y_{n+1}^\alpha}\right\|$.

Table 1: Initial conditions used for the computational simulation.

Parameter	Value
L_1	1 m
L_2	2 m
$\theta_1(0)$	0.2 rad
$\theta_2(0)$	0.2828 rad
$\dot{\theta}_1(0)$	0 s^{-1}
$\dot{\theta}_2(0)$	0 s^{-1}
m_1	1 kg
m_2	1 kg
g	-9.8 ms^{-2}

The four $\overrightarrow{k_{n+1}^\alpha}$ were orthonormalised using Gram-Schmidt orthonormalisation, generating the four $\overrightarrow{\varepsilon y_{n+1}^\alpha}$. These steps were repeated for 150 seconds (i.e. $n = 15000$) and $\lambda(t)$ was calculated utilising Equation 2.

If λ was positive (ie. the system is chaotic), the simulation was repeated for the length ratio halfway between the tested ratio and the closest known ratio that produces periodic motion; if λ was negative (ie. the system is periodic), the simulation was repeated for the length ratio halfway between the tested ratio and the closest known ratio that produces chaotic motion.

Results

The Lyapunov exponent time series of each length ratio was generated within the Maplesoft simulation. For each length ratio, λ initially fluctuated (even between positive and negative values) and then settled to a more consistent value which was observed and recorded to characterise the motion of the system (Figure 2). Figure 2A shows a time series with a negative Lyapunov exponent. In contrast, Figure 2B shows λ to be positive. At length ratio 1:2.359375 (Figure 2C) it cannot be determined whether λ is positive or negative with certainty. It was determined whether the motion is periodic ($\lambda < 0$) and therefore if the length of the second arm was to be increased,

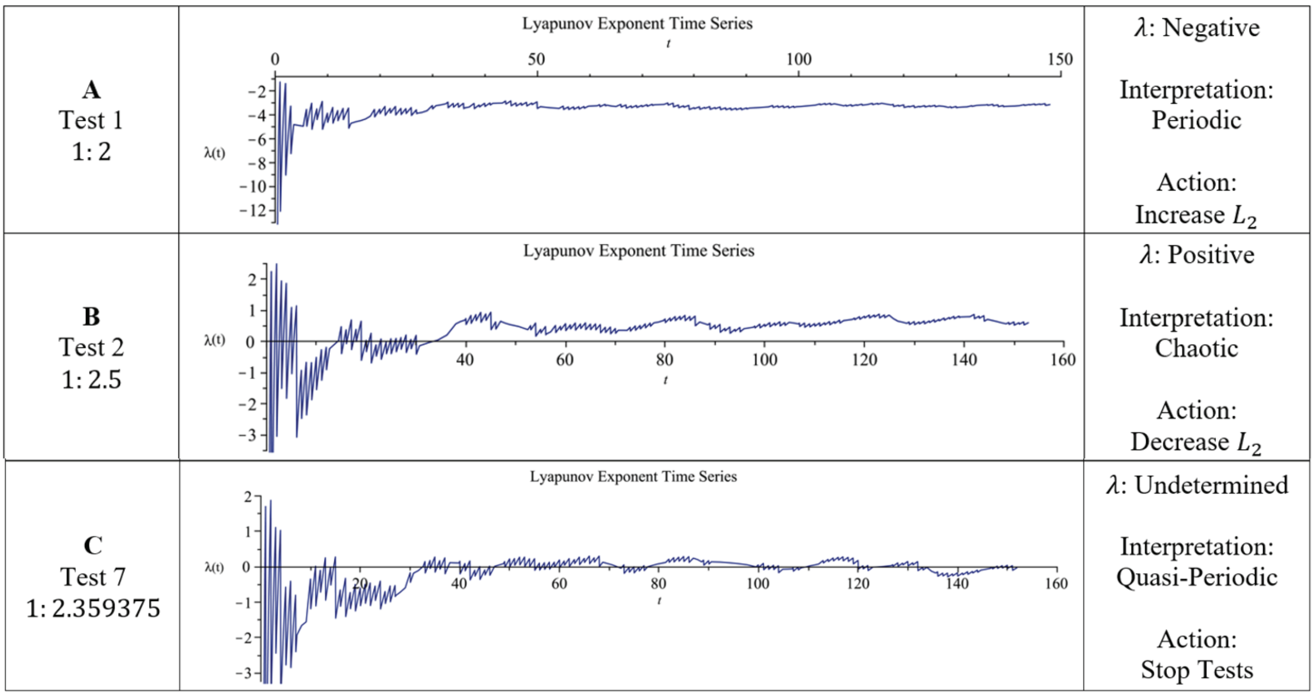

Figure 2: Lyapunov exponent time series for initial length ratio of 1:2 (A) with iterative steps to length ratio 1:2.359375 (C), where the sign of the Lyapunov exponent is undetermined.

Table 2: Lyapunov exponent values for each length ratio evaluated through the Maplesoft computational simulation.

Length Ratio	**1 : 2**	**1 : 2.25**	**1 : 2.3135**	**1 : 2.34375**	**1 : 2.359375**	**1 : 2.375**	**1 : 2.5**
				$\lambda(t)$			
$t = 40$	-3.03	-1.42	-0.26	-0.47	-0.14	-0.45	0.52
$t = 150$	-3.22	-1.31	-0.32	-0.28	-0.02	0.56	0.49
Average	**-3.18**	**-1.40**	**-0.29**	**-0.24**	**0.05**	**0.37**	**0.51**
Interpretation	**Periodic**	**Periodic**	**Periodic**	**Periodic**	**Quasi-Periodic**	**Chaotic**	**Chaotic**

or chaotic ($\lambda > 0$) and therefore the length of the second arm was to be decreased. Seven tests were completed in total and the transitional length ratio was 'telescoped' to a more precise measurement with each test. Three of these tests are shown in Figure 2. This bisection process of varying the length ratio based on λ continued until there was uncertainty in whether λ was positive or negative, i.e., the system was producing quasi-periodic motion.

The average value of λ between the time period of 40s to 150s was found within the Maplesoft computational program, using the integral in Equation 6. This time period was chosen as $\lambda(t)$ becomes relatively stable at $t = 40$, and the Maplesoft simulation could not compute $\lambda(t)$ for values >~150. The average value, the value at $t = 40$ and the value at $t = 150$ have been summarised in Table 2.

$$\frac{\int_{40}^{150} \lambda(t)dt}{110} \qquad (6)$$

Using the data in Table 2, Figure 3 shows the relationship between the average Lyapunov exponent and the length ratio, expressed as the fraction $L_2 \div L_1$.

