NEWSLETTER

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Beginning Bit

Welcome to the first online version of the *Fusion Newsletter* in glorious A4!

Glorious? A4?

Well I find A4 easier to read on a computer screen.

This isn't quite the version of the newsletter I'd been intending to produce. That one was intended to be focused on the forthcoming exams. I intended to highlight some of the revision resources to be found on the website. I also meant to feature the excellent student Revision Weekends: Revision Weekends: Science Revision Weekend (SRW), Astronomy Weekend and the M500 (maths society) Revision Weekend.

Since then coronavirus has struck and we are now in lockdown. And the OU has now cancelled all face to face tutorials and face to face exams and SSTs are working from home. And it is not clear what form the end of assessment of modules will take. Meanwhile, sadly, SRW has had to fold. By my reckoning Astronomy Weekend would have fallen during the lockdown. And the M500 Revision Weekend was scheduled many months ago for May. This is just after the lockdown, which I would expect to be extended.

So instead of producing a newsletter related to revision and exams I thought it might be more useful to do during the lockdown. This includes a guide to some of the interesting resources to be found on the OU website as well as some other things to be found on the internet.

Of course much of the original newsletter remain. That includes Dwyn's account of the Fusion Weekend, an article by Michael on the Curiosity Rover and the first of two pieces by Jim on the History of Dimensions. I've included an article on Jocelyn Bell Burnell. We also have a quiz. But what is Stephen Hawking doing? And why is he in space? All will be revealed inside.

I am hoping to get the next Newsletter out towards the end of the year. This will include the second and final part of Jim's article on Dimensions. One or two other things are also in the pipeline But we will need more than that. So, if you have news, articles, pictures, anything you think might be of interest, please email it to me at: nigeldpatterson@blueyonder.co.uk

Stay safe! Nigel

Fusion Weekend 2019

Dwyn Padfield

Last year's Fusion weekend was held at the OU Campus at Walton Hall the weekend of 7th/8th September – a change of dates to best coincide with the change of the OUSA financial year.

Robert Hooke Building, Open University. Credits: Chmee2

On the Saturday morning we had a variety of talks on observing in Chile, opportunities for physicists in government, the IOP 5 year strategy, block chains and their relationship to biology.

We held the AGM in the afternoon – not the most interesting bit I have to admit! but an essential part of the weekend - when one member offered to join the committee – thank you Gareth!

After this Sally Jordan, head of the Department of Physical Sciences, gave us an interesting talk on the 50 years of the OU, in particular the physics department and personnel, which, of course, coincided with the 50th anniversary of the first lunar landing.

The Paul Ruffle Memorial Lecture was given by Callun MacCormack, of the OU, on quantum computing – a subject which had previously completely floored me, but after Callum's lecture I am now rather more informed.

We had an evening meal at a local hostelry, after which the weather gods decided to be good to us and observing using the OU telescope on site revealed images of the moon, Saturn and Jupiter. Thank you to Andrew Norton for organizing this.

Sunday am we visited Bletchley Park, the home of the WW2 code breakers. This was a return visit – but there is always something new to see.

Due to covid-19 this year's Fusion Weekend/AGM will be held online on Saturday, 26 September starting at 10.00am. Further details will be provided on the [Fusion Website]() **and** [Facebook page]() **as soon as these are available**.

Identify the Physicists

Find the physicists from the anagrams and helpful(?) hints

1	Car laid up?	(no matter!)
2	Elite brain nest	(an original thinker)
3	Gets her pig	(the one with bows on?)
4	Ach! I fear malady	(an induced one, presumably)
5	I wasn’t a cone	(but I did explain Kepler’s ellipses)
6	J.W. at steam	(one way of producing power)
7	Herring downs rice	(before the cat gets it?)
8	Damn China ferry	(he was good at getting things across)
9	I rue a crime	(but I didn’t disintegrate over it)
10	His rays change unit	(or I’m a Dutchman)
11	Her serene brewing	(not certain about that gender though)
12	NHS boiler	(for making tea – with a Danish?)
13	Ran for skill in DNA	(but she didn’t get a prize)
14	O! X-value man	(although it’s crystal clear he’s not called Ray)
15	Fierce minor	(but the “father of”… something terrible)

Exploring Mars with the Curiosity Rover

Michael Taylor

The lecture took place at the ARA Social Club in Bedford and was jointly hosted by the Royal Aeronautical Society and the Bedford Civil Engineering Society.

