fusion

The Open University Physics & Astronomy Society

NEWSLETTER

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Contents

Beginning Bit

Hello all.

Welcome to the second digital only edition of the Fusion Newsletter. I look forward to the day when we can also send out printed versions. And when we can safely meet again. We will also be able to print out copies of the present digital only versions.

I am very sorry to report the death of our friend Michael Taylor. Michael was, for the past three years, Secretary of Fusion. During this time he was also a student rep on the School of Physical Sciences. It was there, as a fellow student rep, that I got to know him.

Some of Michael's friends, in Fusion and OUSA, have produced some words on him that were read by the Minister conducting his funeral. I have included a modified version of this as a tribute to Michael and which is printed below. I would like to thank Mark Jones (Director of Teaching in the School of Physical Sciences) for liaising with Michael's church and passing on our tribute.

Very many thanks to Sally Jordan and Ulrich Kolb for steering the School of Physical Sciences through some very difficult times. They were able to protect the physical sciences curriculum at a time when the University had been making cuts in modules and qualifications and have since introduced a new single honours Physics BSc. During the past few years there has been a rewrite or refresh of the levels 1 and 2 modules with work on the level 3 modules.

Congratulations are in order for Stephen Lewis, who has taken over as Head of School, and Mark Jones, who has taken over as Director of Teaching. Mark is also the new Deputy Director of eSTEeM. eSTEeM is the bit of the STEM Faculty that is responsible for the Scholarship of Teaching and Learning. Stephen has written a personal profile which is included in this issue of the Newsletter and Mark will write a profile for the New Year issue.

We are pleased to announce a visit to Lord Rayleigh's Laboratories on Thursday, 22 March 2022. Places are limited so please register early if you would like to attend.

David Talbot has written an introduction to the new OUSA Space Society. The Space Society grew from the OU Space Science Club which was itself founded just a year ago. That is an impressive achievement. In passing David is also a student rep on the School of Physical Sciences Board of Studies. I have an equivalent role on the School of Maths and Stats Board of Studies and am also a member of the eSTEeM Student Reference Panel.

Thanks to Dwyn for providing a report of last year's Fusion Event and a Word Sudoku. And a big thank you to Jim for providing me with material of different kinds for the Newsletter as well as contacting other people and asking them to contribute an article. But 'material of different kinds'? Well, in this issue we have the second and final part of his article on *A Brief History of Dimensions*. And he has sent me an essay *Does E equal mc²?* for inclusion in the next issue. But he also some sent me some fascinating photographs of ancient instruments. The first of these is printed on the back of this Newsletter. Do you know what it is and what it is for.

If you would like to contribute anything – an article, a book review, a picture, a puzzle… please email me at nigeldpatterson@blueyonder.co.uk.

In the meanwhile stay safe and best wishes, Nigel

In Memoriam – Michael Taylor

We are sad to announce the death of our friend and colleague Michael Taylor. Michael died on 31 August 2021 after a long battle with cancer.

Michael had a long-standing interest in the sciences – he took his first degree in Chemistry but also had a fascination with Physics and was particularly keen to understand Quantum Physics. This inspired him to begin studying with the Open University towards a degree in Mathematics and Physics.

Michael was not content just with formal study. He became a very well-liked and active member of the OU students Physics community. He soon got involved with Fusion, the OU Students Physics and Astronomy Society, and loved to attend the society's events. He deepened his involvement by joining the committee, regularly represented Fusion at the Societies Committee of the OU Students Association and then serving as Secretary for the last three years. He shared plenty of ideas with the Committee and was really keen to move the society on. Sadly, Michael had to stand down as his health worsened, but he has definitely had a lasting impact on the society.

Michael and Cath sitting at the Alchemy stall

In addition to his work on various OU and student committees Michael regularly attended Institute of Physics (IOP) lectures held at the University campus in Milton Keynes as well as student Conferences organized by the IOP. Very often he was accompanied to these by his friend Charles.

Michael was always keen to support and represent the interests of his fellow students, and with that in mind, he applied to become a student representative on the School of Physical Sciences Board of Studies. Here he gave the student view on key developments in the Open University's curriculum in Physics, Astronomy and Planetary Science.