Discussion

As per the literature review, if λ is < 0, the system is periodic, and if λ is > 0, the system is chaotic [6]. From the visual and numerical analysis of the Lyapunov exponent times series, between the length ratios 1:2 to 1:2.34375, λ was negative and so the pendulum system was periodic. Furthermore, it was shown both visually and numerically that at length ratios between 1:2375 and 1:2.5, the pendulum system was chaotic as $\lambda > 0$. It can be inferred that the transitional length ratio lies between the length ratio of 1:234375 (the upper bound of periodic motion) and 1:2.375 (the lower bound of chaotic motion). This represents an improvement in precision of determining the transitional length ratio by a factor of 64 times in comparison to extant research [7]. As there was uncertainty in whether λ was positive or negative in Figure 2C, it was concluded that at the length ratio 1:2359375, the pendulum produced quasi-periodic motion.

From the plot in Figure 3, it can be observed that there was a positive association between the Lyapunov exponent and the length ratio; however, an exact linear correspondence between the two variables was not evident from the data. One reason this could arise is due to errors within the Lyapunov exponent calculation. However, this was not likely to be the cause of this non-linear correspondence, as the

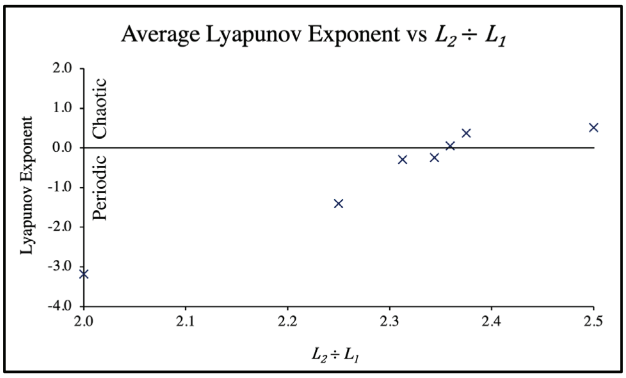

Figure 3: A plot of the average Lyapunov exponent as a function of the length ratio (expressed as the fraction $L_2 \div L_1$).

computation simulation provided a numerical solution of the Euler-Lagrange equations that were accurate to 1 part per 10^6 [15]. The exact uncertainties of the Lyapunov exponent calculations are quite hard to derive; however, they could be investigated in future research. Another explanation for this non-linear correspondence is that the two variables (length ratio and λ) are correlated through a third variable, which may cause a change in both λ and the length ratio.

One possible candidate of this third variable is the total energy of the system, which is increased as the length ratio increases [12]. Furthermore, there is evidence that there is a clear boundary between periodic and chaotic motion at $E \approx 4.46$ [12]. As the total energy is given by the sum of the gravitational potential energy, U, and the kinetic energy, K, E stays constant throughout the motion of the pendulum. Furthermore, within this study, at $t = 0$, $K = 0$. Because $dE/dL_2 = -gm_2 \cos\theta_2 = 9.41 > 0$, it is clear that, when the length ratio is increased, the total energy of the system also increased.

It is proposed that the more energy the pendulum system has, the more likely it will be chaotic. This is because the phase space velocity will have a larger magnitude and, hence, a slight perturbation to the phase space trajectory will have a larger proportional influence on the system. This may cause the phase space trajectory to diverge from its original path, i.e., produce chaotic motion [6].

Further research into the planar double pendulum might investigate the total energy of the system in two ways. The length ratio could be varied while ensuring that the total energy of the system stays constant throughout the tests. This can be achieved by changing a variety of variables ($m,\ \theta,\ \dot{\theta}$). If λ remains constant when the length ratio is changed and the total energy of the system is kept constant, it can be proposed that the length ratio is not the cause of the changing λ observed in this study. However, a relationship between E and λ would also need to be investigated. This can be done by keeping the length ratio constant and varying E. A proposed method would be to provide one mass with differing initial angular velocity, rather than the zero initial angular velocity that was used in this work.

It is most likely that the reason for a pendulum's chaotic motion is a combination of all the factors discussed above; however, this is not yet clear from known research [16].

Finally, this study only focused on length ratios between 1:1 and 1:3. At the limit as $L_2 \to \infty$, the planar double pendulum system can be thought of as a planar pendulum system (i.e., only one mass on one rod), which is a periodic system [17]. This suggests there is another transitional length ratio, where the pendulum transitions from chaotic to periodic motion. A conclusion that can be drawn from this is that there may be a finite range of length ratios of a double pendulum system that produce chaotic motion, which could be investigated in future studies.

To summarise, it is proposed that the increase in length ratio may not solely be the cause of the increase in λ. Other qualities of the system, specifically the total energy E, should now be investigated in order to determine if there are additional factors influencing the system's chaotic motion.

Conclusion

Our project explored the transitional length ratio between periodic and chaotic motion of a planar double pendulum system. Through the use of a computational simulation of a double pendulum, the chaos of the system was quantified and analysed through calculating the Lyapunov exponent (the accepted measure of chaotic motion). Previous research determined that the transitional length ratio lies between the bound of 1:1 and 1:3. The bisection method was used to increase the precision of this measurement, and it was determined that the transitional length ratio occurs between 1:2.34375 and 1:2.375, improving the precision of this measurement by a factor of 64.

Acknowledgements

We would like to thank Professor Nusantara of the State University of Malang for sharing his code that generated the displacement initial condition, without which the calculation of the Lyapunov exponent would not have been possible. We would also like to thank Boyd Carruthers and Jeremy von Einem of Barker College for reviewing our paper and providing valuable feedback.

About the authors

Harry Breden is completing his HSC at Barker College in 2021 and is the Vice-Captain of the College. Excelling in an array of STEM courses, he is preparing to study mathematics and science at university. Harry hopes to use his analytical skills to find creative solutions to real-world problems and has enjoyed the chance to engage with academic literature in the Science Extension HSC course.

Matthew Hill is the Director of The Barker Institute with a focus on professional learning, research and innovation in the school. He specialises in Physics, Chemistry and especially the new Science Extension course supervising students to conduct university-level research while in high school. His diverse research interests include education, leadership and science.

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Editors' Note

We are delighted to present this technical article from a secondary school student. *Australian Physics* welcomes such high-quality articles from students who, otherwise, would have only very few options to publish their work.

This piece by Harry Breden is of high standard. It acknowledges academic collaborators and builds on well-established theory which is carefully referenced in the article. As such, it is an extension of established research, rather than new theory. Hence we think it is compatible with *Australian Physics'* editorial policy to not publish original research that has not previously passed peer-review.

