
# Australian Physics

VOLUME 57, NUMBER 4, AUG - SEP 2020


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EXCITONS UNDER THE MICROSCOPE

THE YOUNG PHYSICIST AND NAMES

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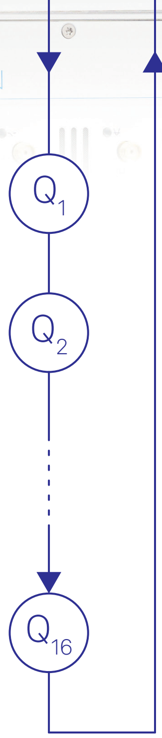


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***The Radio Telescope***

*Section of a larger poster, designed by artist Sean James Cassidy, based on a poem by his aunt Kerrie Peden. This literary caricature became the main element of the poster. Other symbols on the poster refer to the importance of harvest as the Radio Telescope sits amidst farming land. Native animals represent Goobang National Park to the east and hand prints signify the human spirit that has reached out and touched the moon. – This poster is one in a series of three, based on poems by the artist's father and aunt, created to celebrate the 50th anniversary of the moon landing, in which the Parkes Radio Telescope played a vital role. Animated versions of the posters are available at https://ububboexchange.com/films-and-documentaries.*

*(image courtesy Sean James Cassidy, Director – Ub Ubbo Exchange)*

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# EDITORIAL

## Taking a closer look

The front cover of this issue invites you to take a closer look. While the Dish, now heritage listed, gazes into the sky and helps looking at big things like galaxies, it is ultimately also connected to the land it stands on. We are grateful to the artist who gave us permission to use his work and help share the connection with you. See the image caption for more.

We are also having a closer look at lightning in one of our articles, presenting a comprehensive explanation of Ball and Bead lightning.

Looking closely is also often associated with microscopy, and so our second article puts excitons under the microscope. We learn how clever microfluidics can be used to track exciton stages in quantum dots in-situ.

For our young physicists, there is a closer look at naming things; for example, what does Power mean to a physicist? Different associations with the same term in different settings are nothing new; being conscious of how meaning changes is a good idea, though. And if you are familiar with the word "sublimation", then have a look at how it is used in psychology.

Speaking of transformations, Australian Physics keeps changing. Later last year we mentioned that from 2021 onwards there will be four quarterly issues of the magazine per annum. The current year is a stepping stone containing five issues, so expect to see one more coming this year.

As the magazine evolves, you will see new forms of content appear from time to time. In the last issue, we included a poem, and we hope to feature your creative works more regularly – keep them coming to aip_editor@aip.org.au. You will also notice that we have made a minor change to the Samplings section, which is now called "Physics around the World". While only a change to the headline, it reminds us that physics in Australia is not standing in isolation and is embedded in a regional and global context. This is also a reason why we often include the covers of the bulletin of the Association of Asia Pacific Physical Societies, AAPPS. There is a thriving community of physicists in our region who are increasingly linked with developments in Australian science.

Peter Kappen and David Hoxley

# FROM THE EXECUTIVE

## The role of science in the international response to COVID-19 and the imminent cuts to STEM education

The role of science in response to COVID-19 has not been the same in countries around the world. There has been a strong embrace of science, e.g., in some parts of the EU while other countries have taken a more political and less effective approach.

In Australia, the government engaged science in a positive and productive manner. The response to the current second wave is data driven, and this is clearly communicated. Scientists like the Chief Health Officer are in the news every day and data science plays a central role in the communications. The government also hopes to encourage an uptake of science, technology, engineering and maths (STEM) related courses in tertiary education in response to the pandemic and linked economic fallout. It is encouraging to see that job opportunities and STEM skills are currently seen as synonyms, given that science in Australia is at times portrayed more as an enrichment rather than a cornerstone of society and a prosperous career choice.

While the government rolls out rescue programs and embraces the importance of science, it also implements measures to limit spending given the enormous budget impact of the emergency measures. This is understandable since, even though this is a centennial event, the fallout has the potential to develop into a budget deficit that could impact many generations. So, the proposed cuts to tertiary STEM education may, at first, appear justified as all sectors need to contribute. However, the tertiary education sector has been hit exceptionally hard with lost income from international students and no access to support measures, such as JobKeeper. This is leading to changes in workplace structures that include substantial job losses for academics and professional staff at Australian universities.

Australia's university sector operates at the international forefront in research and education. This has been in part financed by internationalisation driven by the aim to create world-leading institutions for research and learning in an environment where government support continually decreased. In the past, this approach has been an immense success story without a major downside. Universities climbed the world rankings by improving educational and research performance. Beyond the tertiary education sector, the impact on Australia in general has been positive due to the diversification and the influx of overseas funds that benefit a broad section of society.

Mid-August this year, the Minister for Education, the Honourable Dan Tehan, released a draft legislation for the so-called "Job-Ready Graduates Package" [1] with substantial implications for university funding, including science funding. The release only allowed for a few days of consultation and the AIP engaged you, the members, for input and submitted a formal response pointing out the double impact and short-sightedness of the package [2].

At the moment the university sector faces a two-punch knockout scenario with the loss in revenue and drafted government funding cuts. In my opinion, programs like the one initiated in the ACT and SA to bring international students back to Australia [3] in a well-controlled manner financed by the universities represent a win-win scenario and should be supported by the government. Initiatives like this would lessen the blow. STEM education cannot sustain further cuts while delivering a high-quality on-campus experience like before COVID-19. This crisis cannot lead to a sustained drop in educational standards in the STEM sector which would hurt the Australian society in the long run. We must all stand up for the university sector and the importance of STEM on the road to recovery.

Sven Rogge, AIP Vice President

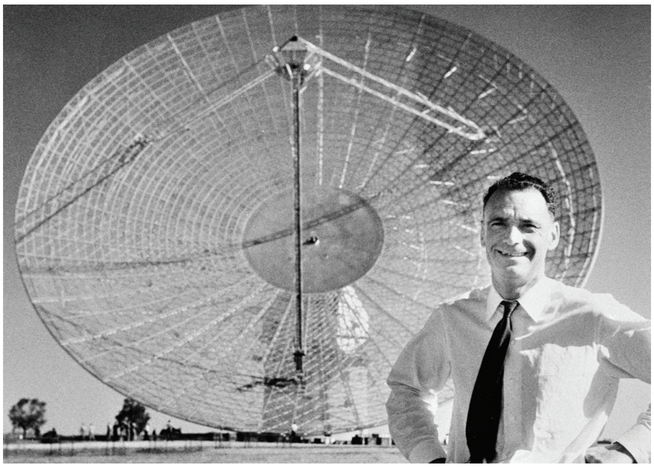

[1] www.dese.gov.au/job-ready/job-ready-graduates-package-draft-legislation-consultation

[2] link to AIP submission

[3] www.abc.net.au/news/2020-06-18/international-uni-students-could-return-to-canberra-proposal/12366876; www.sbs.com.au/language/english/government-reveals-plan-to-re-open-australia-includes-international-student-travel

# The Dish added to National Heritage List

CSIRO's Parkes Radio Telescope has been officially recognised for its contribution to international astronomy, and to our understanding of the Universe, with its addition to the National Heritage List. The telescope, better known as The Dish, has been in operation for nearly 60 years.



**The driving force behind the Parkes dish was Dr 'Taffy' Bowen, Chief of CSIRO's Radiophysics Lab. Parkes was the world's second large dish following the 76 m giant at Jodrell Bank in Cheshire, built by the University of Manchester and completed in 1957 (courtesy CSIRO Radio Astronomy Image Archive).**

The Heritage List of over one hundred sites tells the unique story of Australia from its earliest fossil records, to the long history of Indigenous settlement and through to the places that have made contemporary Australia. The Mayor of Parkes, Councillor Ken Keith, said the local community in Central West NSW is very proud of the telescope. "It holds a special place in all our hearts. The telescope has certainly cemented its position as an iconic attraction for our community and has been pivotal to the growth of the Parkes Shire visitor economy", Cr Keith said.

The construction of the telescope in the late 1950s was very much an international project. Half the funding came from the US Carnegie and Rockefeller Foundations, while the design was carried out by the London engineering firm of Freeman Fox (known for its design of the Sydney Harbour Bridge). The German steelmaker MAN fabricated the components and oversaw the construction of the 64 m diameter dish at the site near the Parkes. The inauguration in October 1961 marked the beginning of 'big science' in Australia.

Among the early triumphs at Parkes were the detection and mapping of the Milky Way's magnetic field, which is a million times weaker than that of the Earth. In 1963 the Dish discovered the first quasar and since then several Parkes quasars have held the record for the most distant object in the Universe detected from earth. Parkes has also played a leading part in the study of pulsars, including the discovery of the first double pulsar system which has enabled stringent tests of Einstein's General Relativity.

Outside of astronomy, the Parkes dish is best known for receiving the TV signals of the first moonwalk by Apollo 11 astronauts Armstrong and Aldrin in July 1969 (see AP 56(3), 44–49). Parkes also provided support for NASA during the following Apollo missions, including the dramatic rescue of Apollo 13.

The main reason for the longevity of the Parkes dish has been continual upgrades to the receivers, electronics and computing power. The accuracy of its parabolic surface has also been improved several times to allow operation at shorter wavelengths. The sensitivity of the telescope is now 10,000 times greater than it was in 1961.

**The Parkes Observatory joins the Australian Academy of Science dome building in Canberra as the only two scientific structures on the National Heritage List (courtesy CSIRO/Alex Cherny).**

In 2007 Parkes data led to the discovery of the first 'fast radio burst' – an incredibly intense burst of radio energy, lasting only a few milliseconds and coming from an unknown source at cosmological distances. The detection and study of FRBs is now one of the hot topics in astronomy. The addition of the 'grand old lady' of Australian radio astronomy to the National Heritage List has been welcomed by the astronomical community.

**(Peter Robertson, The University of Melbourne)**

# Excitons under the microscope: Uncovering the fundamentals of quantum dot synthesis *in situ*

**Susanne Seibt**
**SAXS/WAXS Beamline Scientist, Australian Synchrotron, ANSTO, Victoria – seibts@ansto.gov.au**

***Nanoparticles from semiconducting materials, widely referred to as quantum dots (QDs), show an increasing impact on the scientific world, as well as our daily lives. To date, however, the mechanism underlying their synthesis remains a mystery. The fast reaction kinetics of their synthesis necessitates a new approach to understand how QDs form and grow. Here, we present microfluidics as a powerful tool, using hydrodynamic flow-focusing, to access insights in the nucleation and growth of nanoparticles.***

Over the last two decades, the unique properties of quantum dots have led to their use in various widespread applications. Today, they find uses in photovoltaics, solar cells, photodetectors, quantum light-emitting diodes, as well as biomarkers for bio-labelling [1,2]. One of the most important aspects which controls their chemical and physical properties, is the size and shape of the nanocrystal [3]. The chemistry and physics of colloidal semiconductors, in particular how they interact with light, is of intense interest, such that in 2017 the Australian Research Council funded the Centre of Excellence in Exciton Science, dedicated to finding innovative solutions for renewable energy, partly through the study of the properties of QDs [4].

## What is an exciton?

The size dependent properties of quantum dots arise from a confinement effect. This quantum confinement is a result of changes in the density of electronic states which arise when the nanoparticle size becomes comparable to the Bohr radius of the excitons in the bulk material [1]. But what exactly is an exciton?

An exciton is formed when a single particle of light, a photon, is absorbed by an atom. The photon elevates an electron within the atom to a higher energy level, leaving a positively charged hole behind. The resulting electron-hole pair, which is bound together through charge attraction is termed an *exciton*. Excitons play a central role in the conversion of light into energy and energy into light. They typically live for only a few nanoseconds before the electron jumps back to the orbital it vacated. During this recombination process the electron releases the energy absorbed from the photon [4]. The released energy can be detected, for example as visible light (luminescence) or heat. An alternative to recombination is the diffusion of excitons along a molecule by transferring the energy to a neighbouring atom. This process is key to application in novel photovoltaics, flexible solar cells, or energy efficient LEDs.