Michael was excellent company and happily chatted on a range of subjects including Science, Philosophy and Religion. We will miss him.

Cath, Cin, Dwyn and Nigel

Fusion Weekend 2020

by

Dwyn Padfield

Fusion's annual weekend had to be abandoned last year due to the Covid situation, and so we decided to venture into the realms of a virtual meeting.

We had four speakers during the day – Professor John Bridges, of Leicester University, who spoke on exploring Mars with the Curiosity Rover, Jo Bridges, of the OU, on her research on exoplanets, Anthony Bridges, an OU student and Fusion member, on the recently formed Space Science Club. Ulrich Kolb, the director of teaching at the OU School of Physical Sciences gave an overview of the Physical Sciences curriculum and the various degree routes.

The AGM was held during the day, with all committee members re-elected in their present roles.
The evening events were a quiz and virtual bar – both enjoyed by participants.

The event was very successful, but it was disappointing that more people did not attend, given that there was no traveling involved.

Thank you to our speakers, and to Cath and Greg who set up the technology for the day.

A Brief History of Dimensions

by

Jim Grozier

Part 2

In the first article in this two-part series, I traced the history of dimensions from the time of Descartes to that of Maxwell. In this second and concluding part, I extend the story into the 20th century, before embarking on a detailed study of the strange case of the dimensions of angles.

Dimensions in the 20th Century

The change-ratio concept , introduced by James Thomson, gives dimensional formulae legitimacy, since it identifies the terms appearing in such formulae as ordinary numbers – the ratios by which quantities have to be multiplied when we change units. Without it, we would have to *postulate* that dimensions – whatever they are – can be algebraically manipulated. Yet, strangely, explanations of dimensions in terms of change-ratios are very rare in the physics literature of the late 20th century. A typical textbook definition of dimension is that given by Serway & Jewett in *Physics for Scientists & Engineers*: "The word *dimension* has a special meaning in physics. It denotes the physical nature of a quantity" [Serway & Jewett p10]. Most textbooks give qualitative definitions like this one – which calls to mind the strong view of dimension – and omit any reference to change-ratios.

Change-ratios are equally rare in the philosophical literature. Brian Ellis describes dimensions as "the names of particular classes of similar scales for the measurement of quantities" [Ellis p139], which is at least consistent with the change-ratio concept, since the process of changing units is effectively a scaling process. Henry Kyburg's definition is similar: the dimension of a quantity "is to be construed as the set of its magnitudes" [Kyburg p163]. Mario Bunge defines dimensions similarly, as "species" of similar quantities "such as the class L of all length-like quantities" [Bunge p2]. In fact, I have found only one recent book that *does* feature the change-ratio definition – G.I. Barenblatt's *Scaling, self-similarity, and intermediate asymptotics*, published in 1996, and even here, the author does not actually use the term "change-ratio", though his definition is identical to Thomson's. [Barenblatt p32].

The existence of a fourth, electrical, base quantity was formalised by the introduction of the ampère as a base unit by the Conférence Générale des Poids et Mesures (CGPM) in 1948. This four-dimensional "MLTC" quantity space (where C stands for current) gets rid of the problem of fractional powers: all electromagnetic quantities now have dimensions which are products of integer powers of the change-ratios of these four base quantities.

In 1954 the CGPM defined a base unit of thermodynamic temperature, and in 1967 this unit was named the kelvin. Units of "amount of substance" (the mole) and luminous intensity (the candela) followed. This brought the number of base units (and hence, by implication, the number of dimensions) up to 7.