Encouraging young and upcoming scientists and giving them a platform is important. When we were met with enthusiasm about the opportunity to include this work in the magazine, we got a sense that the future of physics in Australia is potentially strong.

Weight and mass for young physicists

Chris Hall, ANSTO Australian Synchrotron – christoh@ansto.gov.au
Clara Teniswood - clara.teniswood@gmail.com

A reader response to the previous Young Physicists' article about buoyancy raised an interesting question regarding the difference between weight and mass. Would the Ever Given sit higher or lower in the water of the canal if it was nearer the south pole?

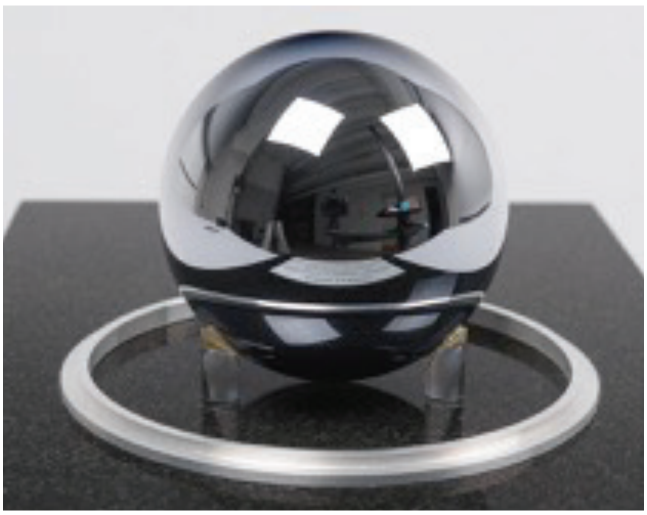
In other words, is the draft of a ship dependent on where in the world it is sailing? The answer to this question brings us back to considering the difference between mass and weight. We addressed this briefly in the buoyancy discussion. Just as an aside, as young physicists it's important you should nurture your skills of explanation. Learn how to tell someone about science who is not a physicist – perhaps a younger sibling. If you can successfully explain the weird things we learn and already know about physics, then you can say you truly understand them. One of my favourite sayings are along these lines attributed to Albert Einstein: 'The explanation you give as a scientist should be as simple as possible, but no simpler' [1].

How would you explain the difference we physicists understand between mass and weight? In everyday life those words are often used interchangeably, but as we saw in the last article when calculating the draft of the ship Evergreen, they are not the same. The two quantities are certainly proportional, but mass is a fundamental unit. It cannot be split into other units. Weight on the one hand is actually a force, measured in Newtons (the S.I. unit for force) [2]. One Newton is the force required to accelerate a one kilogram mass to a velocity of one meter per second, over the interval of a second. On the other hand, mass is a measure of the amount of material in an object. We can say it's the number of atoms that make up whatever it is we are measuring.

When we talk about a weight being in kilograms then, it should really be described as kilograms force (kg-f), and we need to agree on the gravitational pull to use it as a standard. If we know the local value of the gravitational acceleration, which in physics is usually given the letter 'g', we can then work out the mass. There is an internationally agreed value of g, which is 9.80665 m/s^2. That doesn't mean it's the same all over the world, though. The variation with latitude is about 0.5% for high latitude places, compared to the equator. For instance, in Sydney the value of g is 9.797 m/s^2. If you live in Melbourne, it is 9.800 m/s^2, and in London, England, it is 9.816 m/s^2.

On Mars, g is only 3.721 m/s^2. If you stood on Mars, you would weigh less than you do on Earth, because gravity is less. However, you would still have the same mass because you are made up of the same amount (and type) of 'stuff' (atoms). Next time you go in an elevator, take some scales with you and stand on them while you go up and down a few floors – what do you notice?

When we are explaining something, it is often useful to offer an illustration. Consider a sphere of pure silicon. Silicon is an abundant and remarkably useful element. I choose a ball of silicon as an example, because this is exactly what is used as our international standard mass. The Australian CSIRO have made a sphere of silicon for the international Avogadro project [3]. This shiny ball will be used as the new international kilogram reference object. It is exactly 1 kilogram, down to a precision of 10 parts per billion.



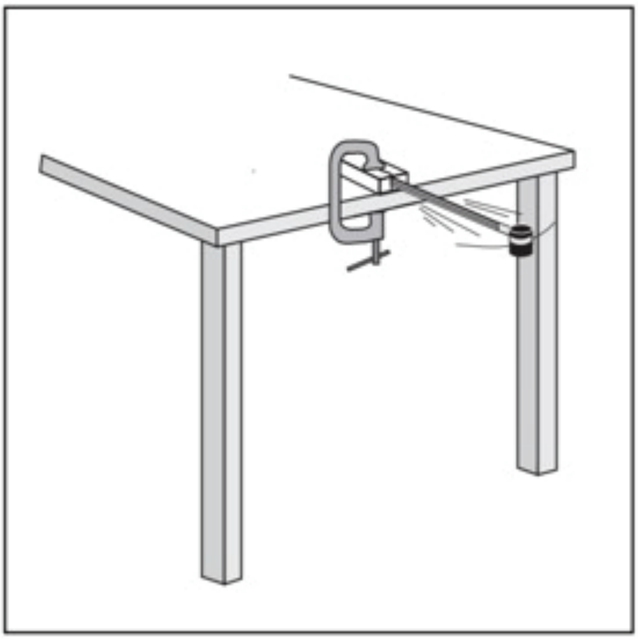
One kilogram silicon sphere. Source: [3].

At normal temperatures and pressures, silicon atoms like to stick to each other. So, silicon is said to be a solid material. It's also a crystalline solid since the atoms stick to each other in a nice regular pattern. It is easy to distinguish silicon atoms from any atoms in the air around it. The gas atoms in the air don't stick to each other, or stick to the silicon. They do regularly bump into the silicon atoms, but they won't stay. Because of this, we may define a precise number of atoms in our ball of silicon, and therefore its mass.

The question then is: how do we measure that mass? We could use a balance or some scales perhaps, but what if we were trying to make the measurement in a different gravity field, for instance on the Moon where $g_{Moon} = 1.62$ m/s^2? The answer lies in another physical phenomenon that is dependent on mass: inertia. Inertia only depends on the mass and how fast the mass is moving. Inertia does not depend on gravitational pull. For example, on the International Space Station (ISS) the astronauts float around weightlessly (we leave it to you to figure out why they are weightless; it's not because the ISS cruises a few hundred kilometres above the Earth's surface). Even though astronauts are weightless on the ISS, they still have mass. They still need to push themselves off one end to float to the other, so they still need to overcome their own inertia to move. On the ISS, with weight out of the equation, one could devise measurements to measure mass. Down on Earth, measuring mass and weight gets more entangled, but there are ways to use inertia to measure mass.