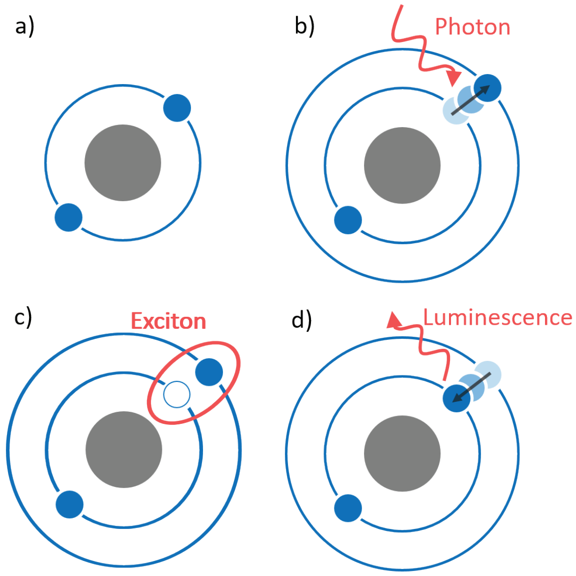



**Figure 1: Simplified scheme of the formation and destruction of an exciton. (a) Simplified atom with negatively charged electrons (blue) orbiting a positively charged nucleus (grey). (b) Excitation process by an incoming photon (red), lifting the electron to a higher energy level. (c) Formation of an exciton, the bound electron-hole pair. (d) Recombination process of the electron relaxing to the initial energy level through energy release.**

To engineer the size and properties of quantum dots, a multitude of synthetic routes has been developed for batch-processing nanoparticles of different materials. However, as a consequence of their often fast reaction kinetics, the fundamental synthesis mechanisms of nucleation and growth are relatively unknown [5].

## Microfluidics – the magnifying glass

As a platform developed in the 1970s, microfluidics looks at the behaviour of gases and liquids at the length scale of up to several hundred micrometres. In this regime laminar flow, and thus viscous forces, normally dominate. One of the most important benefits of microfluidics is the ability to perform quantitative and qualitative analysis with high sensitivity and temporal resolution while only needing a small amount of substance. Its real breakthrough came with the development of rapid prototyping [6].

The physics of fluid dynamics at the micro-scale is significantly to that of fluids at the macro-scale. While inertial forces are dominant in turbulent flow, in laminar flow regimes, as present in microfluidics, viscous forces are more prominent [10]. To show the relation of inertial and viscous forces, the Reynolds number (Re), as a dimensionless number, is defined as

$$Re \equiv \frac{\text{inertial forces}}{\text{viscous forces}} = \frac{|\rho(u.\nabla)u|}{|\eta\nabla^2 u|} = \frac{\rho v}{\eta} d \quad (1)$$

where $\varrho$ is the fluid density, $\eta$ the viscosity of the fluid, $u$ is the vector of the fluid flow, $\nabla$ is the Nabla-Operator, $v$ is the flow velocity and $d$ is the characteristic length of the system. In microfluidics $d$ is typically the channel diameter, becoming smaller with decreasing size of the system. Microfluidic regimes are dominated by very low Reynolds numbers. The typical threshold between laminar and turbulent flow lies around Reynolds numbers of $Re = 2040$.

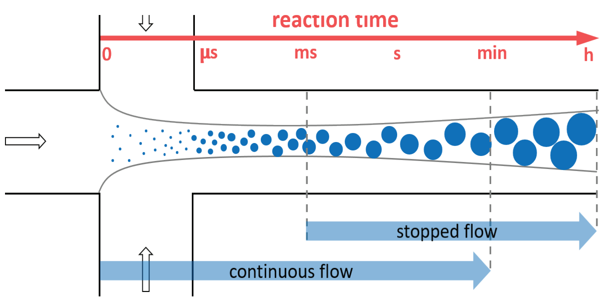



**Figure 2: Schematic comparison of the provided time scales in continuous and stopped flow microfluidic devices. Top view of a microfluidic channel design with one main channel and two side channels for hydrodynamic focusing in flow. The white arrows indicate the flow directions of liquids introduced in the channels.**

Apart from droplet-based microfluidic experiments, two fundamental methods can be used to study fast reaction kinetics: stopped and continuous flow (Fig. 2), giving access to a wide temporal range for studying a process, from nanoseconds to hours. In these experiments, the time axis of the reaction is transformed into a distance axis along the outlet channel of the microfluidic channel, providing a position in the device for every point during the reaction [7].

For fast nanoparticle reaction kinetics, continuous flow can provide time-resolution down to nanoseconds, depending on device design and flow velocity, making the investigation of nucleation and growth stages of nanocrystals possible. To further define the onset point of the reaction, hydrodynamic focusing devices can be employed, restricting mixing to diffusion and improving the quality of synthesised products [7,8]. There are two categories of hydrodynamic flow focusing devices: coaxial tube and on-chip planar devices. The latter can be in a two-dimensional or three-dimensional geometry, depending on their horizontal and vertical compression of the central flow away from the channel walls [8]. A completely different, pioneering approach to investigate fast reaction kinetics of nucleation and growth with microfluidics employs free-jet setups [9].

## Combining the puzzle pieces

Instead of sampling aliquots out of a batch reaction solution to monitor reaction conditions during a synthesis, microfluidics has emerged as a powerful tool to access QD synthesis parameters *in situ*, that is, in real time and without disruping nanoparticle growth [11]. There are several examples of micro reactors for nanoparticle synthesis, ranging from simple Y-shaped devices coupled to tubing to much more complicated multi-component mixing systems. The simplest approach to microscale synthesis of QDs is a two-dimensional Y-shaped microfluidic device preceding a mixer (Fig. 3a), as applied to the high temperature synthesis of CdSe and CdSe/ZnS nanoparticles [12]. The advantage of this setup is the exact control of temperature and heating time, as this can be well defined by the flowrate, tube length and temperature of the external heating unit. However, *in situ* measurements during such high temperature synthesis are challenging as the heating mechanism normally encloses the channel completely and prevents optical access to the reaction stream.

For a spatially resolved synthesis approach in microfluidics, Sounart et al. showed the use of a Y-shaped two-dimensional design, following the synthesis of CdS nanoparticles within the microfluidic channel (Fig. 3b) [13]. As this synthesis is at ambient temperature, *in situ*

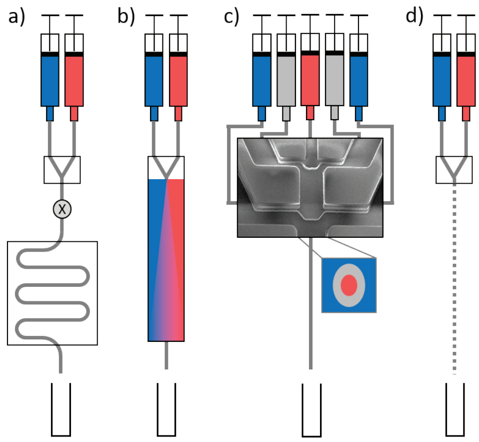



**Figure 3: Schematic layout of the different microfluidic setups, adapted from [12, 13, 17, 18]. (a) The two precursor solutions are pumped through a Y-shaped microfluidic device into a convective mixer before flown through a heated PTFE tube. (b) The two precursor solutions flow through a continuous flow microfluidic device, growing nanocrystals at the boundary of the two laminar streams. (c) Two precursor solutions and an inert buffer are pumped into a three-dimensional hydrodynamic focusing device, showing the flow profile in the cross-section. Reaction occurs through interdiffusion of the reactants along the channel. (d) The precursor solutions are brought together in a Y-shaped micro-mixer before being ejected as a continuous free jet.**

fluorescence showed the growth of particles through interdiffusion of reactants. This provided access to the fast reaction kinetics of quantum dots nucleation and growth. However, *in situ* measurements of high temperature syntheses are not possible with this method.

Devices for simultaneously measuring both optical (absorption and emission spectroscopy) and structural properties (small and wide angle X-ray scattering) during a heated nanoparticle synthesis for metal [14] and semiconductor [15] nanoparticles in microfluidic chips were developed. To meet the requirements for both optical and X-ray scattering measurements, a hybrid device of a Y-shaped microfluidic mixer and a quartz capillary has been developed to reduce the scattering background from more commonly used polymeric materials, as well as increasing the heat transfer capacity. To achieve the required synthesis temperature, a special copper heating tube setup was employed, through which the nanoparticle synthesis could be measured. In this case, stopped flow was used to achieve a dead time of approximately 1.3 seconds.

In the channel geometries shown in Figure 3 (a) and (b), the interface of reaction solutions is in contact to channel walls, which can be disadvantageous as it often leads to sticking and agglomeration of formed particles on the wall surface. This might not interfere with the laminar flow conditions, however it is a problem for analytical investigations as they need to be performed through the adsorbed material. The worst case scenario in this regard would be a completely blocked channel, leading to leaking and abortion of the experiment. Therefore, three-dimensional flow focusing devices, introducing a buffer layer between reactants and focussing the central stream fully enclosed in the channel centre, have been shown to avoid wall contact during mixing and reaction of components (Fig. 3c) [16,17]. Furthermore, the three-dimensional buffer layer brings the advantage of a well-defined point of first contact of reactants, which provides the possibility to extract rate constants for reactions occurring through interdiffusion along the outlet channel. This was first demonstrated by our experiments with fluorescent hydrogelators in 2018 [16].

These three-dimensional focussing devices are especially useful for nanoparticle growth and nucleation, as they prevent particle aggregates, which could act as a seed for heterogeneous nucleation. This was shown with great success in form of a hybrid device (Fig. 4b), a combination of all-PDMS (polydimethylsiloxane) multilayer device and laser-cut glass capillaries (Fig. 4a), to provide complete optical and X-ray transparency. An ambient temperature CdS synthesis was used as an example for in situ absorption and emission spectroscopy, as well as in situ confocal laser scanning microscopy (CLSM) studies to directly access millisecond timescale reaction kinetics (Fig. 4c) [17].

Figure 4a shows an optical microscopy image of this hybrid microfluidics device. The hydrodynamic focusing can be achieved through the mixing cross section, while the focused flow profile with inter-diffusing reactants remains undisturbed in the inserted glass capillary but can be accessed by both optical and X-ray measurements. A photograph of the hybrid device is shown in Fig. 4b, demonstrating the small dimensions and preciseness necessary for device fabrication. The transition from PDMS to glass capillary back to PDMS (for stability reasons) can clearly be seen. The arrows indicate three positions where three-dimensional CLSM scans at different times (via measuring at different positions along the outlet channel) during the synthesis were taken, shown in Fig. 4c (top). By rotating the 3D stacks 90 degrees, the focusing and channel (capillary) dimensions become visible (Fig. 4c bottom). The growing CdS nanocrystals along the capillary can be seen in form of a circularly focused, fluorescent stream in the centre. During the dura-

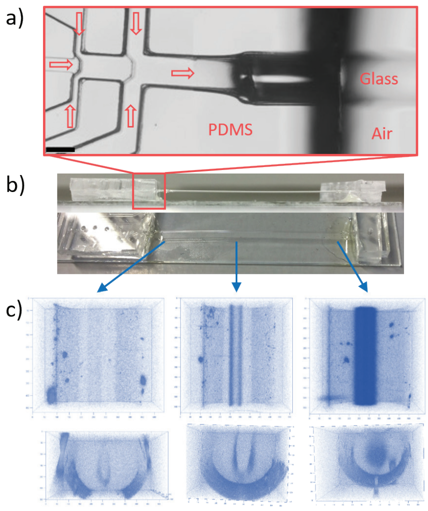



**Figure 4: (a) Optical microscopy image of the hybrid PDMS-glass device. The three-dimensional double focusing mixing crosses in the PDMS part merge the downstream channel with the inserted laser-cut glass capillary. The PDMS cut-off edge is shown by the dark vertical line. The arrows indicate the flow direction in all channels. (b) Photograph of the hybrid microfluidic device on a glass substrate from the side (top) and the top view (bottom). (c) Single three-dimensional CLSM images in top and front view of three positions at the beginning (left), the middle (centre) and the end (right) of the capillary during a CdS synthesis. The circular profile of the growing QDs from gradual interdiffusion of the reactant solutions in the centre of the capillary is visible. Figures adapted from [17]**

tion of the synthesis the complete interdiffusion can be followed until a fully photoluminescent central stream can be seen (Fig. 4c right). The surrounding glass from the capillary appears in form of a ring as a result of inelastic scattering of the incoming laser light on the silica glass [5].