The metrology community appears to have accepted the new base units relatively quickly; for instance, in a 1964 book, R.C. Pankhurst of the National Physical Laboratory included a fourth dimensional constant (which he wrote as $1/\varepsilon$) in electrical equations [Pankhurst p43]. Yet the view that there are really only three fundamental quantities, and hence three dimensions, did not go away; many authors continued to regard all quantities as having mechanical dimensions only. This can be seen in the continued use of formulae for electrical quantities that only make sense in systems of units based on an MLT space, such as that for the fine structure constant, α – still very often written as $e^2/\hbar c$, omitting the electrical constant ε_0. Even textbooks have been slow to adopt the new approach: as recently as 1996, a general physics textbook was published which included the statement that "all measurements can be reduced ultimately to the measurement of length, time and mass. Any physical quantity, no matter how complex, can be expressed as an algebraic combination of these three basic quantities" [Fishbane, Gasiorowicz & Thornton, p. 9]. The reluctance to accept a separate electrical dimension may stem partly from the view that the number of dimensions can only diminish with time, as we come to regard quantities, previously seen as distinct, as sufficiently closely connected that one can be defined in terms of the other; and indeed, that they *should* diminish with time, even beyond MLT – perhaps by defining length in terms of time [see *e.g.* Lévy-Leblond] – and even, perhaps, ultimately reaching zero [see *e.g*. Duff et al.]. This drive to constantly simplify our physical laws is of a piece with the mechanical reductionism of the late 19th century.

One question that appears at odds with this narrative is that of the dimensions of angles.

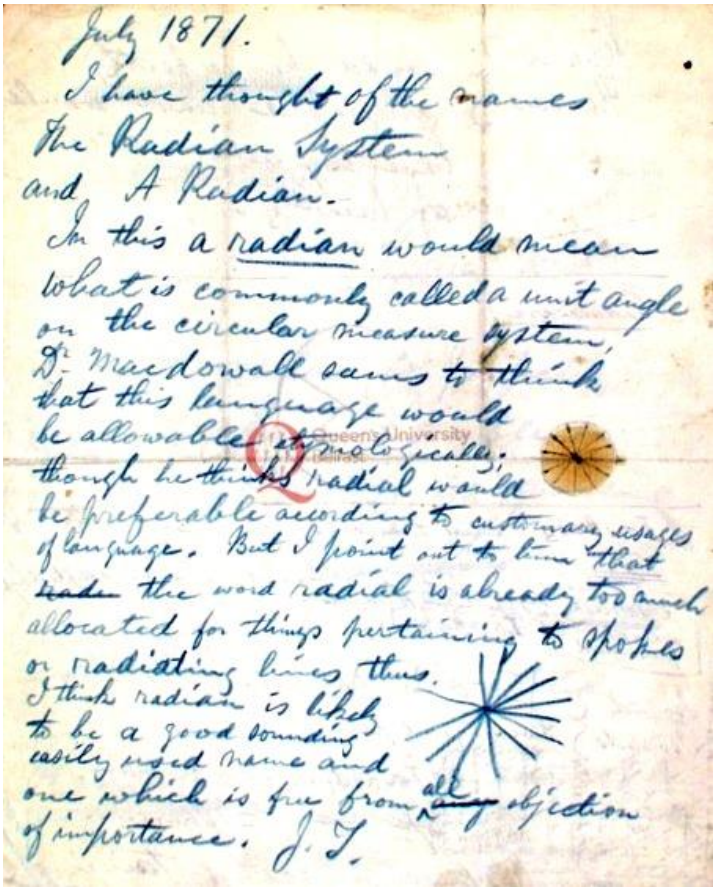
The Dimensions of Angles

Krantz *et al.*, in their monumental work *Foundations of Measurement*, describe angle as "the bastard quantity of dimensional analysis, about which everyone seems a bit uncomfortable" [Krantz *et al*. p455]. Angle is often described as a dimensionless quantity, yet it is also a measurable, physical quantity like length, which we might feel ought to have dimensions; and in a sense it is on a par with length, since the concepts of the homogeneity and isotropy of space, which give rise to the fundamental principles of conservation of linear and angular momentum respectively, appear to put the two on an equal footing.