Have you learnt about the physics of guitar strings? One thing that you may know is that the string will change its tune (frequency) depending on its length, how tightly it is pulled (tension) and, most importantly, its mass. If we assume the string is made from the same material all along its length, then we can define a property called linear mass density, which can substitute for mass. If we fix the string's length and tension, then more massive strings sound lower than thinner ones. So, here is a way of measuring mass. A mass-measuring device that uses this technique is called an Inertial Balance. We can place our unknown mass into a system that oscillates (that is, to move back and forth from a central point) and measure the change in frequency of the oscillation. If accurately calibrated, this will give us the mass (rather than the weight). NASA has actually created instructions for how you can do this experiment at home or at school [4].

So now you should know the difference between mass and weight and that gravity varies depending on where you are. Thinking back to what you learnt about buoyancy in our previous article, can you now answer the question: would the Ever Given sit higher or lower in the water of the canal if it was nearer the south pole? Send your answers to aip_editor@aip.org.au; the first correct answers will win a (modest) prize.



Inertial Balance experiment. Source: [4].

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#PhysicsGotMeHere

This 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.

Hannah Edwards

I am a veterinarian working in general mixed practice, which means that I provide routine care as well as complex medical and surgical diagnostics and treatments for domestic animals; not just for cats and dogs but anything from rats and lizards to alpaca and horses, as well as wildlife.

It's not just cuddling puppies and kittens! We provide expertise in a range of services for each patient, acting not only as the general practitioners (GPs) but also the dentists, dermatologists, anaesthetists, soft tissue an orthopaedic surgeons, radiologists and pathologists, to name just a few of the roles we fill.

On a daily basis I not only perform general health checks and vaccinations for people's pets, but I also consult on issues relating to problems with pet health and behaviour.

Hannah Edwards BVSc (Hons I), BSc (Adv.) (Hons I, Physics), Veterinarian at Benetook Vet Clinic

I may collect and analyse diagnostics such as blood tests and radiographs, provide medical treatments such as intravenous fluid therapy and complex medication regimes for simple to life-threatening diseases, and perform many kinds of surgery from a routine desexing, to stitching up wounds or emergency exploratory laparotomies. At the sadder end of the spectrum is euthanasia, where I am privileged to be part of a family's goodbyes to their beloved pets.

I have also contributed to wildlife conservation through treatment of individual animals who are rehabilitated with wildlife carers before being released, and wildlife forensics by performing post-mortem examinations for authorities during their investigations of wildlife crime such as poisonings and shootings, as well as public health issues such as botulism.

Another big part of my job is communicating with pet owners. It is an important part of the diagnostic and treatment processes. Educating them about and working with them as a team for their pets' health and behaviour is imperative for animal welfare.

My career story so far:

My higher education started with physics rather than veterinary science. I had always wanted to be a vet, but I fell in love with physics in high school; so, when I didn't get into vet school straight away, I chose to continue on with physics! In fact, I almost didn't study vet science at all but was going to do a PhD in physics, modelling and developing technology for medical diagnostic imaging.

When I completed my physics honours year (in which I studied detection of electromagnetic resonance using magnetic fields, again for the advancement of medical diagnostic imaging) I transferred to veterinary medicine. All the skills I learned through my undergraduate physics degree I was able to apply – from analytic thinking and problem solving, to scientific writing and the constantly dreaded group work.

To me, physics is the basis of understanding the world around me, even within veterinary medicine. When it came to learning about blood pressure and action potentials of nerves, intra- and intercellular fluid dynamics and cell signalling, optics of the eye and animal gaits and locomotion – physics was there. From understanding the basics of bone fracture repair and intrathoracic pressure changes due to wounds and how these impact breathing, to understanding diagnostic ultrasonography, radiography and electrocardiograms, to drug molecule actions in pharmacodynamics – physics was there!

I've studied and worked very hard to get where I am and be the vet I am today, but I think I am all the more equipped to be good at my job because of my undergraduate training in physics.

Errol Hunt
Senior Communications Coordinator at ARC Centre of Excellence in Future Low-Energy Electronics Technologies (FLEET)

I share news about FLEET's research with various external audiences, including the public, scientific and general media, industry, collaborators and schools. I also coordinate internal communications, which is a huge challenge for a geographically separated Centre of Excellence, and even more so in 2020!

My career story so far:

My school career advisor once told me, "You can't be both a writer and a scientist, Errol. You have to choose one or the other." #worstcareeradvice

I chose science, so after a year with NZ Electricity testing high-voltage equipment in the dank bowels of remote hydro-electric stations, I went to uni and studied physics, including a couple of stints with industry.

Post-uni, I had a lot of fun as a physicist in an industry research centre, modelling and measuring heat flow and magneto-hydrodynamics in aluminium reduction cells. I loved the problem-solving aspect – coming up with new ways to measure molten-metal velocities, magnetic fields or solid crust formations. This was all accomplished in relatively hostile conditions: perched over fuming 1000°C molten cryolite, in magnetic fields strong enough to occasionally trip you up by your steel-cap boots.

I abandoned science a while after that to join the travel publishing industry, including on-the-road guidebook research gigs in the Cook Islands and New Zealand, ghost-writing a book on the effects of climate change in Tuvalu, and being coordinating author on the company's first multi-country guide to the South Pacific.

Mostly, I commissioned work by other authors. These included some personal heroes, such as Booker prize winning novelist Keri Hulme, writing about the traditional Polynesian homeland of Hawaiki, historian James Belich on NZ history, and All Black Tana Umaga on Wellington cafes.

I was involved in a little media-engagement work for the company, mostly about Pacific Islands or NZ tourism, the highlight of which was swearing on national TV.

I'd had to talk fast to persuade the company that my experience as a scientist was somehow useful in travel writing, but the most transferrable skills from my previous job were actually project management, working in teams, commercials, and problem-solving.

Post travel-industry I decided to prove my old school careers advisor wrong and combine my two career streams of science and writing – thus, science-communications.

I discovered I got much more enjoyment from talking to other people about their science than I'd ever got from doing my own, and so a career in science-comms was born.

Since then, I've talked to scientists about their work in space weather and climate extremes, immunology, coral reef health, coal dust, and black holes. I've learned how to run events (including some with the AIP), and written short articles on antibiotic resistance, solar panels, habitat restoration, and physics (lots about physics…).