This device design opens possibilities for uncovering the fundamental kinetics behind a multitude of QD syntheses, as it can be combined with the heating setup shown by Chen et al. [14]. as well as X-ray scattering studies similar to Herbst et al. [15].

To avoid the restrictions of channel walls during the nucleation and growth reaction of QD nanocrystals, Schiener et al. developed a free-jet setup, consisting of a Y-shaped micro-mixer with a short exit nozzle, producing a jet of mixed reactants with controllable diameter [9]. The formation of QDs along the continuous free-jet can then be followed *in situ* by small and wide angle X-ray scattering. In combination with *ab initio* calculations, the species of the smallest formed clusters and the formation mechanism of CdS QDs could be derived.

## A peek into quantum dot kinetics

Looking deeper into the nucleation and growth kinetics of QDs, Rempel et al. [17] provided a detailed study of tracking the temporal evolution of the cluster size distribution from small nuclei through the whole growth process. This allowed the authors to compute experimental observables, such as mean size and distribution at every point during the synthesis. Furthermore, they found an optimum of high temperature exposure time and additive concentration, aiming to minimise the polydispersity of the final solution [16]. When regarding an *n*-sized cluster, $C_n$, the growth and dissociation reactions from monomer attachment and detachment, respectively, are defined by:

$$C_n + C_1 \underset{D_{n+1}}{\overset{G_n}{\rightleftharpoons}} C_{n+1} \qquad (2)$$

where $G_n$ and $D_n$ are the time dependent growth transition frequency for monomer attachment and dissociation transition frequencies for monomer detachment. The free ligand concentration in solution is several orders of magnitude higher than the amount of nanocrystals. By assuming that the free ligand concentration stays approximately constant during the reaction and that the nanocrystals are spherical, $G_n$ and $D_n$ can be described by:

$$G_n = k_a n^{2/3} C_1 \qquad (3)$$

$$D_n = k_d n^{2/3} \qquad (4)$$

with $k_a$ and $k_d$ as effective rate constants, including the intrinsic rate of monomer addition and dissociation and several invariable terms [17].

When incorporating diffusion limitations into growth rate expressions modelled from the terms defined in equations 2, 3, and 4, the growth rate becomes proportional to the radius of the nanocrystal, rather than the available surface area. Hence, the diffusion limited growth rate, $g_{n,D}$, is

$$g_{n,D} = a_D n^{1/3} c_1 \qquad (5)$$

where $c_n$ is the scaled cluster concentration ( $c_n = (C_n)/(P_0)$ ). The scaled parameter for addition via diffusion is defined as:

$$a_D = \frac{k_{a,D}P_0}{k_f} \quad (6)$$

with $k_f$ as the rate constant for the change of precursor and $P_0$ as the initial precursor concentration. The effective addition rate can then be defined as:

$$k_{a,D} = 4\pi N_A D_{c_1} \left(\frac{3}{4\pi\rho}\right)^{1/3} \quad (7)$$

where $D_{C1}$ is the monomer diffusivity and $\varrho$ is the material number density. Even derivations for limit cases, such as for slow diffusion, are possible, assuming the concentration of the monomer at the growth site is pseudo steady [17]. This tells us that nanocrystal nuclei grow directly proportional to the diffusion coefficient of the monomer, which is in line with experimental observations in microfluidic setups [5].

## Conclusion

For their application, the size dependency of QDs is a vital part for conversing light to energy or energy to light. With microfluidics, this feature, provided by excitons, can be used as a simple access tool to follow the synthesis of semiconductor nanoparticles from as early as sub-nanometre nuclei to the final grown nanocrystals. Understanding the materials in which excitons form, and the ability to control excitons, are key steps to all commercial applications of quantum dots. Using microfluidics as a magnifying glass into the separate stages of nanorcrystal synthesis and the influence of reaction parameters proves to have a crucial role in providing otherwise inaccessible inside knowledge on fast growth reactions.

Microfluidics is a novel platform to gain access to *in situ* measurements of the nucleation and growth processes of very fast reactions, such as those employed in quantum dot syntheses. By combining advanced synthesis routes with novel three-dimensional hydrodynamic focusing devices, we can gain insights into the early stages of reactions by spectroscopic and scattering methods. Even heated reactions over a wide range of temperatures can be adapted to the microfluidic *in situ* setup, enabling investigations over the complete time scale from seconds to days. Applying detailed nucleation and growth mechanisms on a variety of QD syntheses leads to a higher quality production of nanocrystals with tailored properties for a multitude of applications.

## About the author

Dr Susanne Seibt works as a Beamline Scientist at the SAXS/WAXS beamline of the Australian Synchrotron at ANSTO. She received her PhD jointly from the University of Bayreuth, Germany and the University of Melbourne, Australia, where she was part of the ARC Centre of Excellence in Exciton Science in the group of the director, Prof Paul Mulvaney. Susanne has a broad experience of microfluidics, using it as a tool for in situ investigation of nucleation and growth of nanoparticles and self-assembly of molecules as part of her PhD, for orientation in flow and spray of anisotropic particles as free jet, as well as for tracking the hydrogen production and storage in proton batteries during her postdoctoral research fellowship at RMIT University.

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# A New Comprehensive Theory for Ball and Bead Lightning

**Richard Morrow**
**Research Affiliate, School of Physics, The University of Sydney, NSW, Australia – richard.morrow@sydney.edu.au**

*Ball and bead lightning originate from a lightning channel that has been expanded, then snipped into plasma sections by the pinch effect of a secondary discharge. The individual balls have a net positive charge which drives positive charges from the centre, and negative charges towards the centre, until a plasma structure is formed which can be stable for more than 10 s. Burning negative solid particles are trapped inside the plasma balls and produce the light output of various colours, and explain many observations. Without the burning particles phantom plasma balls are produced.*

## Introduction

Ball and bead lightning are wide, distributed, luminous plasmas generally associated with a lightning strike [1, 2]. Ball lightning appears in the form of a luminous sphere 0.1 to 1 m in diameter lasting for 10 to 30 s, while bead lightning consists of a series of similar spheres or elongated luminous sections along a lightning channel lasting about 1 s (see Figure 6.) [1, 2]. Very few people have seen these phenomena; however, there have been sufficient observations in the last 200 years for several books and several recent review papers to be written on the subject [3, 4, 5, 6]. The author has a friend who saw ball lightning as a child in Indonesia [7], and the author himself has seen bead lightning once.

Ball and bead lightning have never been convincingly produced in the laboratory. This is despite the existence of many impulse generators in high voltage laboratories around the world designed to simulate lightning strikes in order to test high voltage equipment [8]. Also, experiments using extremely high current arcs at Liverpool University and The Culham Laboratories in the UK never produced a wide, distributed plasma as found in ball and bead lightning [9]. All the experiments above produce a narrow filamentary discharge; the high current is confined by the "magnetic pinch effect" [1]. Bead lightning has been observed during triggered lightning strikes, which is of course real lightning rather than a laboratory simulation, and the significance of this observation will be discussed below.

Following the theory outlined below, a method of generation of ball lightning in the laboratory, based on that theory, is proposed.

## Theories of Ball lightning

Many theories have been put forward for ball lightning involving a variety of different mechanisms: electrical, chemical, nuclear, vortices, radio frequency radiation, relativistic electrons that trigger a microwave bubble, and a silicon chain burning theory [10]. A relatively recent review of ball lightning theories has been presented by Donoso et al. [31]. None of these theories explain the origin of an extended plasma ball from a lightning strike, nor the longevity (~ 10 s) and stability of ball lightning. A comprehensive theory must explain the following properties of ball and bead lightning:

- The origin of a large-diameter, distributed plasma from a lightning strike.
- The segmentation of such a plasma into balls and elongated segments of bead lightning.
- The longevity of ball and bead lightning (1 – 10 s).
- The light output from ball and bead lightning.
- The different colours observed for ball lightning.
- The different appearances of the surface of ball lightning.
- The appearance of streamer-like streaks inside and outside ball lightning.
- The burning marks observed when ball lightning hits a wooden object.
- The dusty brown residue left when ball lightning dies.

Such a comprehensive theory has recently been developed by the author in a series of four papers [10, 11, 12, 13]. Thus, it is necessary to draw all the related concepts developed into a single concise article, leaving the interested reader to find the computational details in the original papers.

## The Origin of an Extended Plasma Region from a Lightning Strike

In order to understand the development of an extended plasma region it was necessary to develop a new theory for the expansion of lightning channels [12]. The methodology used is the same as that used successfully to describe streamer propagation and positive glow corona in air: the simultaneous solution in time of Poisson's equation with the continuity equations for positive ions, negative ions, electrons and oxygen metastable molecules [14, 15]. The equations include the effects of ionization, attachment, detachment, electron and ion diffusion, recombination and photoionization. The calculations were performed in cylindrical coordinates with variations only in the radial dimension; the results therefore apply to the entire length of the channel at all angles about the axis.

Due to the very high mobility of electrons the channel is left with a net positive charge during the first lightning discharge [12, 14, 16]. While the lightning current flows the charges are confined to a narrow channel by the "magnetic pinch effect" [1]. If the current stops abruptly, which is known to happen [12] (possibly due to a discharge in another part of the cloud) the space-charge effect of the excess positive charge causes an ionizing wave to propagate out radially. In the case considered in [12] the ionizing wave propagates out to a diameter of 3 m in 3 μs. The diameter attained by the channel is directly related to the net excess positive charge. The ionizing wave is a new phenomenon, not a streamer.

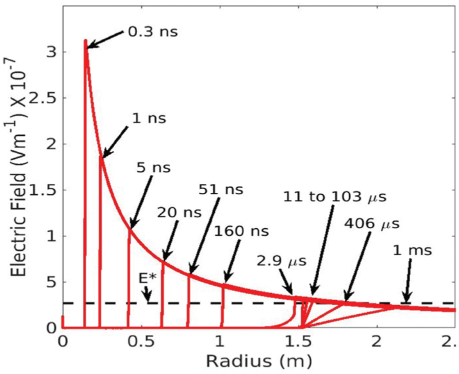


**Figure 1: Electric field as a function of radius for a lightning channel (from [12]). E* is the electric field where ionization equals attachment.**

The electric field calculated as a function of radius and time for one case [12] is shown in Figure 1 where the ionizing wave propagates while the radial electric field is above E*, the field where ionization equals attachment. The ionization wave stops after ~ 3 μs propagating to a radius of ~1.5 m.

Examples of such an expanded lightning channel are shown in Figures 2 a) and b). In each photo there are telegraph poles from which a scale can be obtained and the diameters of the channels can be estimated; for

A B

**Figure 2: Photographs of lightning strikes. (a) Famous 1.4 m wide lightning strike "The Sword of God" (Reproduced with permission from Johnny Autery [17]); (b) 12 m wide lightning channel. (Image Courtesy: Mitchell Krog - mitchellkrog.com , "Monumental Chaos/ Lightning Strikes over Voortreker Monument in Pretoria, South Africa" [18]).**

Figure 2 a) the diameter is estimated to be around 1.4 m, while for Figure 2 b) the diameter is estimated to be around 12 m.

## The Segmentation of Lightning Channel

The expanded lightning channels of Figure 2 are very bright. Radiation from the ionizing wave and the neutralization of positive ions are not sufficient to account for this brightness [12]. It was proposed that the expanded channels are illuminated by secondary lightning discharges that propagate down such channels [12]. This proposition is supported by the photograph of a "Pinched Lightning Channel" by Matthias and Buchsbaum [19], presented in Figure 3. They estimate a diameter of 1 to 5 m for the channel, supporting the expanded channel theory. Also, they find the channel to be much brighter than a normal lightning channel, supporting the secondary discharge proposal. Most importantly, they find that the channel is pinched in various places due to a large axial current which causes a "sausage instability" [20].

Thus, it is clear that the distributed plasma required for ball and bead lightning is produced by an ionizing wave expanding a lightning channel, and that the segments and balls of plasma are produced by a secondary lightning discharge which pinches the expanded channel into segments.