The origin of this conundrum is of course the widespread use of the radian as an angular measure; an angle in radians is the ratio of subtended arc length to radius, so as a ratio of similar quantities it does indeed appear to be dimensionless. The radian was invented by Euler in 1765, although it was not named until over a century later, when James Thomson came up with the name as a contraction of "radial angle". It has become an invaluable tool for theoretical physicists, because of the simplicity it affords to various formulae, in particular to the Small Angle Approximation, and thence to Taylor series for trigonometrical functions. But it is a strange unit, because it is *theoretical* only; we never measure angles in radians, but only use them in derivations. The SI literature nominates the radian as the unit of angle, but describes it as a "dimensionless derived unit" [Bell p15].

There is plenty to be "a bit uncomfortable" about here! A unit which is never used in measurement (have you ever seen a protractor calibrated in radians?) is an odd concept to begin with, and appears even more bizarre when we consider that all the commonly-used angles, when measured in radians, are represented by irrational numbers. But there is more to be concerned about in the concept of a "dimensionless unit". If we use the change-ratio definition of dimension, it is difficult to see how a unit can have a dimension, since this view of dimension is based on *changing* units. Giving the BIPM the benefit of the doubt, one might dismiss this as simply a clumsy use of words: what they really meant to say, perhaps, was that angle is a dimensionless *quantity*, and the radian is its unit.

A reductionist narrative might then suggest that, before Euler's time, angle *was* considered a dimensioned quantity, and that the demise of an angular dimension was simply a part of the onward progress of science in its quest to simplify natural laws, in the vein of the confluence between work and heat in the mid-19th century; see, for instance, Lévy-Leblond on the "unification" of physical concepts and the corresponding disappearance of fundamental constants. Yet if we look at the earlier writings of Descartes and Wallis previously quoted, we will find no mention of any angular dimension. This is not because they had not considered the question of angle; Wallis, at least, wrote an entire treatise (entitled *Treatise on the Angle of Contact*) in which he included angles in a class of properties that he called "inceptives": "the Angle ... tho it be no whit of Distance, yet is inceptive of Distance, and so soon as ever we be past the Angular Point, the legs are actually Distant" [Wallis p96]. This classification may stem from the perception that the angle exists *at a point* (what Wallis calls the Angular Point) and therefore cannot have dimension in any sense of the word. (Later, though, he does admit that "these Inceptives ... have a magnitude of their own") [*ibid*].


July 1871.
I have thought of the names
The Radian System
and A Radian.
In this a radian would mean
what is commonly called a unit angle
on the circular measure system.
Dr Macdowall seems to think
that this language would
be allowable etymologically;
though he thinks radial would
be preferable according to customary usages
of language. But I point out to him that
the word radial is already too much
allocated for things pertaining to spokes
or radiating lines thus.
I think radian is likely
to be a good sounding
easily used name and
one which is free from all objection
of importance. J. T.

A page from James Thomson's notebook including his naming of the radian

[courtesy Queens University Belfast]

Fourier – writing in his *Analytical Theory of Heat* – stated that "Angles, sines and other trigonometric functions, logarithms or exponents of powers are, according to the principles of analysis, *absolute* numbers which do not change with the unit of length; their dimensions must therefore be taken equal to 0, which is the dimension of all abstract numbers" [Fourier art. 161]. Note that, although this was written some 60 years after Euler's introduction of the radian, he does not seem to be appealing to circular measure here, but rather to the fact that angles appear in mathematical formulae which have no connection with measurable quantities. If angle was traditionally included among geometrical, rather than concrete, properties, this might explain why it has been thought inappropriate to consider it as having dimension; although the same could be said of distance, of course. (However, he may perhaps be confusing angles with *phases* here; I will have more to say about this distinction later on).

K.R.Brownstein, in a 1997 paper, describes the situation regarding the interpretation of the concept of angle as "not very satisfying", and attempts to resolve this problem. He cites examples from elementary mathematics and physics which require, on insertion of numerical values and units, either the deletion or insertion "seemingly at will" of additional units to make the equations give a consistent answer with the right units.