Errol Hunt demonstrating 'Maunder and Hunt's Very Fabulous Rainbow Position Locator' (FLEET.org.au/rainbow)

I regularly write up FLEET science for non-specialist audiences, and I've written a Year 12 textbook chapter on gravitation.

I've also helped develop and deliver a Year 10 unit on future computing, working with teachers and FLEET scientists to develop and guest-present the material. That was a fantastic experience.

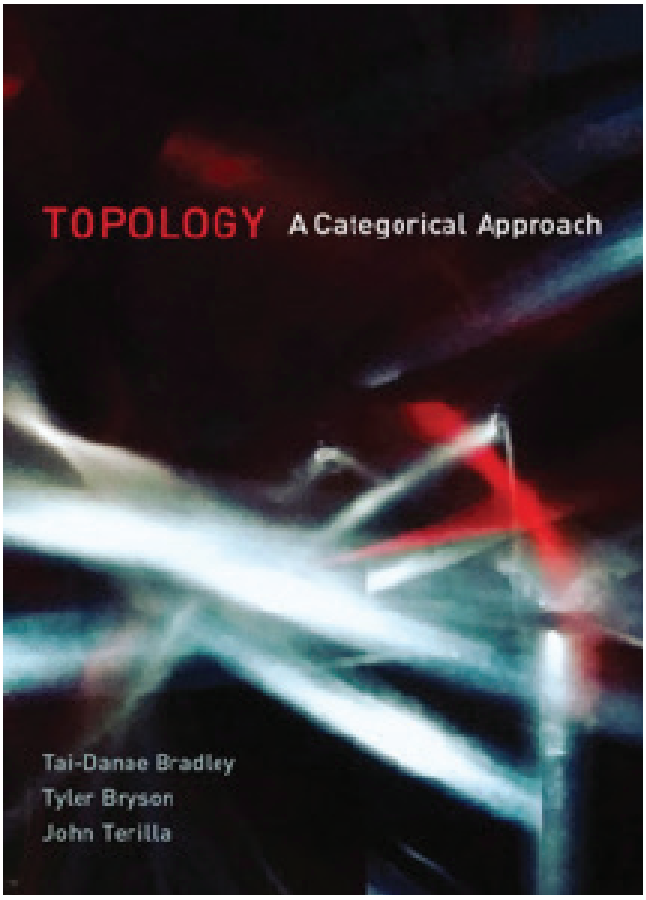
I'm looking for ways to do more of this, including in schools that don't always get these opportunities. (Got ideas? Contact me!)

My latest passion is training scientists to do their own comms. Our Centre's outreach projects have been really key in this. Explaining their science to schoolkids helps our members explain it to potential industry collaborators, or politicians, or funding partners.

I'd also like to keep proving that bad careers advice wrong and persuade more people that it's not necessary to choose between science and writing, or other artistic endeavours.

I'm more passionate about awakening an appreciation of science in non-scientists than I am about persuading more kids to pursue a career in science. I think a science-engaged public is better equipped to sift and debunk misinformation and is more likely to elect science-engaged politicians.

BOOK REVIEW



Topology, A Categorical Approach

by Tai-Danae Bradley, Tyler Bryson and John Terilla, Paperback ISBN 9780262539357

Reviewed by Christina Pospisil pospisil.christina@gmx.de

In the book Topology, A Categorical Approach, topology is introduced in 7 chapters focusing on describing mathematical representation of space theory by starting with defining the characteristics of injective functions combined with other functions, and the characteristics of the disjoint union of sets regarding mathematical application with further sets. The book continues with examples of spaces and continuous functions, and begins defining topology with the subspace topology. Moreover, the quotient, product and coproduct topologies, with their universal properties, are defined.

The second chapter is dedicated to the definition of connectedness and compactness. Important theorems include: the implication of connectedness from path connectedness, the characterization of a general space as the quotient of a Hausdorff space, the Bolzano-Weierstrass Theorem about infinite sets in compact spaces, the Tychonoff Theorem I about the product of compact spaces, and the Heine-Borel Theorem about subsets of the n-dimensional space of real numbers. The Tube Lemma about open sets and particular products of open sets is also introduced in chapter 2 as fundamental basics for topology.

In the third chapter, one can find mathematical concepts about filters and limits of sequences. Filters on sets are defined through a collection, and cofinite subsets of a set are named Frechet filter. The Tychonoff Theorem II and its proof are one of the main sections of the chapter. Tychonoff's Theorem II states that the compactedness of a product of compact spaces from a collection. Furthermore, the chapter presents the reader Zorn's Lemma of the implication of the existence of a maximal element of a poset from a general chain in this poset, which cannot be empty to fulfill the lemma. From the Ultrafilter Lemma, one knows, that proper filters can be embedded in ultrafilters. A main result in this chapter is the equivalence of Tychonoff's Theorem and the implication about non-emptiness of products of non-empty sets from a collection. The definition with examples of limits (from the category based definition) and colimits can be found in chapter 4, including the concepts of completeness and cocompleteness for categories.

Adjunctions and compactifications are presented in chapter 5. Main terms and theorems to name are the Stone-Cech compactification, the One-Point Compactification, the Adjoint Functor theorem about the implication of the existence of left adjointness for a continuous functor, that fulfills the Solution Set Condition, the Compact-open topologies, Ascoli's theorem about equicontinuity and compact closure, and Arzela's Theorem about equicontinuity, boundedness and uniform convergence.

Mixed topics about path adjunction, the fundamental theorem of algebra, groupoids, the fundamental group, the fundamental groupoid and further particular adjunctions like the Smash-Hom Adjunction are defined and presented in the sixth chapter. Results about spaces, continuous functions and the category of groupoids are summarized in the Seifert van Kampen Theorem. The textbook Topology, A Categorical Approach can be used for self-study and is published by the MIT Press.

Physics around the world

Biological systems inspire new method for extracting lithium

A new way to extract lithium from contaminated water could make this technologically important metal much easier to produce. The technique, which involves passing aqueous brines through lithium-selective polymeric membranes, works in a way that mimics the potassium channels that regulate the balance of ions in biological systems.