## The Structure and Longevity of Ball and Bead Lightning

Having established that extended plasma balls and elongated segments can be produced from an expanded lightning channel it is then necessary to determine the structure of such plasma balls and how they can exist for up to 10 s or more.

**Figure 3. Photograph of "Pinched Lightning" from Matthias and Buchsbaum [19], reproduced here with permission.**

Most ball lightning is observed to be spherical and this was the most convenient geometry in which to examine the structures numerically [10, 11]. Thus, the continuity equations mentioned above, adjusted to be in spherical geometry, were solved only in the radial coordinate to describe the evolution of a ball of plasma with an excess of positive ions, as for the lightning channel [10, 11].

The net positive charge is crucial to the structure of ball lightning as follows: the net positive charge creates a space-charge electric field that drives the positive ions away from the centre of the ball, essentially repelling each other. This same space-charge electric field drives the negative charges, electrons and negative ions towards the centre of the ball. This charge movement continues with the net positive charge decreasing at the centre and the net negative charge increasing until the net charge at the centre is zero; the space-charge field goes to zero, and the ions stop moving. This central neutral plasma region is the core of the ball lightning, and it is surrounded by a uniform distribution of positive ions still being driven away from the centre by mutual repulsion [10, 11].

Figure 4(a) shows the movement of charges for the first 200 μs from the data presented in [10]. Note that the ion densities almost overlap in the central region after 200 μs. Similarly Figure 4 b) shows the changes in the electric field distribution, and the electric field is close to zero in the central region after 200 μs. At later times the ion distributions in the central region exactly overlap, and the electric field is essentially zero, as shown in Figure 5.

The distributions of positive ions and negative ions 1, 2, and 10 s after the start of the calculations are shown in Figure 5 (reproduced from Figure 6 of [10]). Figure 5 a) shows that the positive and negative ion distributions completely overlap in the central region, with some rounding of the curve due to the effects of ion diffusion which is included for both species. The external ion distribution remains flat and decreases with time as discussed in detail in [10]. The central plasma density decreases steadily with time due to ion neutralization according to the equation derived by Morrow [11] :

where $N_p$ is the positive ion density at time $t$ after the initiation of the ball lightning structure, and $\beta$ is the ion neutralization or recombination coefficient.

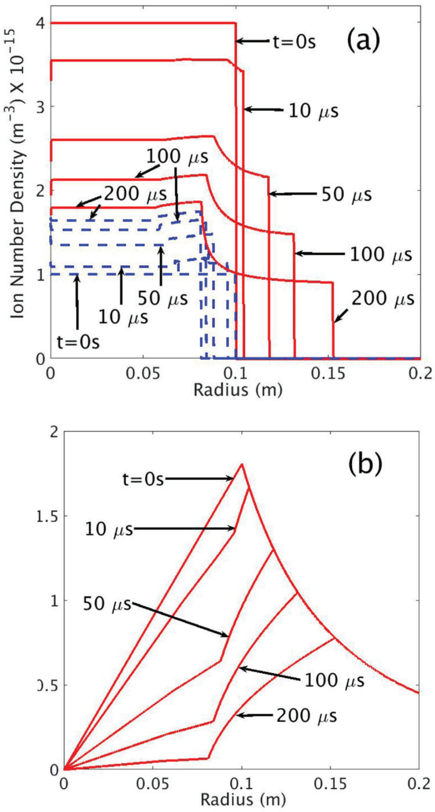


**Figure 4. The motion of a ball of positive ions and a minority of negative ions under the action of space-charge effects: (a) positive ion density distributions represented by the solid 'red' curves and the minority negative ion density represented by the dashed 'blue' curves, with times shown in μs; (b) the corresponding electric field distributions at those times. Reproduced from [10].**

The electric field is essentially zero in the central region as shown in Figure 5 (b), with a rising electric field outside the central region due to the mutual repulsion of the excess positive ions which are still steadily moving away.

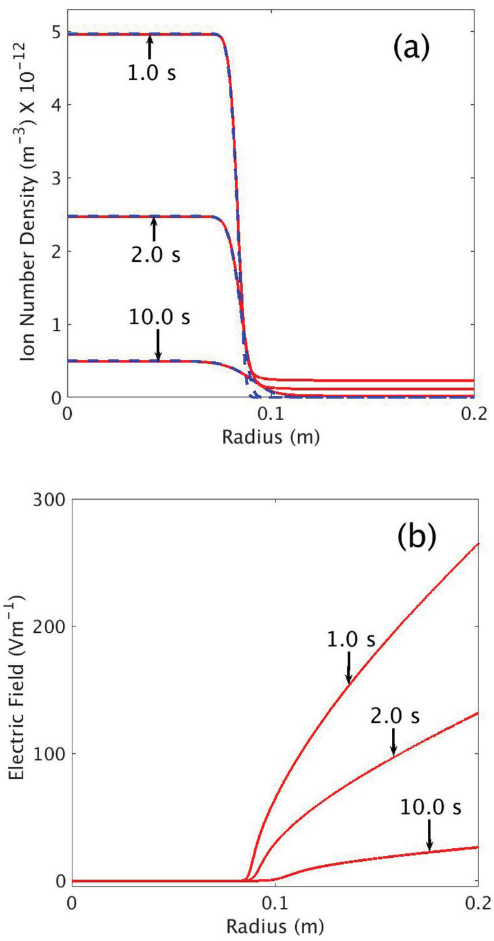


**Figure 5. The plasma ball structure from 1 s to 10 s. (a) The positive ion density distribution (solid 'red' lines) and negative ion density (dashed 'blue' lines) at times 1, 2, and 10 seconds after the start of the calculation. (b) The corresponding electric field distributions.**

Figure 5 shows that the ball lightning structure is very stable for 10 s and longer. The only factors changing the central ion distribution are ion neutralization and ion diffusion which are very slow. Outside the plasma region the positive ions maintain a flat distribution due to mutual repulsion and continue to move well beyond the centre [10, 11].

$$N_p(t) = \frac{1}{t\beta} , \qquad (1)$$

## Light Output from Ball and Bead Lightning

One of the most important aspects of ball and bead lightning is the light output which most observers say is relatively constant over the lifetime of the phenomenon [1, 2, 3, 4, 7]. While the size of ball lightning and intensity and colour of the light output can vary considerably, the most common observation describes the light output as being equivalent to a 60 W incandescent lamp [11]; this equates to about 1 W of actual light power output.

The light output due to positive ion neutralization is shown to be inadequate to account for the brightness of ball lightning [11]. Only at times much less than 1 ms is the output above 1 W; the output then decays rapidly and becomes many orders of magnitude below this level [11].

Thus, ball and bead lightning structures can exist with no light output at all; these were christened "Phantom Plasma Balls" by Morrow [10]. So, ball and bead lightning may be far more common than realized; if phantom plasma balls are produced by a lightning strike and last for 10 s or more, who would know?

The means by which such phantom plasma balls are made visible must therefore be considered.

## Light Output due to Ion Neutralization and Phantom Plasma Balls

Theories for the light output of ball lightning involving burning solid particles have been proposed previously, e.g. burning silicon chains (Abrahamson and Dinniss [21]) or dusty plasmas (Smirnov [22]); however, none of these theories provide a convincing mechanism for the burning particles staying together in a ball.

There is evidence for ball lightning being fuelled by burning particles from the soil. The spectra of various metal ions from the soil were measured during the ball lightning observations of Cen, Yuan, and Xue [26]. The generation of metal ions during a lightning strike has been explained by Abrahamson and Dinniss [21] and Abrahamson [23] as being due to the reduction of metal oxides by carbon from carbon material in the soil (as with the refining of silicon metal). These metals can then oxidise to produce the light output of ball lightning and the observed spectra of metal ions discussed below.

An ingenious method of getting the soil particles into the region of the plasma ball is described by Abahamson and Denniss [21]; the lightning strike creates a channel in the soil called a fulgurite cavity which is full of hot gas, reacting oxides and carbon particles during the lightning current flow; as soon as the current ceases a jet of hot gas and soil particles rises into the air to be trapped inside the plasma ball [13].

It was proposed by Morrow [11] that the particles are ignited and become highly-charged by the lightning strike; the particles then become trapped by the electrostatic field of a phantom plasma ball. The electrostatic field of a plasma ball is shown in Figure 5 b); the electric field is zero near the centre and rises positively beyond the boundary of the plasma ball [11].The positive field drives positive ions and particles from beyond the boundary of the plasma region away from the centre; negative particles beyond the plasma boundary are driven back to the boundary and into the central region. Thus, negative burning particles of a suitable size and charge attempting to leave the neutral plasma region will be driven back into the central region and not escape. Positive particles can escape once they reach the boundary. The phantom plasma ball is an electrostatic trap for negative particles; if the particles are burning then the ball will be luminous and no longer a phantom.

Calculations were made to determine the electric field required to retain negatively charged particles within the plasma ball [11]; for particles of mass 10-18 to 10-7 kg electric field strengths of 10 to 200 V/m were sufficient to contain such particles [11]. The electric field for the plasma ball studied in Figure 5 b) can easily contain negatively charged burning particle for times 1 to 10 s.

The composition and size of the burning particles must vary considerably from case to case. Thus, a set of small particles would generate light output that has a well-defined edge, as described by Berg [7], because they are easily repelled at the plasma boundary by a small electric field. Larger particles would move further from the edge of the plasma until they reach an electric field strong enough to repel them; the ball lightning would appear fuzzy as reported by some observers [3, 6].

The colour of ball lightning varies over a considerable range [2, 24]; this can be traced to metallic elements from the soil caught up in the burning particle material as described above. The elements Li, Na, K, Rb, Cs, Ca, Sr, Ba, Cu and Pb produce the following colours in a flame; red, orange, lilac, red, blue-violet, orange-red, red, pale green, blue-green and greyish-white respectively [25]. All these colours have been observed for ball lightning and this provides evidence of these metals being present amongst the burning particles in ball lightning. Note that the spectra of Ca, Fe, and Si were observed by Cen, Yuan, and Xue [26] when making direct measuremnts of the spectra of ball lightning.

Consideration of the burning of small coal particles (Smirnov [27]) leads to the conclusion that typical 'burnout' times are long enough to account for the lifetime of the light output from ball lightning. Only a few hundred coal particles are required to produce the 1 W of light output for ball lightning. A total energy output of ~ 60 W would account for the lack of heat output reported for ball lightning [2, 3, 4], and the gas inside ball lightning cannot be very hot because buoyancy considerations would make the ball rise rapidly [28].

The most compelling evidence for fine particles being involved in the light output from ball lightning are the many reports of a cloud of brown dust released after a ball lightning event ceases [1, 3, 4]. There are also many reports of burn marks left after ball lighting strikes an object [3, 4]; these are consistent with burning particles. Further, reports of streamer-like objects within the ball [29], or of a ball having "the appearance of being 'spun' or 'fuzzy' like silk threads or wool" [2] could be explained by larger burning particles moving inside the plasma ball. The small external streamers reported [3, 4] may be caused by burning positive particles escaping the ball region and being driven away while they still burn.

## Bead Lightning Illumination

Bead lightning consists of spheres or elongated luminous sections along a lightning channel lasting about 1 s, as shown in Figure 6. For visible bead lightning to be produced some form of fuel must be introduced and ignited in the segmented plasma regions high in the lightning channel. (Such fuel cannot come from the soil.) In the case of rocket-induced lightning, bead lightning is known to occur [1, 2]; the fuel is provided by the metal wire exploding into fine droplets of metal which

**Figure 6. Bead lightning from a meteorology photo on the web [30] ], reproduced with the permission of Phil Krider at krider@arizona.edu.**

burn and provide the observed light output. In other cases, the fuel may be provided by dense smoke which can contain carbon particles and other organic materials that could be ignited. However, such fuel will in general be less dense than the material from soil so the lifetime of the illuminated regions will be shorter. This was the case for the bead lightning observed by the author; the light output from a string of beads lasted ~ 1 s. Note that the famous woodcut of ball lightning appearing down the chimney of a farmhouse (Figure 1.2 in [22]) could have been fuelled by the smoke from the fireplace.