Brownstein starts from several assumptions, including that "each symbol used for a physical quantity must have definite physical dimensions", and an assumption of unit-invariance: "the actual numerical value as well as the associated units of any symbol need not be specified until one has to evaluate an expression containing that symbol" [Brownstein p606]. He then states that "From our point of view, the concept of "angle" has a meaning which is not tied to any relation of the form $\theta = s/R$" [*ibid*. p607]. Indeed, using Norman Campbell's theory of measurement, which explores the basic requirements of a measurement system and derives certain laws which any such system is required to obey [see Campbell pp 1-27], it is easy enough to formulate a procedure for defining and measuring angles which does not require any concept of an arc or a circle. Angle is then not linked to length, but must be regarded as a separate base quantity. Trivially, if we apply the change-ratio A to the unit of angle, the numerical magnitude of any given angle will increase by the same factor A, so that angle can be described as having dimension A.

K. R. Brownstein

Brownstein re-writes the equation relating angle to arc length as $s = □R\vartheta$, where "□" is a constant with the dimension A^{-1}. [1] He also draws a distinction between "geometric" trigonometric functions which map angles to numbers, and more generalised trigonometric functions which map numbers to numbers, by giving the former a capital letter (e.g. Sin) and the latter a lower-case letter [*ibid*. p609]; these "angle-like" numbers Brownstein defines as *phases* [*ibid*.] Since it is these latter functions that tend to be associated with Taylor series, the complication introduced by the use of Brownstein's constant would not arise here, because we are not dealing with angles.

W.E.Eder endorses this view. He quotes R.D.Stiehler's definition of plane angle as "the divergence between two intersecting straight lines ... The magnitude of the divergence can be expressed in a variety of measurement units, such as radian, grad, degree, minute, or second. The magnitude is *not* a number without units." [Eder (1980) p320]. And Kyburg says of angle: "measured directly, it has its own dimension, of course" [Kyburg p129]. This reminds us that it is only when the "measurement" is of the indirect kind in which an arc length is divided by a radius, that the question of angles being dimensionless arises. J-M. Lévy-Leblond also welcomes Brownstein's constant, although, as an ardent reductionist, he welcomes it only to prophesy its imminent demise in the onward march of scientific progress. [Lévy-Leblond p815].

Brian Ellis, in dealing with a problem associated with the displacement of the sides of a cube of material subjected to a shearing stress, multiplies the angular displacement by "a new scale-dependent constant dependent not only on the choice of stress scale, but also on the choice of angle scale". This constant is clearly on a par with Brownstein's. Ellis points out that such a units-invariant format gives us more information than one restricted to a particular angular scale; the moral of which, he says, is that "we can only get out of our dimensional formulae what we put into them. And, if we choose to express our laws with respect to particular scales, we shall inevitably impoverish our dimensional formulae" [Ellis (1966) pp147-148].

Brownstein recommends the reclassification of angle as a separate (8^{th}) SI base quantity. An opportunity to do this presented itself during the recent overhaul of the SI system, but sadly was not taken up. Nevertheless, present-day metrologists are aware of the problem: at a conference in 2015, a former Director of the BIPM said that "this question of angle, how you measure it, and what you call it, is indeed something that is still being discussed in the metrological community".[2] And I have recently had some correspondence with a metrologist at the National Physical Laboratory, Paul Quincey, who co-authored a paper in 2017 which called for changes to the way the radian is described in the SI literature [Quincey & Brown 2017]. Quincey sees angle as on a par with length, and believes that "angle as a physical quantity is fully entitled to its own dimension" [Quincey 2016 p3]. He tells me that the relevant committee at NPL has been asked to "get coherent positions on angle together", but he is not hopeful for a change as he says there is "a range of contradictory but strongly-held positions" on the committee.

One interesting consequence of angle being upgraded in the way Brownstein recommends is that it would remove the degeneracy cited by Bridgman against the strong view [3], since then such quantities as

[1] Brownstein explains that the square symbol is a Hebrew letter, chosen as a pun – both linguistic and visual – on his main thesis of "treating angles squarely".

[2] Terry Quinn, *The Making of Measurement* conference, Cambridge, July 2015.

[3] See part 1 of this article for a definition of the strong view of dimension.

torque and energy would take distinct dimensions, and this might add further fuel to the debate about the exact status of dimensions.