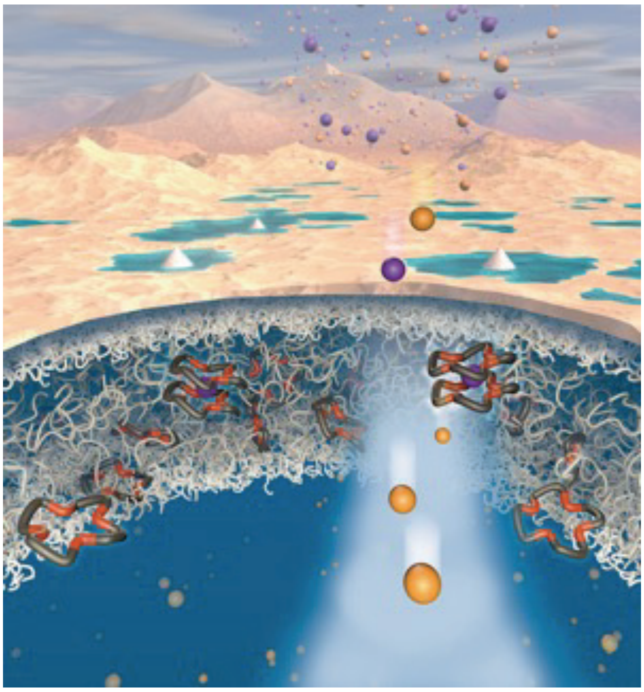
Lithium has several applications in low-carbon energy and is widely employed in electrochemical technologies. Lithium-ion batteries, for example, dominate today's market for rechargeable power storage thanks to the element's low mass, large reduction potential and high energy density.

As electric vehicles become more popular, industrial demand for lithium is set to increase still further. This creates challenges, because although lithium is an earth-abundant metal, extracting it from natural sources is not easy. Currently, it is sourced from deposits of a mineral called pegmatite and salt brines via solar evaporation – a costly and inefficient process that can take over a year.

Crown ethers

Researchers have previously explored ways of using polymer membranes to extract lithium from aqueous solutions. Conventional polymer membranes typically separate solutes based on differences in either the size or the charge of ions, but this is not specific enough to target lithium alone. Most such membranes allow sodium ions to permeate at a greater rate than lithium ones.

A team led by Benny Freeman of the University of Texas at Austin has now succeeded in reversing this behaviour by developing a novel polymer membrane containing crown ethers – chemically functionalized ligands that can bind certain ions. These ligands hinder the permeation of sodium but "ignore" lithium, meaning it passes through the membrane at a greater rate than sodium. Indeed, the team's lithium transport measurements revealed that the material boasts an unprecedented reverse permeability selectivity, preferring lithium over sodium by a factor of roughly 2.3 – the highest selectivity ever documented for a dense, water-swollen polymer.



Lithium extraction. (Courtesy: The University of Texas at Austin)

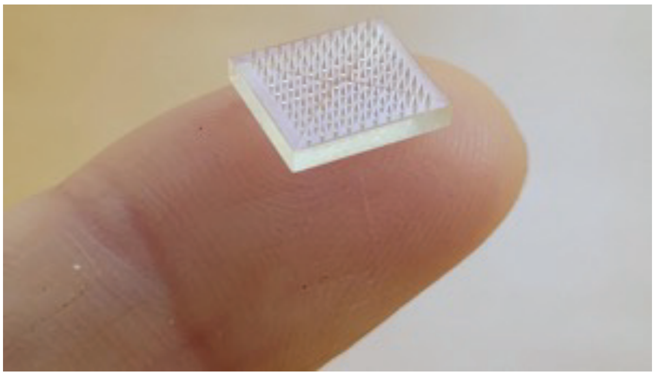
"Lithium is currently extracted from brines through the use of evaporation ponds, which is a slow and laborious process," explains Freeman. "Using membranes such as ours that can extract lithium is advantageous because they are energy efficient, scalable and can have a much higher throughput than evaporation ponds."

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

Could the future of vaccines be syringe-free?

In the global fight against COVID-19, around 6.8 billion vaccine doses have been administered across the world, a figure that is likely to rise as more doses become available and with many countries now recommending booster jabs. As often in times of health crises, new medical technologies have emerged, driven by the sense of urgency and extra funding, that address difficulties of existing methods and could change healthcare paradigms for years to come.

During the COVID-19 crisis, we have witnessed the rise to prominence of messenger-RNA vaccines, which trigger immune reaction by directly teaching cells to produce subunit antigens, rather than by introducing weakened forms of the virus. This design makes them easier to design and manufacture than traditional vaccines.



Vaccine delivery: The 3D-printed patch designed by researchers in the US contains 100 microneedles. (Courtesy: Shaomin Tian)

But the pandemic also highlighted logistic and delivery hurdles. Indeed, many supply chain and delivery challenges have hindered mass vaccination against COVID-19, particularly in resource-limited countries: vaccines need to be stored in freezers, both during shipping and at delivery sites, and injected by trained healthcare professionals. This usually requires a visit to a clinic or a hospital, while those who fear needles may be offput by the traditional syringe-based vaccine delivery.

To address these challenges, two independent teams from the US and China set out to create patches composed of multiple microneedles, each smaller than a millimetre high, that can deliver vaccines into the skin. This technique can result in more antigen-presenting cells (the vaccine's targets) than achieved via muscular injection. The teams report their findings in two separate articles, where they also highlight the technology's potential for boosting immunity while reducing the volume of compound administered.

Customizing patches

In a study described in PNAS, researchers from the University of North Carolina and Stanford University in the US, led by Shaomin Tian and Joseph DeSimone, took advantage of continuous liquid interface production (CLIP) 3D printing to create vaccine patches with microneedles of different sizes and shapes. CLIP functions by triggering a photochemical reaction at the interface of a liquid resin, curing the resin into a solid state. It relies on a tuneable light sequence that meticulously manages the light–resin interaction.

Until now, 3D-printed patches could not offer a high level of customization, resulting in bed-of-nails-like patches created through moulds. Repeated use of the moulds over time decreased the sharpness of the microneedles created, which eventually limited the vaccine efficiency.

"Our approach allows us to directly 3D print the microneedles, which gives us lots of design latitude for making the best microneedles from a performance and cost point-of-view," Tian says.

The needle design chosen by the team is shaped like a fir tree, which increases its surface area and cargo loading (36% greater loading than a conventional pyramidal design). When compared with traditional subcutaneous injection, patches containing a common model antigen (ovalbumin) and the immunostimulator CpG induced an immune response 20 times higher after prime immunization, and 50 times higher after booster injection in mice.

The studies also highlighted the potential dose sparing ability of the patch, as the immune response elicited was the same with 10 times less ovalbumin (but the same level of CpG), or with five times less CpG (but the same level of ovalbumin).