## Two-Dimensional Dynamics of Ball Lightning

A two-dimensional calculation is required to study effects such as the evolution of an extended segment of a lightning channel into a ball of plasma, or the influence of electric fields and the presence of conductors on ball lightning. Such calculations are beyond the scope of this paper. However, such a calculation is being developed by the author and one observation can be made: the ball lightning structure is largely neutrally charged. Thus, an electric field will not physically move the ball lightning; it will merely distort and polarize the plasma structure.

## Experiments to Produce Ball and Bead Lightning

From the discussion above, it is clear that most attempts to produce ball lightning in the laboratory are doomed to failure because they do not produce the expanded plasma generated by an ionizing wave from a narrow high-density column [12]. One way to achieve this would be to use an impulse generator to produce a narrow highly- ionized channel, and to use a "trigatron" [8] to short the current abruptly to zero so as to produce a "radial ionizing wave" as described in detail by Morrow [12]. If an expanded plasma channel is produced then a copper wire, smoke or suspended silicon dust could be used to inject fuel into the plasma ball to produce illumination and hence ball lightning. Otherwise the plasma structure will be a phantom plasma structure, and such phantom structures may well have been produced in laboratories already.

The suggestion that the light output from triggered bead lightning is due to the burning of the wire used to trigger the lightning can be tested by using different metals for the trigger wire. The change in the metal of the wire should change the colour of the illumination of the plasma segments; this is suggested for ball lightning.

## Conclusions

The theory presented has explained the following properties of ball and bead lightning:

The origin of a large-diameter distributed plasma from a lightning strike is explained in terms of a radial ionizing wave triggered when the lightning current stops momentarily; the space-charge effect of the excess positive charge drives the ionizing wave out radially and secondary discharges further ionize the broadened channel.

The segmentation of such a broad plasma into balls and elongated segments of bead lightning is explained in terms of a secondary lightning strike down an expanded lightning channel which cuts the channel into a series of segments and balls via the magnetic pinch effect.

The longevity of ball and bead lightning (1 – 10 s) is explained by the effect of the excess positive charge driving positive ions from the centre and negative particle towards the centre to produce a stable plasma ball.

The light output from ball and bead lightning is due to burning particles. In the case of ball lightning the particles come from the soil. In the case of triggered bead lightning the particles come from the metal wire used as a trigger. In other cases of bead lightning the fuel may come from smoke.

The different colours observed for ball lightning are thought to be due to different elements from the soil dominating the colour in different cases.

The different appearances of ball lightning are due to the variable size of the burning particles. Some are smooth because the burning particles are small with little mass so the negative particles cannot venture far beyond the plasma boundary where the electric field starts to rise positively driving them back into the plasma region. Some are "hairy" and this is because the burning particles are more massive and can venture further away from the plasma boundary into regions of higher electric field before they are driven back into the plasma region creating a hairy appearance.

The appearance of streamer-like streaks inside and outside ball lightning are due to the burning particles being visible as they move; the apparent streamers leaving the ball lightning are probably positive burning particles being driven away by the electric field with the positive ions. These moving particles within the ball lightning would create the "woollen" appearance reported. Note that electrical streamers in air can only be seen with dark-adapted eyes; they are not easily visible in daylight.

The burn marks observed when ball lightning hits a wooden object are clearly due to burning negative particles escaping the confines of the ball on impact and burning the wood.

The dusty brown residue left when ball lightning dies must be the residue of the burning negative particles that illuminated the ball; this observation is the clearest evidence for the burning particle theory presented here.

An electric field is unlikely to physically move the ball lightning; therefore, the erratic movement observed for ball lightning must be due to stormy wind movements associated with a lightning storm.

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## About the author

Dick Morrow obtained his PhD from Flinders University on Alfven Waves with Max Brennan. His postdoctoral studies were at Liverpool University, UK, with Professor Craggs on the conductivity of saturated sodium vapour. He also worked on industrial radio-frequency heating applications at the Electricity Council Research Centre, Capenhurst, UK. Then he joined the high voltage laboratory of CSIRO Division of Applied Physics, Sydney, where he worked for 25 years. He started his own company "Morrow Corona Solutions" and completed many contracts including solving a major precipitator sparking problem in WA; he now acts as an expert witness for electrocution cases. In 2006 he joined The Department of Applied Physics at Sydney University and used Surface Plasmon Resonance to detect the effect of electric fields on proteins on surfaces; he continues to work there part-time.

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# Dr John Grenfell Jenkin (13/3/1938 – 12/7/2020)

Physicist and historian Dr John Grenfell Jenkin was born in Adelaide in 1938 as a child of the nuclear age. He was raised by his parents Olive and Trevor Jenkin, along with his grandfather and Methodist minister, the influential Reverend John Grenfell Jenkin, who lived with the family for a time.

It was an era of new physics, of war, of the atomic bomb, and of new medicines. As a young child John was one of the first public patients to be administered penicillin, developed by fellow Adelaidean Howard Florey. Olive recalled John's black-and-blue face before the medication cured his septicemia. By the time John was 15 years of age, Britain had begun Cold War testing of atomic bombs just 1,000 kilometres north-west of his home.

John attended Prince Alfred College, Adelaide, a short bicycle ride from his home in Prospect. He was a member of the school debating team and was heavily involved in sporting activities, including cricket, football and rowing. Being physically larger than many of his contemporaries – his nickname was "Tank" – he would approach oppositions head-on, a strategy he used from time to time later in life. John did well at his studies, became Head of School, and was awarded a scholarship to the University of Adelaide.

John met Constance (Consie) Bishop when they were both still at secondary school. Their relationship continued into their late teens and early 20s while John studied, played cricket and debated at university. They were married in 1959 at the Bishop home in Glandore, the year before John graduated with a Bachelor of Science degree with Honours, majoring in Physics. Their first child, Mark, was born in Adelaide.

A postgraduate award took John and his new family to the Australian National University in Canberra where, in 1964, he completed a PhD in low-energy nuclear physics under the direction of Sir Ernest Titterton. While in Canberra, John and Consie's second child, Astrid, was born. A photograph of John in his doctoral gown with his two young children was published with his online death notice in News Corp publications. John was very proud of both his academic achievements and his children.

Soon after graduation in Canberra, the Jenkin quartet shipped off from Port Adelaide aboard the Orsova, headed for England, where John took up a post-doctoral appointment at Britain's Atomic Energy Research Establishment at Harwell in Oxfordshire. He worked there for three years with scientists such as the notable Perth-born nuclear physicist Dr Joan Jelley (née Freeman). The Jenkins then flew to Minneapolis in the USA, where John had a second post-doctoral position for two years, pursuing research and teaching undergraduates at the University of Minnesota. In later years the Jenkins returned to England and the USA for John's sabbaticals at the University of Reading and the University of California, Berkeley.

In 1968 the Jenkins returned to Australia, where John joined the fledgling Physics department at La Trobe University in Melbourne, one of a wave of talented young staff appointed to the university following its establishment in 1964. The institution also catered for John's sporting interests and his handy left-arm, medium-to-quick bowling impressed cricketing colleagues.

John's expertise in digital technologies, gained while experimenting in nuclear physics, was a welcome addition to the department's photoelectron spectroscopy group. Robert Leckey and John Liesegang had been inspired to enter the field by the work of Swede Kai Siegbahn for which Siegbahn later won the Nobel Prize in Physics. The La Trobe group's experimental work focused on understanding the state and structure of electrons within molecules and solids. Early work used an ultraviolet photon source to bombard solids and a small spectrometer to measure the photoemissions and had met with some success; however, the La Trobe group had had difficulties using analogue picoammeters to measure the vanishingly small currents produced by the photoemission. The alternative – counting individual emitted electrons using digital technology and John's know-how – was instrumental in turning the group's frustrations into success.

The collaboration led to the publication of notable papers by members of the group and the awarding of the university's first doctoral degrees in Physics. John was a particularly active mentor for the group's graduate students and was meticulous in preparing written material for them. He was always available to provide generous support and understanding. John remained at Latrobe for the rest of his career, rising in due course to the rank of Reader and serving a term as Head of the Physics Department.

During the 1970s John began to present seminars on the history of photoelectron spectroscopy, and this led to insightful papers tracing the history of the technique back to 1900. His passion for the history of science was growing, in part because he strongly believed in the need to place contemporary research in an historical context.

By the early 1980s, John's interest in history led to a fascination with Englishman William Bragg, professor of mathematics and physics at the University of Adelaide, 1886-1909, and his son, Lawrence. Like John, Lawrence was born in Adelaide and educated at the university there before he returned to England with his family in 1909. Six years later, father and son shared the Nobel Prize for Physics for their work on X-ray crystallography. Under their leadership the technique came to be used to study the structure of atoms and molecules and, almost fifty years later, was the means by which the structure of DNA was revealed, in the Cavendish laboratory at Cambridge of which Lawrence Bragg was by then director.

John's pursuit of the Braggs became less of a hobby and more of a passion over time and, while maintaining his commitments at La Trobe, his historical investigations eventually came to supplant his commitment to experimental physics. This change in direction saw him collaborating with the University of Melbourne's Department of History and Philosophy of Science, where there was an active group researching various aspects of the history of science in Australia that he found very congenial to work with.

In due course, John published a number of high-quality historical papers, served as book reviews editor for the journal Historical Records of Australian Science, and was the journal's acting editor on a couple of occasions. He continued to delve into the Bragg archives in Adelaide and in Britain, and he and Consie developed a strong relationship with members of the Bragg family, who were a significant source of information for John's work. An early result was a slim volume of 80 pages titled The Bragg Family in Adelaide: A Pictorial Celebration, which was published by the University of Adelaide Foundation in conjunction with La Trobe University, for the 1986 Centenary of the appointment of William Henry Bragg as first professor of mathematics and physics.

In the late 1980s John served on the La Trobe University Council as a staff representative, at a time when the administration was coming to terms with the Hawke-Keating government's plans to turn the tertiary education sector on its head. Colleagues remember and admire John for making sure his sometimes forthright representative voice was heard.

John found a new academic home in 1993 when he transferred to La Trobe's Philosophy Department, which housed a strong History and Philosophy of Science program. He taught there until retiring in 2000 as an emeritus scholar.

John co-authored, with Trevor Ophel, Fire in the Belly: The First 50 Years of the Pioneer School at the ANU (1996), a valuable study of the Research School of Physical Sciences at the Australian National University in which he had received his initial research training. His major writing, of which he was most proud, was William and Lawrence Bragg, Father and Son: The Most Extraordinary Collaboration in Science. By the time this work was published by Oxford University Press in 2008, John was generally regarded as the world authority on the Braggs. The Bragg family has credited the book for not only spelling out the science, but for portraying the scientists as whole persons. They are grateful that the Bragg contributions to science, begun in Australia, are now more widely acknowledged.

John's last written work is a yet-to-be-published extended entry on Sir Mark Oliphant for the Australian Dictionary of Biography, co-authored with Rod Home of the University of Melbourne. The work again took John back to his roots in Adelaide – where Oliphant, too, was born and grew up – and to the start of his research career in Canberra at a time when Oliphant was Director of the ANU's Research School of Physical Sciences. As in everything John did, he threw himself into the project with enormous gusto.

In 2012 John and Consie Jenkin came to Adelaide to help celebrate the centenary of the Braggs' discovery of X-ray crystallography. He organised a civic dinner and participated in a small group from the Royal Institution of Australia, to set up a bust of Sir Lawrence Bragg on North Terrace. One of John's last convocations with the Braggs was in 2015 when the centenary of the father-and-son Nobel Prize was celebrated at the University of Adelaide. He was also invited by scientific societies and publishers to write articles and make presentations to international conferences, and it proved a busy but rewarding academic finale for the then 77-year-old.

John was a highly respected stalwart of the university community, someone with great integrity and sometimes fearless pursuit. He will be remembered for his distinguished career as a physicist and an historian of the discipline, and for his generosity of spirit, open-mindedness, humility and compassion.

He is survived by his wife Consie, children Astrid and Mark, and grandchildren Katherine, Isobel, William and Atticus.