Conclusion

I hope to have convinced the reader that there is far more to dimensions than is commonly appreciated – particularly by physicists. I have struggled to do justice to the topic in this short article, and would refer anyone who is interested in researching it more thoroughly to the bibliography below – particularly the asterisked works.

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Introducing the Open University Space Society

by

David Talbot

The OU Space Science Club is no more and has transformed to become the Open University Space Society. One of the newest OUSA Societies, it is for all OU students, staff and alumni. Everyone is welcome. Our interests cover anything relevant to exploration and exploitation of space from science and technology to law and politics and everything in between. The society owes its genesis to a bunch of Open University under- and post- graduate students meeting informally at the UK Students Space Science Conference, run by UKSEDS, in March 2020 (just before lockdown) at Birmingham University. Over the course of the day it transpired that our interests spanned the whole of the space sector. Not just science and engineering but policy, human factors, space medicine, space law, space art and everything else space. Wouldn't it be good if we had a club? So after a lockdown summer of planning we launched the OU Space Science Club in the midst of the pandemic in October 2020.

After a busy winter of talks, and engaging anyone and everyone we could get to talk to us from across the international space sector and around, came the UKSEDS conference again. Pretty much as we turned 6 months old (and had grown to be biggest UKSEDS branch by a long way with over 400 members). Online throughout 2020 the whole committee was amazed when the OU Space Science Club was declared UKSEDS branch of the year:

> "The best performing branch which has displayed the vision of UKSEDS at every opportunity. This branch worked on a variety of projects and made a great effort to interact with other members nationally."

Not bad for a six month old Club! It also became apparent that our little idea was rather more popular than we had expected. So work began to transform our Club into a Society. This happened as we turned 9 months old and this gave us the foundation for the future as the world moves out of Covid. Plans for the future include face to face meetings, once Covid allows, and supporting our members to enter national and international student space and rocketry competitions.

Everyone is welcome! If you are interested enough in space to read this article then you qualify for membership! Join the Space Society here , or just search for us on your favourite social media platform or the OUSA forums, to be kept up to date on all we are doing. If you want to see what we are up to check out our social media:

https://twitter.com/space_ou

https://www.instagram.com/ouspacesociety/

https://discord.gg/BcRqWQZyXR

https://www.facebook.com/groups/3421877267919229

https://learn1.open.ac.uk/mod/forumng/view.php?id=23446

https://www.youtube.com/channel/UCYgeHjcIBh1d_pxX5wRZkLg

Word Sudoku

A	E			N		P		
V				E	A	U		O
				R				
		V						
			U				A	
	S	P	R				O	
			A			N		
E	U							
	N		V		O	A	S	

You should solve this in the same way that you would solve a traditional numerical Sudoku. But with the twist that instead of numbers you use letters. From the letters provided can you work out what they spell?

Online Places for OU Students of the Physical Sciences to Visit

[Inspiring physics lectures]

[Upcoming events]

[Student Hub Live]

Stephen Lewis
- A Profile

On the 1st August 2021 I was proud to become the Head of the School of Physical Sciences, where I am the Professor of Atmospheric Physics at the Open University. The first thing that must be said is a huge and heartfelt "Thank You" to Prof. Sally Jordan for her years as Head of Department and then later School. Sally put tremendous time, energy and care into everything that she did for Physical Sciences at the OU. I hope that I will continue much of her good work as well as bringing a few new ideas to the role.

I joined the Open University in 2005, having previously researched and taught in the Department of Physics, Oxford University. Despite mostly studying the atmospheres of other planets, I'm also keenly interested in that of the Earth and am an accredited Fellow of the Royal Meteorological Society. My research interests include studying the climate of planetary atmospheres and the interpretation of spacecraft observations using large-scale numerical models of atmospheres. These atmospheres include those of Mars, Venus, the Giant Planets, extrasolar planets and the paleoclimate of the Earth. For the last few years my primary focus has been on Mars discovery and exploration, but my original research topic concerned the dynamics of vortices in the atmosphere of Jupiter and I have also worked on the dynamics of the super-rotating atmosphere of Venus and climate transitions on the ancient Earth.