(extracted with permission from an item by Samuel Vennin at physicsworld.com)

Physicists get under the skin of apple growth

Researchers in the US have used the physics of singularities to study the recess, or cusp, that forms around the stalk of an apple. Based on field and laboratory experiments as well as simulations, they determined that the cusp is self-similar, meaning that it looks the same at different stages of the apple's growth. They also investigated the emergence of multiple cusps, as are sometimes seen in real fruit.

Singularities are points at which a certain quantity becomes infinite or ill-defined. The infinite space-time curvature thought to exist at the centre of black holes is one well-known example, but singularities also crop up in other areas of physics. In biology, meanwhile, examples include the sharp folds on the surface of the brain and the way bacteria clump together in the presence of certain chemicals.

Move over, Newton

The latest research sees Lakshminarayanan Mahadevan and colleagues at Harvard University explore the singularity created by the abrupt change in the orientation of the apple's surface at the base of its stalk. In a paper published in Nature Physics, they describe how this singularity develops as the apple grows from a slight bulge in the stem of a blossom into a fully-formed fruit with a seed-containing core, a fleshy cortex surrounding it and a tough outer skin.

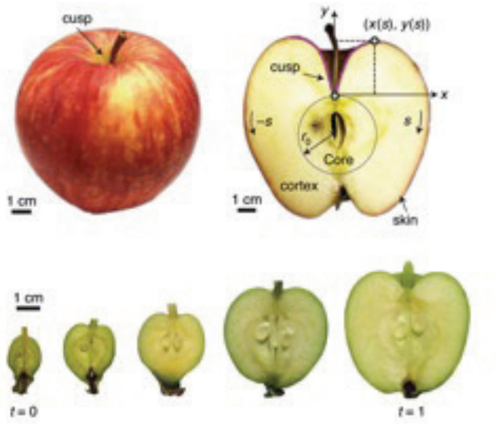


Figure depicting the cross-section of apples at different stages of growthFruity physics Top: A Gala apple with a cusp where the fruit meets the stalk. Bottom: Apple cross-sections at different stages of the fruit's growth. (Courtesy: Modified from Fig. 1 of A Chakrabarti et al., Nature Physics 17 1125. Reused with permission.)

To make their observations, Mahadevan and colleagues began by studying the shapes of 100 apples picked at different stages of their growth from the orchard of a college, Peterhouse, at Cambridge University, UK. By slicing each apple in half, they created a series of cross-sections, then arranged them in order as if they were stills from a film depicting the changing shape of a single apple.

The team found that apples measuring less than about 1.5 cm across displayed no discernible cusp, while those with a diameter of more than 3 cm had a distinctive dip at the base of the stalk. This is because in the early stages of the apple's growth, the contour of the peel varies smoothly. As the cortex starts to expand more quickly than the core, however, a bulge forms away from the core and a discontinuity appears in the apple's perimeter.

Harvesting data

Next, the researchers analysed the apple's shape by defining its cross-sectional profile as a one-dimensional curve with a height that depends on both the distance from the stalk and the size of the apple. After generating Taylor expansions of the height and distance variables in terms of the size, they succeeded in expressing the apple's profile in a self-similar way.

To establish whether real apples also display this self-similarity while approaching a cusp-like singularity, Mahadevan and co-workers rescaled the height and stalk-distance axes using appropriate coefficients and then plotted each apple's profile. They found, as expected, that the measured profiles all overlapped with one another near the cusp – tracing out what they describe as a "universal curve".

(extracted with permission from an item by Edwin Cartlidge at theconversation.com)

Access all areas: The Sakura Samurai group of ethical hackers infiltrated Fermilab's data systems with the knowledge of the lab's managers. (Courtesy: Fermilab/Reidar Hahn))

Ethical hacking group worms its way into Fermilab

A group of "ethical hackers" has obtained access to sensitive systems and proprietary online data hosted by the Fermi National Accelerator Laboratory in the US after accessing multiple unsecured entry points in late April and early May. The group – Sakura Samurai – discovered configuration data for the lab's NoVa experiment and more than 4500 "tickets" for tracking internal projects.

The Sakura Samurai team has previous experience probing the vulnerabilities of scientific and educational organizations, which hold critical information that if leaked could put those institutions at risk. "Fermilab was no different," Sakura Samurai member Robert Willis told Physics World. "Oversharing can be very dangerous, especially when it's sharing credentials that could enable a malicious actor to take over a server with the potential to move across their network to access items that the organization wouldn't even think of being vulnerable."

(extracted with permission from an item by Peter Gwynne at physicsworld.com)

Product News

Coherent Scientific

ContourX Family of Optical Profilometers

The ContourX family of optical profilometers uses numerous advances in Bruker's white light interferometry technology to deliver the industry's most capable benchtop metrology system with easy to use surface measurement software. Available in three models, the ContourX profilers feature new, robust design and provide a range of capabilities and price points optimised to match individual metrology and budget requirements.

New hardware features include an innovative stage design for larger stitching capabilities and a 5MP camera with a 1200x1000 measurement array for lower noise, larger field-of-view, and higher lateral resolution. In addition to the new USI and Advanced PSI modes, software enhancements include Bruker's new VisionXpress interface, which provides simple and intuitive access to the full power of the award-winning Vision64® analytical software suite and makes these profilers ideal for multi-user environments. The latest version of VisionMAP software further complements those features with customised reporting and advanced analysis capabilities.

Offering faster data collection and improved ease-of-use the ContourX systems offer previously unattainable measurement capabilities in a benchtop form.

New Excimer Laser, 248nm, 1.2J

LEAP Excimer Lasers from Coherent deliver a unique combination of high duty-cycle output, outstanding reliability, and low cost-of-ownership. This makes them an ideal source for a diverse range of demanding, high throughput, high precision microprocessing tasks ranging from display fabrication to reel-to-reel manufacturing of superconductive tape.

The new LEAP K 1.25J has been designed to extend the available pulse energy range of the LEAP family, enabling superior field size at the 248nm wavelength.

LEAP lasers are available at wavelengths 193nm, 248nm or 308nm with output powers of up to 300W (and pulse energies of up to 1.25J).

Andor Continuous Flow Helium Cryostat

The OptistatCF-V sample-in-vacuum cryostat from Andor is well suited for experiments requiring a large sample space and minimum number of windows in the optical beam path (reducing reflective losses).