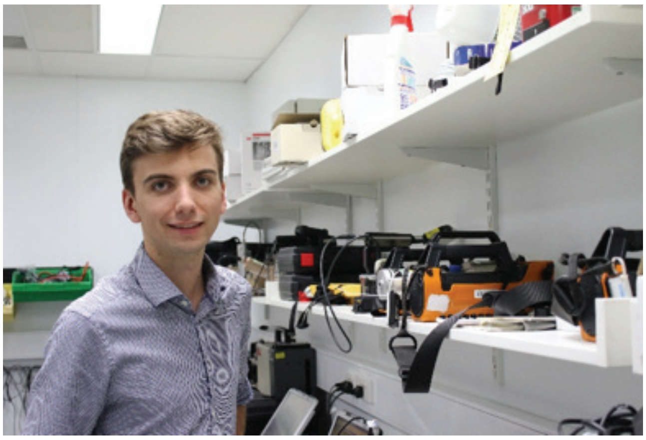
**Mark Jenkin**

with contributions from Rod Home, Robert Leckey and John Riley

# #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.***

**Matthew Wiggins, Radiation and Nuclear Sciences, Queensland Health**



I'm a Health Physicist. I provide radiation science-based solutions to Queensland Government, public and private sector clients. Some tasks require me to travel around Queensland to do radiological surveys of different sites. These can range from travelling to historical mine sites where mineral sand activities might have been done, to laboratories using radiopharmaceuticals. In some special cases I even had to travel interstate to Tasmania for a radiological survey.

I really enjoy my work. It allows me to apply my studies, travel around Queensland and learn how radiation is used in many different fields and purposes ranging from medical and industrial applications all the way down to simple home appliance like smoke alarms.

Before I started University I did an online course through the University of Pittsburgh, just to get a taste to see if I would enjoy this field. After realising I did enjoy it all, I started my undergraduate degree in science, majoring in physics at the Queensland University of Technology, where I was the president of the QUT physics society and a member of the AIP.

After graduating I took a small break from studies and decided if I could not find a job within the next six months, I would start a degree in medical physics. I ended up getting a job at Safe Radiation as a Technical/Scientific officer.

During my time at Safe Radiation, I joined other societies such as the South Pacific Environmental Radioactivity Association (SPERA) and the Australasian Radiation Protection Society (ARPS). At one of the ARPS meeting in Queensland there was the advertisement for my current role at Radiation and Nuclear Sciences – Queensland Health. That was only 8 months ago!

**Jane Turner, Chief Petrophysicist, Woodside Energy Ltd**

Petrophysics is about studying the physical and chemical properties of rock and how it interacts with fluids, particularly in reservoirs of oil and other hydrocarbons.

I'm responsible for ensuring Woodside Energy properly understands its producing assets, new developments and exploration prospects by ensuring all petrophysical work performed by Woodside or on Woodside's behalf is reliable, transparent and fit for purpose. I'm also the manager for the Reservoir Development Petrophysical Services Teams.

I started my career as a commercial pilot! I did a Bachelor of Science at the University of Western Australia, Honours in Astrophysics. I then joined Shell as a geomechanicist in the Exploration and Production division in Aberdeen, Scotland. After moving to Woodside Energy, I moved through several roles: Geophysicist, Petrophysicist, Reserves Coordinator, Studies and Wellsite Teams Lead, and am now the Chief Petrophysicist.

# Young Physicists and Names

**Chris Hall**
**Senior Instrument Scientist ANSTO Australian Synchrotron – christoh@ansto.gov.au**

***As young physicists you might dream of one day becoming a research scientist. A dream to explore parts of nature where no one else has explored. To discover things no one has seen before. To explain things that no one understood, until you uncovered their secret. It's an exciting prospect. One that drives us scientists to work hard. There are lots of rewards if you succeed. One of these is that you and your fellow scientists will have to give your discovery a name.***

Phys·ics *physikḗ (epistḗmē)*

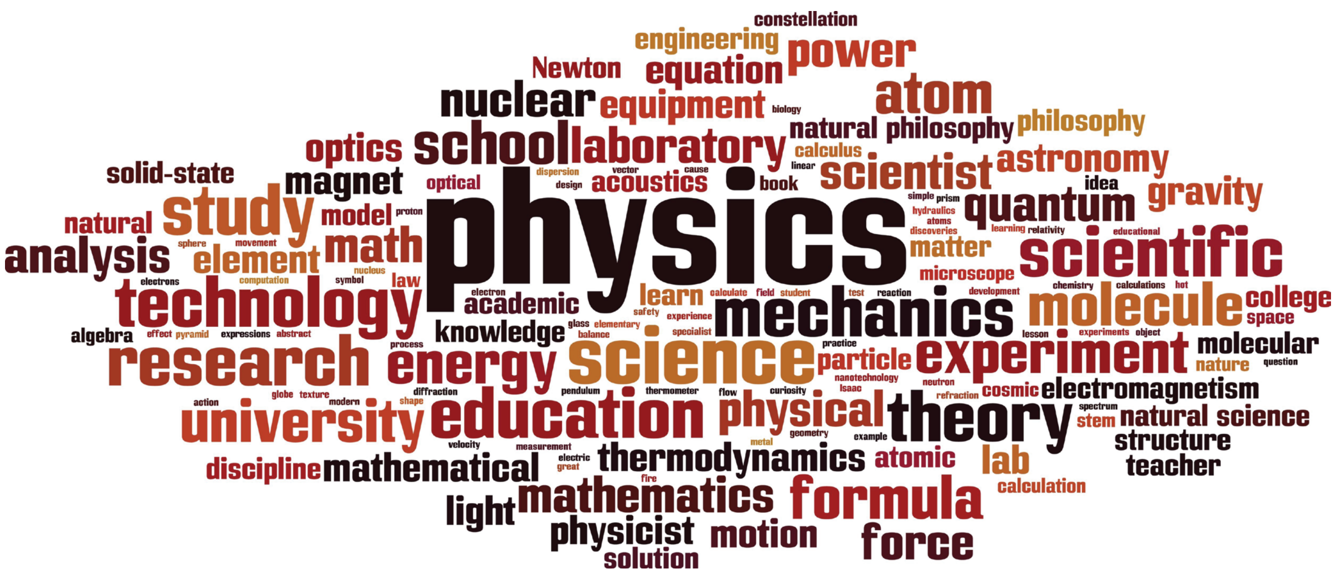
/ˈfɪzɪks/ Knowledge of nature

## The naming of names

Scientists are fairly humble, and so the right to name new scientific discoveries is often handed to someone else. If your colleagues are kind and respect you, they may give your name to the invention. Such names are called eponyms. This gives rise to words in science which are described as eponymous. I'll give you an example which is close to me. Did you know that the electrons which carry current in a wire can be pushed sideways by a magnetic field? It's one of those fascinating phenomena which arises from the famous eponymous equations of James Clark Maxwell. As the electrons gather on one side of a wire they build up a voltage across it and perhaps you can guess what this effect is called. Yes… 'The Hall Effect'

Whatever we call things in science we must make sure that the name has a clear and precise meaning. At the very least amongst our colleagues. One of our greatest scientists had something to say about this. Robert May was a physicists by training, born in Sydney he studied to be a scientist at the University of Sydney. Sadly he died in April this year but he left us with many great ideas. He was the scientist who remind us 'We share half our genes with a Banana!'. He also said this: 'Science is just thinking about things very clearly.' We scientists train to be able to do this, and try hard to ensure that the complex fuzzy aspects of human life don't obscure clear scientific thinking. So when it comes to giving words to our work, we also need to give them a clear meaning.

We may borrow names that already exist, and press them into service for our scientific use. One examples of this is the word energy. It's used by people every day. You can say that 'My friend is so full of energy'. Or that the electricity and gas suppliers to our houses are 'energy providers'. Perhas you have asked someone 'What do you think about nuclear energy?'. We know intuitively what is meant by these phrases, and that is good enough for our day to day communication. It's not good enough for science, though. In physics energy has a particular



meaning. If you go to a physics dictionary you will find something like this: Energy is the property of matter and radiation which is manifest as a capacity to perform work.

If you read the Young Physicists article in a previous AIP magazine you may remember a word we used when talking about rockets: momentum. When they are not talking about physics, people use this word to describe a movement which is difficult to resist. For instance 'The move towards combatting climate change is gathering momentum'. In physics we learn that momentum is clearly defined as the product (multiplication) of the mass and the velocity of an object.

Quite often a discovery in physics makes the news. Then the swap can happen the other way. A word used to describe a discovery may be taken into the common language. Here's an example. About 100 years ago we thought that the description of the movements of objects were completely covered by the laws written by Sir Isaac Newton way back in 1687. The way that balls, rockets, and everything else we see move, fitted very well with the Newtonian Laws of motion (a fine example of an eponymous law in physics here). However, when we had the technology to study objects on a much smaller scale. It seemed that at this level not everything obeyed Newtonian mechanics. This discovery shook the world, and people suddenly became aware of a new form of mechanics called quantum mechanics. Like many words in English the word quantum comes from Latin, meaning quantity. It was used in the past to mean the smallest possible quantity of something. It wasn't used very much, but scientists borrowed it for describing the way energy is divided up at these very small scales. The word sounded very modern and scientific, and so it was borrowed back from science into everyday language. It is now used to describe earnings in economics, a length of time in finance, and even dishwasher tablets! Can you think of other examples of physics words that have been borrowed for everyday use?

Over to you…

You may have come across familiar words in your studies, which you now know the clear scientific meaning. How about making a table of them, showing the scientific meaning and the everyday meaning side-by-side? I have given you a few to start you off. See if you can add to the list.

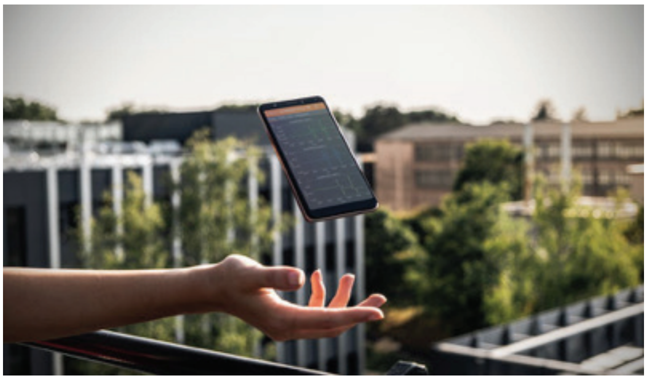
| **Word** | **Common meaning** | **Meaning in physics** |
|---|---|---|
| Friction | Disagreement | A force resisting the motion of materials moving again one another. |
| Impulse | Doing something without thinking | The integral of a force, over the time which it acts. |
| Power | Control over people | The amount of energy used or transferred over a period of time. |

## About the author

Chris Hall started his research career studying gamma ray emission from outer space. His PhD involved building working models of a sophisticated satellite borne gamma radiation telescope. He now works at the ANSTO Australian Synchrotron in Melbourne, working with novel x-ray imaging and radiotherapy techniques for the benefit of human health.

# Physics around the World

## Teaching experimental science in a time of social distancing



**Thanks to its sensors, the smartphone can be a measuring instrument. (A. Kolli, _LaPhysique Autrement_, CC BY)**

When lockdown measures were announced in France and other countries, secondary-school teachers and university professors had to quickly make the transition from classroom teaching to remote education. As a result, practical work was often abandoned – experiments were no longer possible without a lab, test tubes, oscilloscopes and other equipment.

To overcome this problem, some educators used digital simulations, while others analysed existing data. But people familiar with experimental science know that simulations and simple analysis do not replace the lab bench and real experiments. The role of science is to help us to understand everyday phenomena and "real" experiments are absolutely essential.

As academics working in the field of physics, we have been reflecting about developing new forms of practical work that allows for greater student autonomy for several years now. At Université de Bordeaux and Paris-Saclay, we asked our students to create their own experiment, and in some cases, to conduct them independently with smartphones or Arduino boards, an open-source solution for experiments with electronics.

Lockdown was a great chance to test autonomous practical work, so we jumped on it immediately. During the two months of French lockdown – it began on March 17 and ended May 11 – we adapted and continued to teach using experiments without compromising the quality of content. These "life-size" tests convinced us that it is possible to remotely conduct lessons with experiments for both secondary-school teachers and higher-education professors. We have even observed very positive aspects of this new approach. It changes the student's relationship with science and with their teachers.

These new education techniques are fantastic opportunities, particularly given that social distancing is likely to persist over the coming year. They do, however, require preparation.