As part of my research I have worked on many spacecraft and instrument science teams, which include:

- the Nadir and Occultation for MArs Discovery (NOMAD) instrument aboard ESA/RosCosmos ExoMars 2016 Trace Gas Orbiter;
- I was Co-Principal Investigator for ESA/Roscosmos ExoMars 2016 and 2022 entry, descent and landing science;
- the Mars Climate Sounder instrument aboard NASA Mars Reconnaissance Orbiter (2005–), a descendant of earlier instruments I worked on for Mars Climate Orbiter and Mars Observer (both spacecraft were sadly lost);
- the atmospheric science group for NASA InSight (2018–);
- the entry, descent and landing team for NASA Curiosity (2012–) and NASA Perseverance (2021–);
- the Near Infrared Mapping Spectrometer (NIMS) on NASA Galileo (1989–2003), which flew past Venus on its way to its main target Jupiter.

Since joining the Open University I have written, taught on and chaired science modules throughout the undergraduate curriculum. I have enjoyed working as a tutor at residential schools at all levels and helped to develop materials for online practical science. Most recently, I chaired the production of a new stage three Electromganetism module, a subject I have taught for a long time.

When possible, I give talks to science societies and festivals and have contributed to citizen science projects, connected to monitoring the weather and its human impacts. A particularly interesting part of my job is as the academic consultant for BBC television series. Amongst others, I worked on The Planets (first broadcast on BBC2 in 2019) and A Perfect Planet (first broadcast on BBC1 in 2021).

Fusion Visit to Lord Rayleigh's Laboratories

John William Strutt (1842-1919), the third Baron Rayleigh, was one of the most important physicists of the late 19th and early 20th centuries. He won the Nobel prize for the discovery of argon, and gave his name to many other physical phenomena.

Rayleigh did much of his experimental work in his home at Terling Place in Essex. After Rayleigh's death, his laboratories were effectively mothballed; the Strutt family still lives in the house, and the laboratories are not open to the public, but thanks to the co-operation of the current Baron and the enthusiasm of Ted Davis of the History of Physics Group for all things Rayleigh, they do occasionally allow small private parties to visit, and Fusion has been promised some places on a visit scheduled for Thursday 3rd March 2022. Having been lucky enough to go there myself a few years ago, I can testify that these visits provide a unique window into the experimental physics of the early 20th century. Remember that numbers will be strictly limited, so don't delay! Contact Greg Vaughan (gvaughan15@icloud.com) to secure a place.

Jim Grozier.

Solution To Word Sudoku

A	E	U	O	N	V	P	R	S
V	R	S	P	E	A	U	N	O
O	P	N	S	R	U	V	E	A
N	A	V	E	O	S	R	P	U
R	O	E	U	V	P	S	A	N
U	S	P	R	A	N	E	O	V
S	V	O	A	P	E	N	U	R
E	U	A	N	S	R	O	V	P
P	N	R	V	U	O	A	S	E

The word is 'supernova'.

What Is It And What Was It For? Answer

It is an aperiodic/ ballistic galvanometer (post-1919). A ballistic galvanometer was one with a very long period (seconds) whose main use was to measure charge, the change in reading being proportional to the charge passing through the connected circuit. Thus probably used to measure magnetic field by inserting the coil into the field and using Faraday's Law.

Before digital meters became available, most electrical measurements in the lab made use of the tendency of a current-carrying coil placed in a magnetic field to rotate. If suspended on a wire that resists the motion, the coil will come to rest when the net torque on it is zero, so its angular position depends on the current flowing in the coil. That is the principle of the moving-coil analogue meter, but in the days before it was possible to make these small enough to hold in the hand, instead a small mirror was mounted on the coil, which reflected a light placed some distance away onto a calibrated scale, thus amplifying the motion to make it readable. These devices are often referred to as reflecting, or optical, meters, and were the "state of the art" lab measuring instruments in the early 20th century. They were available in various designs for various tasks. Because the wire on which the coil was suspended was very thin, the coil and mirror were very susceptible to air movements, and consequently had to be enclosed in a sealed container with a glass window.

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