- Lowest helium consumption on the market
- Wide temperature range 2.3K to 500K
- Large sample space enabling studies of sample with a wide range of size and geometry
- Superb optical access (f/0.9) for measurements requiring light collection

For further information please contact;
Coherent Scientific Pty Ltd
sales@coherent.com.au
www.coherent.com.au

Lastek Scientific

The digital Kestrel EMCCD camera from Raptor Photonics

Raptor Photonics has launched a new EMCCD camera, the Kestrel 1000, offering ultra-low readout noise while running at 1,000 frames per second (fps) in full frame and up to 1,800 fps with ROI.

Key features:

- Up to 1,800 frame per second with ROI – The fastest EMCCD on the market
- 128 x 128 Back-thinned EMCCD sensor – Enables optimum image resolution in low light imaging applications
- 16 bit Camera Link output – Realtime imaging for low latency photon to digital image
- Up to 95% QE from back-illuminated sensor – Optimum Photon collection
- Strong VIS and NIR response and ultrawide bandwidth – From 350nm through to 1100nm

New Scale Technologies: What's inside an M3 smart module?

Smart modules and microstages built on the New Scale Technologies M3 (micro-mechatronics) platform incorporate:

- A SQUIGGLE or UTAF piezoelectric micro motor

- A motor driver ASIC
- A position sensor (encoder)
- An on-board microprocessor for PID control
- A customized motion guide assembly and housing to suit your OEM application

You provide simple motion commands over a standard serial interface. It's all inside!

High Finesse Linewidth Analyzer

The HighFinesse Linewidth Analyzers are high-end optical instruments for measuring, analyzing and controlling frequency and intensity noise of laser light sources. By combining an interferometric working principle with ultra-low noise electronics, a superb sensitivity is achieved. The real-time signal output offers the option for a fast feedback loop that can be used to actively reduce the frequency noise of the laser.

HighFinesse LWA-1k series. The 1k models are ultimate high-end optical instruments engineered to analyze and control the frequency noise and lineshape of ultra-narrow lasers. Additionally these instruments offer the option to investigate the relative intensity noise of the laser light source with very high resolution and sensitivity.

Analyzing Options

- Frequency deviation time trace and histogram
- Frequency noise density spectrum
- Intensity noise spectrum
- Laser lineshape spectrum

Effective linewidth:

- Noise at all measured frequencies contributing to the linewidth
- Lorentzian, Gaussian and Voigt fits for lineshape spectra

Intrinsic linewidth:

- Level of noise floor at higher frequencies

For further information, please contact
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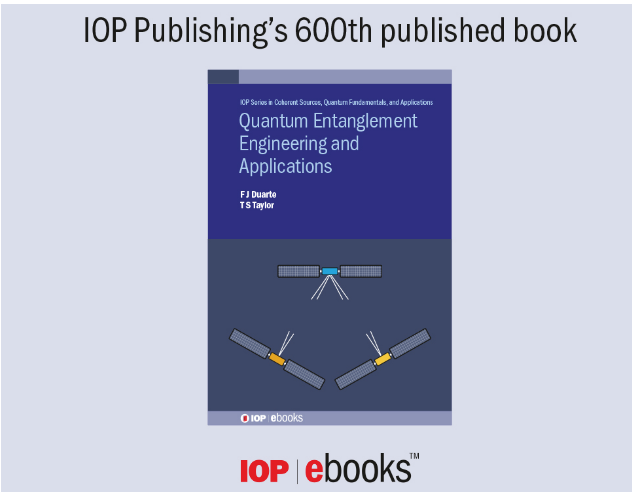
IOP Publishing



IOP ebooks' Milestone

IOP Publishing's ebook collections offer high-quality research across the physical sciences. They have been created to meet the needs of students, early-career researchers and established leaders in the respective fields.

This July we've published our 600th book *Quantum Entanglement Engineering and Applications*, covering one of the most mysterious and yet most promising subjects of current physics.

The Environmental Research Series

IOP Publishing's expanding Environmental Research series offers an evolving suite of fully open access titles covering the most critical areas of environmental science and sustainability. It now comprises of six titles that collectively address all major areas of environmental science, including three ones launched this Oct: Environmental Research: Health (ERH), Environmental Research: Climate (ERCL) and Environmental Research: Ecology (ERE).

The series is aligned with the major international virtual conference, Environmental Research 2021, taking place from 15 to 19 November 2021.

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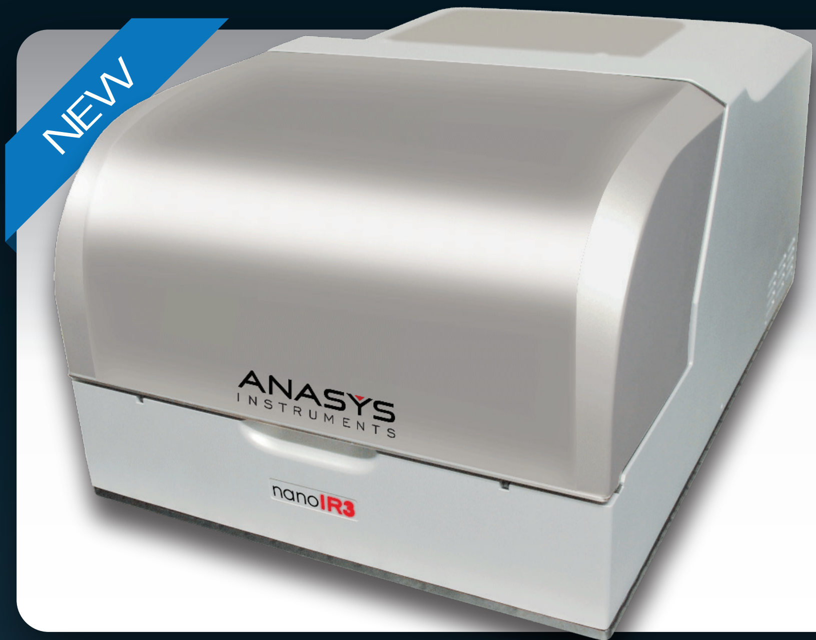
The account benefits range from tagging articles, saving searches and setting up email alerts for new content and citations, to viewing the downloads, articles listed as corresponding authors at a glance.

BRUKER

Surface & Dimensional Analysis



Nanoscale IR Characterisation

Sub-10nm IR chemical imaging resolution

Single monolayer IR spectroscopy sensitivity

Correlated nanoscale property mapping

Matches industrial FTIR databases

Best performance IR spectroscopy and sSNOM in one instrument

Tribology

Comprehensive materials tester for mechanical and tribological properties

Nanoindentation

Highest sensitivity nanoscale to microscale mechanical property measurement and high speed property mapping across the widest range of sample environments

Optical Profiling

High-resolution, non-contact 3D profiling, and fully integrated automated metrology

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