### Smartphone and salad spinner

What is lab work without a lab and lab equipment? The priority tool is a smartphone with its many sensors. Apart from recording images or sounds, smartphones can measure acceleration, magnetic fields, rotation speeds, audio spectrum, and some models can even measure pressure or light intensity. Free applications such as Phyphox can be used to measure, analyse and transfer data in just a few seconds. All you need is a bit of imagination and you can start tinkering.

Want to measure the period and damping of a pendulum? Hang your phone from a piece of string and measure its acceleration. Interested in centripetal acceleration? Place your smartphone in a salad spinner and start the accelerometer and gyroscope at the same time.

The imagination of students and teachers is the only limit to these types of experiments, as demonstrated by "The smartphone physics challenge". The outcome was 61 ways to measure the height of a building!

And these techniques are not restricted to physics. It is also possible to conduct simple and precise chemistry and biology experiments at home. For example, you can turn your smartphone into a microscope with a drop of water (and see cells as a result) or a spectrophotometer.

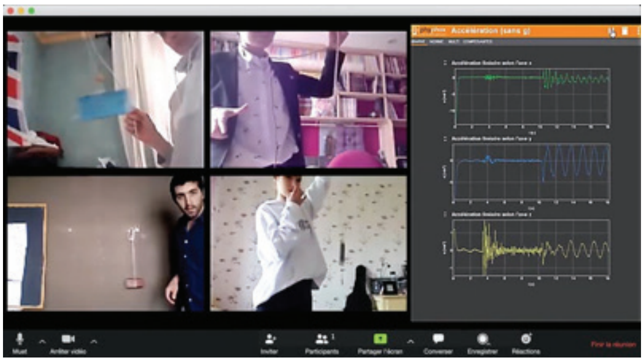
### Reinventing education

We have also adapted our teaching methods. At Université Paris-Saclay, we asked about 100 students to autonomously conduct the physics study of their choice. The subjects chosen varied tremendously, including the study of a vinegar rocket and the acoustic modes of musical instruments, the measurement of the earth's radius and the physics behind yanking a tablecloth from a table without disturbing cutlery placed on it. Students worked in pairs to attenuate the isolation resulting from lockdown.

At Université de Bordeaux, we have set up a site, Smartphonique, that proposes a range of experiments to students and teachers in different fields, including mechanics, acoustic, optics and fluid physics. In addition to protocols, conferences and videos, we organised a collective weekly video conference, "Experiments in Lockdown", during which students simultaneously experiment and share measurements recorded with their smartphone and the means at hand.

**Remote practical exercises are much more interesting**

Such new types of practical exercises are not just emergency solutions in a health crisis. They are interesting new educational techniques because they reinforce the relationship with experimentation and the subject. Teachers are no longer looking over students' shoulders to control each gesture. As a result, students are less afraid of making mistakes, particularly without expensive equipment that could be damaged (aside from the smartphone itself, of course). Results of surveys demonstrate that most students enjoy the freedom and autonomy.



**Practical exercises via video conference at Université de Bordeaux during lockdown: students and teachers measure a pendulum together with their smartphones. (Courtesy: Ulysse Delabre)**

Another advantage: experiments are no longer isolated in a laboratory, which means that physics is no longer an abstract science practised only highly specialised equipment. On the contrary, it is part of everyday life and, as a result, becomes real. Educational qualities also change. Imagination, tinkering and creativity each have a role to play, and they are all features of real research practise. Some student profiles will flourish using this less academic approach.

Finally, by communicating about remote experiments, students use original communication forms typical of participatory science. Working together on a digital platform is conducive to collaborative action.

**Prepare the 2020 academic year this summer**

Distancing measures at the beginning of the 2020 academic year are likely to change how teaching is organised around the world. Practical work could be one of the first victims… Our message is simple: teaching with experiments at home could well be a practical alternative – but not just a second-rate one. It could be a unique opportunity to review the way we teach scientific disciplines by injecting creativity, freedom and fun.

**(extracted with permission from an item by Julien Bobroff, Frédéric Bouquet, and Ulysse Delabre at theconversation.com)**

## Physicists hunt for room-temperature superconductors that could revolutionize the world's energy system

Waste heat is all around you. On a small scale, if your phone or laptop feels warm, that's because some of the energy powering the device is being transformed into unwanted heat.

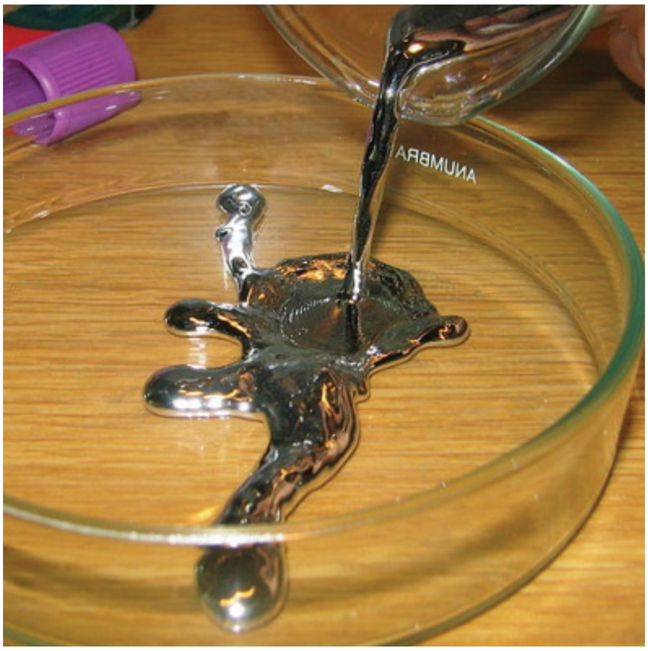
On a larger scale, electric grids, such as high power lines, lose over 5% of their energy in the process of transmission. In an electric power industry that generated more than US$400 billion in 2018, that's a tremendous amount of wasted money.

Globally, the computer systems of Google, Microsoft, Facebook and others require enormous amounts of energy to power massive cloud servers and data centers. Even more energy, to power water and air cooling systems, is required to offset the heat generated by these computers.

Where does this wasted heat come from? Electrons. These elementary particles of an atom move around and interact with other electrons and atoms. Because they have an electric charge, as they move through a material – like metals, which can easily conduct electricity – they scatter off other atoms and generate heat.

Superconductors are materials that address this problem by allowing energy to flow efficiently through them without generating unwanted heat. They have great potential and many cost-effective applications. They operate magnetically levitated trains, generate magnetic fields for MRI machines and recently have been used to build quantum computers, though a fully operating one does not yet exist.

But superconductors have an essential problem when it comes to other practical applications: They operate at ultra-low temperatures. There are no room-temperature superconductors. That "room-temperature" part is what scientists have been working on for more than a century. Billions of dollars have funded research to solve this problem. Scientists around the world, including me, are trying to understand the physics of superconductors and how they can be enhanced.



**Mercury at room temperature. (Courtesy: Wikipedia, CC BY 3.0)**

**Understanding the mechanism**

A superconductor is a material, such as a pure metal like aluminum or lead, that when cooled to ultra-low temperatures allows electricity to move through it with absolutely zero resistance. How a material becomes a superconductor at the microscopic level is not a simple question. It took the scientific community 45 years to understand and formulate a successful theory of superconductivity in 1956.

While physicists researched an understanding of the mechanisms of superconductivity, chemists mixed different elements, such as the rare metal niobium and tin, and tried recipes guided by other experiments to discover new and stronger superconductors. There was progress, but mostly incremental.

Simply put, superconductivity occurs when two electrons bind together at low temperatures. They form the building block of superconductors, the Cooper pair. Elementary physics and chemistry tell us that electrons repel each other. This holds true even for a potential superconductor like lead when it is above a certain temperature.

When the temperature falls to a certain point, though, the electrons become more amenable to pairing up. Instead of one electron opposing the other, a kind of "glue" emerges to hold them together.

**Keeping matter cool**

Discovered in 1911, the first superconductor was mercury (Hg), the basic element of old-fashioned thermometers. In order for mercury to become a superconductor, it had to be cooled to ultra-low temperatures. Kamerlingh Onnes was the first scientist who figured out exactly how to do that – by compressing and liquefying helium gas. During the process, once helium gas becomes a liquid, the temperature drops to -452 degrees Fahrenheit.

When Onnes was experimenting with mercury, he discovered that when it was placed inside a liquid helium container and cooled to very low temperatures, its electric resistance, the opposition of the electric current in the material, suddenly dropped to zero ohms, a unit of measurement that describes resistance. Not close to zero, but zero exactly. No resistance, no heat waste.

This meant that an electric current, once generated, would flow continuously with nothing to stop it, at least in the lab. Many superconducting materials were soon discovered, but practical applications were another matter.

These superconductors shared one problem – they needed to be cooled down. The amount of energy needed to cool a material down to its superconducting state was too expensive for daily applications. By the early 1980s, the research on superconductors had nearly reached its conclusion.

**A surprising discovery**

In a dramatic turn of events, a new kind of superconductor material was discovered in 1987 at IBM in Zurich, Switzerland. Within months, superconductors operating at less extreme temperatures were being synthesized globally. The material was a kind of a ceramic.

**Copper wires. (Courtesy: Pixabay, CC0 1.0)**

These new ceramic superconductors were made of copper and oxygen mixed with other elements such as lanthanum, barium and bismuth. They contradicted everything physicists thought they knew about making superconductors. Researchers had been looking for very good conductors, yet these ceramics were nearly insulators, meaning that very little electrical current can flow through. Magnetism destroyed conventional superconductors, yet these were themselves magnets.

Scientists were seeking materials where electrons were free to move around, yet in these materials, the electrons were locked in and confined. The scientists at IBM, Alex Müller and Georg Bednorz, had actually discovered a new kind of superconductor. These were the high-temperature superconductors. And they played by their own rules.

**Elusive solutions**

Scientists now have a new challenge. Three decades after the high-temperature superconductors were discovered, we are still struggling to understand how they work at the microscopic level. Creative experiments are being conducted every day in universities and research labs around the world.

In my laboratory, we have built a microscope known as a scanning tunneling microscope that helps our research team "see" the electrons at the surface of the material. This allows us to understand how electrons bind and form superconductivity at an atomic scale.

We have come a long way in our research and now know that electrons also pair up in these high-temperature superconductors. There is great value and utility in answering how high-temperature superconductors work because that may be the route to room-temperature superconductivity. If we succeed in making a room-temperature superconductor, then we can address the billions of dollars that it costs in wasted heat to transmit energy from power plants to cities.

More remarkably, solar energy harvested in the vast empty deserts around the world could be stored and transmitted without any loss of energy, which could power cities and dramatically reduce greenhouse gas emissions.

**(extracted with permission from an item by Pegor Aynajian at theconversation.com)**

## Fukushima may have scattered plutonium widely

**The upper side of the unit 3 reactor building at Fukushima Daiichi was damaged by a hydrogen explosion. This area housed the spent fuel pool and the fuel handling machines. (Courtesy: TEPCO)**

Caesium is a volatile fission product created in nuclear fuel. During the Fukushima meltdown, it combined with silica gas created when melting fuel and other reactor materials interacted with the concrete below the damaged reactor vessel. The resulting glass particles, known as caesium-rich microparticles (CsMPs), measure a few microns or tens of microns across.

Satoshi Utsunomiya and Eitaro Kurihara at Kyushu University and colleagues in Japan, Europe and the US analysed three such particles obtained from soil samples dug up at two sites within a few kilometres of the Fukushima plant. They used a range of techniques to study the physical and chemical composition of these CsMPs, with the aim of establishing whether they contained any plutonium.

**Mapping plutonium spread**

To date, plutonium from the accident has been detected as far as 50 km from the damaged reactors. Researchers had previously thought that this plutonium, like the caesium, was released after evaporating from the fuel. But the new analysis instead points to some of it having escaped from the stricken plant in particulate form within fragments of fuel "captured" by the CsMPs.

**Large scale solar and wind energy harvesting. (Courtesy: Pixabay, CC0 1.0)**

Utsunomiya and colleagues used electron microscopy and synchrotron X-ray fluorescence to look inside the CsMPs. Based on these data, they were able to map the distribution of various elements coming from materials within the damaged reactors – including iron from stainless steel, zirconium and tin from the fuel cladding and zinc from cooling water. They also found uranium within one of the CsMPs, in the form of discrete uranium oxide particles less than 10 nm across.

However, the researchers were unable to find any traces of plutonium using these methods – probably due to interference from strontium, another fission product. Instead, they turned to X-ray absorption. To compensate for high levels of noise, they carried out the measurement at two different synchrotrons, transporting their roughly 20 μm diameter particle from Japan to be blasted with X-rays at the Diamond facility in the UK and the Swiss Light Source in Switzerland.

The researchers focused their attention on the three areas of the particle that generated the most fluorescence from uranium. They failed to detect plutonium at two of these locations, but succeeded at the third, with absorption spectra produced at both synchrotrons indicating the element's presence. The low signal-to-noise ratio meant they couldn't identify exactly which plutonium species were present, but the shape of the spectra told them that it probably existed as an oxide, rather than as a pure metal.

Utsunomiya and co-workers also used mass spectrometry to measure the relative abundance of different plutonium and uranium isotopes within the microparticles. They found that three ratios – uranium-235 to uranium-238, as well as plutonium-239 compared to both plutonium-240 and -242 – all agreed with calculations of the proportions that would have been present in the fuel at the time of the disaster. This agreement, coupled with the fact that the measured amount of uranium-238 was nearly two orders of magnitude greater than would be the case if it had simply evaporated from the melted fuel, led them to conclude that the uranium and plutonium existed as discrete fuel particles within the CsMPs.

**(extracted with permission from item by Edwin Cartlidge at physicsworld.com)**

# PRODUCT NEWS

## Coherent

### Superior Intelligent Spectrograph

The Kymera 328i imaging spectrograph from Andor Technology is a highly modular spectrograph featuring patented Adaptive Focus, quadruple on-axis grating turret and TruResTM technology delivering superb spectral resolution performance.

The intelligent, motorised Adaptive Focus of the Kymera allows automated access to the best optical performance for any grating, camera or wavelength range configuration. The TruResTM option delivers unmatched spectral resolution for the third-metre focal length spectrograph.

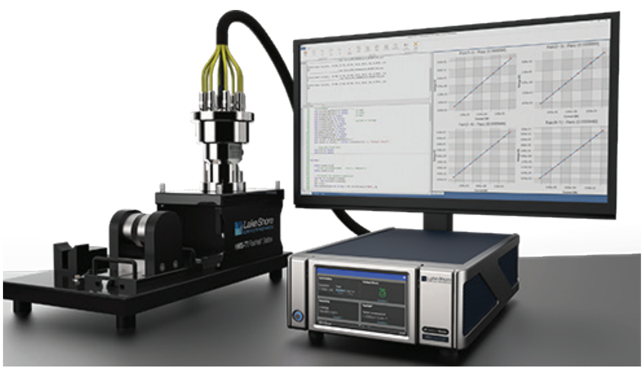
The Kymera 328i sets a new standard when it comes to configurability, being the only imaging spectrograph on the market to offer dual output ports, dual input ports and indexed quadruple grating turret. This provides a unique range of light coupling and spectral performance options to best match current and future setup requirements.

### New 193nm Excimer Lasers

The LEAP range of 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 assortment of demanding, high throughput, high-precision microprocessing tasks, ranging from display fabrication to reel-to-reel manufacturing of superconductive tape. New to the range of LEAP excimer lasers are two 193nm models – 50A and 60A delivering 250mJ and 400mJ respectively.


### MeasureReady FastHall Station

The MeasureReady 155 precision current and voltage source from Lake Shore Cryotronics combines premium performance with unprecedented simplicity for materials scientists and engineers requiring a precise source of voltage and current.



With extensive experience in low-noise instrumentation for research, Lake Shore has leveraged the latest electronic technologies to reduce in-band and out-of-band noise floors for the MeasureReady 155 source to levels previously only possible using add-on filters. The result is a combination AC/DC current and voltage source that is well-suited to the challenges of characterising sensitive materials and devices, where lower excitation signals are needed and minimum injection of noise into the measurement is required.

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# Warsash

**New 1030nm single frequency all-fibre laser**

Azurlight Systems introduces the unique 1030nm high power all fibre laser solution for greatly improved stability, robustness and unprecedented system integration.

The single frequency mode infrared laser offers unique performance in terms of ultra-low noise and high power (5, 10, 20, 50 and 130W options) combined with the inherent efficiency and stability of fibre lasers.

Built upon a MOPA architecture allows Azurlight the freedom to tailor the products to your application. Other wavelengths are available on request using an external seed laser, including the customers own seed laser.

Key application areas are:
- Atom trapping
- Atom cooling
- Bose-Einstein Condensates
- Optical metrology
- Interferometry

**Quantom dot sensor beam profiler at 1550nm**
DataRay, a global pioneer in the design and manufacture of laser beam profilers has launched the WinCamD-QD-1550 imaging beam profiler.


The WinCamD-QD-1550 is the laser imaging beam profiler that does not use a microbolometer or phosphor coatings. With industry leading features such as 15 μm pixels, multiple active area options (640x512, 1280x1024 or 1920x180 pixesl), 14-bit ADC, >2100: dynamic range and port powered USB 3.0. With a global auto-shutter WinCamD-QD-1550 is suitable for both CW and pulsed laser profiling.


**High-precision biocompatible photoresist for 3D printing**
Nanoscribe presents the new IP-Visio printing material for life science applications. This material is non-cytotoxic, low-fluorescent and designed for the 3D Microfabrication of biocompatible microstructures. With IP-Visio, Nanoscribe's 3D printers open up the way to produce intricate, filigree microenvironments needed in 3D cell culture and tissue engineering.

The printing material is non-cytotoxic according to ISO 10993-5. This makes IP-Visio suitable for cell-friendly 3D scaffolds. With this material, high-precision microstructures can be fabricated to mimic realistic and high-precision microenvironments. An exemplary application is multi-cell scaffolds that serve as supporting material to seed and study cells in 3D.

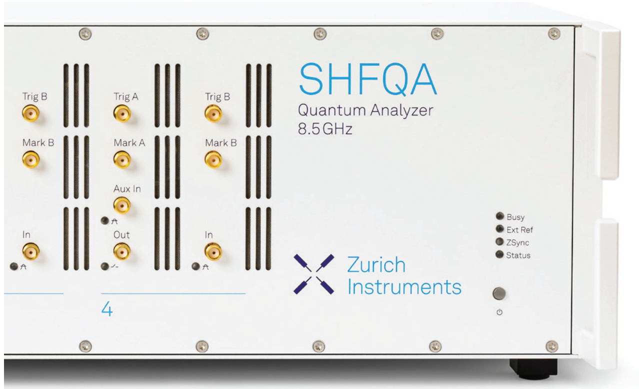
Moreover, IP-Visio shows a very low autofluorescence. This property allows a clear view through the printed scaffolds. Scientists can analyze cellular components and processes by means of fluorescence microscopy without interference of the printed structures.

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

# Zurich

**First quantum analyzer integrating a full qubit readout setup**
Zurich Instruments launches the SHFQA, the first quantum analyzer that can perform direct readout of up to 64 superconducting or spin qubits in parallel. The SHFQA supports readout frequencies up to 8.5 GHz without the need for mixer calibration, and provides a wide and clean analysis bandwidth of 1 GHz.

The SHFQA comes in a compact design with 2 or 4 readout channels, each of which can be controlled and triggered individually. Every channel can analyze up to 16 qubits in real time – time-staggered or in parallel. Thanks to the channels' arbitrary waveform generator, matched complex filters, and multi-state discrimination, both signal-to-noise ratio and readout latency can be optimized. Turnkey features such as the fast acquisition of a resonator spectrum simplify and accelerate system characterization and calibration. A high level of integration with the upper levels of the quantum stack comes through the LabOne software, driver compatibility with Labber and QCoDeS, and API support for Python, C/C++, MATLAB®, LabVIEW™ and .NET.




The SHFQA integrates seamlessly with all devices in the Zurich Instruments Quantum Computing Control System so that it is ready to run fast feedback and error correction protocols. A single SHFQA helps to reduce the complexity of small qubit setups; a few synchronized instruments make it possible to scale up to systems of 100 qubits and more.

**For more information, contact Zurich Instruments AG on +41 (0)44 5150 410 or info@zhinst.com**

**http://www.zhinst.com/products**

ASSOCIATION OF ASIA PACIFIC PHYSICAL SOCIETIES

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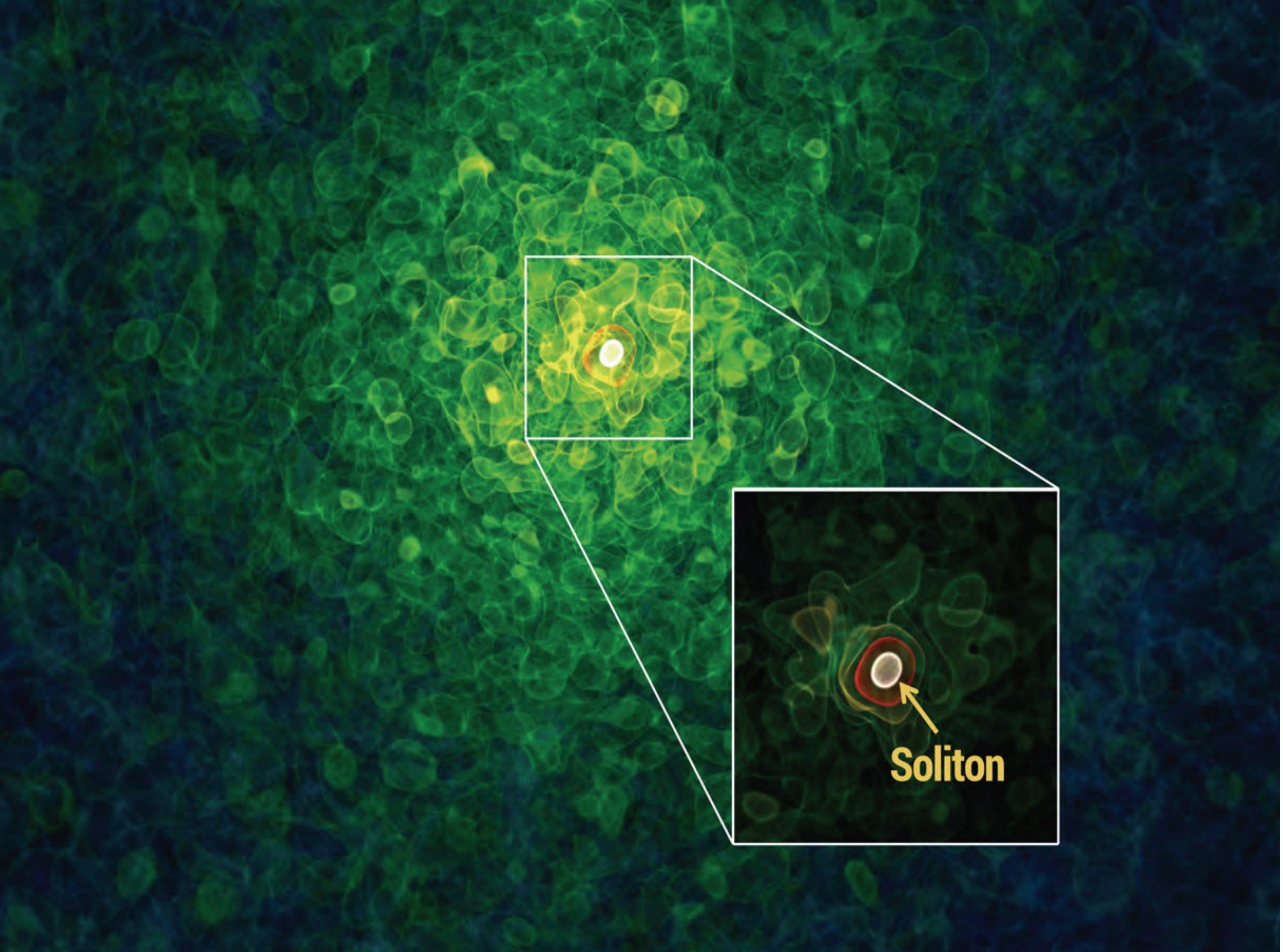
## Wave Dark Matter halo



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