The lecture was given by Professor John Bridges of the Space Research Centre, Dept of Physics and Astronomy, University of Leicester.

The speaker

Prof Bridges was born in Aberdeen and studied geology at the University of Edinburgh. He completed his PhD in mineralogy at the Open University, and has since worked at a number of organisations, including NASA and UCLA. He became a reader in 2012 and a professor in 2015. He now studies Martian meteorites. A major highlight for him was the landing of Curiosity with the Jet Propulsion Laboratory in 2012. He is an Associate Lecturer with the Open University (!!) as well as conducting teaching and research in Leicester.

The lecture

Prof Bridges said that today Mars is a very different place to what it has been like in the past Today it is cold and dry. it is thought that originally it had a very different, Earth-like environment.

History

1666 – Cassini described the polar ice caps

1784 – Herschel described the seasons

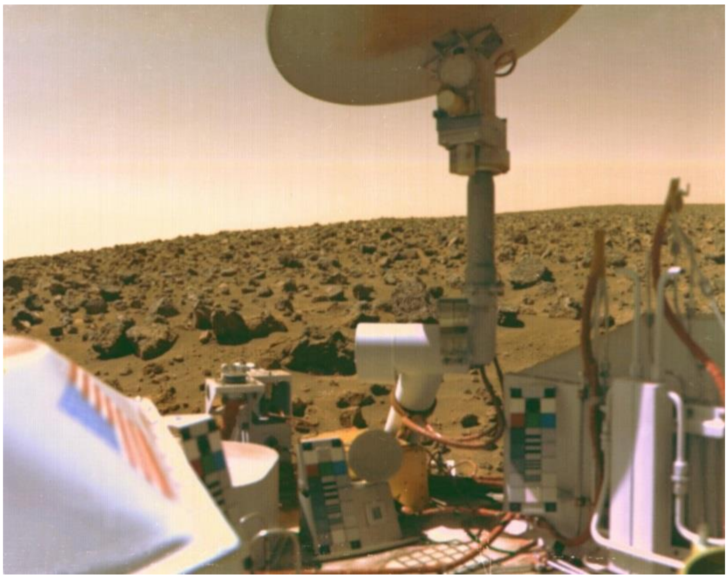
1911 – people wondered whether Mars had ever had life. Until the Space Age, it was thought highly likely that there is life on Mars.

1964 - Mariner 4

1976 – Viking. Gas Chromatography/ Mass Spectrometry (GC/MS) were analytical techniques used to test for life on Mars.

Before Viking there was little knowledge about the atmosphere. There was an investigation into possible landing sites, and scientists wondered whether there were sedimentary rocks or basalt, and whether the planet had ever had life.

Viking 1 and 2 landed on a gentle, undulating surface, at impact craters.



The surface of Mars as seen from the Viking 2 lander. Credits: NASA

In 1997, Pathfinder landed in the same place as Viking 1, because of the nature of the landing technology. It showed that a rover could be operated remotely from Earth, over a range of about 10 metres

The Viking Orbiter provided images of fluvial channels, depending on the resolution. If fluvial, it suggested that Mars had been through the water cycle etc. So it was concluded that there must be more to Mars than meets the eye.

Analysis of meteorites found on Earth suggested that they had originated on Mars, from the composition of gases, which were the same as the Martian atmosphere.

Our view of Mars has changed as the quality of the images has improved.

We could predict with 99.5 % accuracy where landers would land within an ellipse.

The Viking ellipse had a size of about 250 km.

The size of elliptical landing sites has decreased with improvements.

There is a synergy between science and technology in these missions, but science is the driver!

The Jet Propulsion Lab and UK have largely been responsible for the technology.

In the south of Mars, there is a higher density of impact craters, so this area has always been favoured for potential landing sites.

In 1996, there was the Mars Global Surveyor. There were high resolution cameras, in which 1 pixel corresponded to 1 to 2 metres, so you could tell if you were in a room! Before this, it was thought that the rocks were mainly basalt. But Surveyor suggested, from images, that there was probably sedimentary rock, suggesting an environmental history of lakes and rivers.

The Eberswalde Crater must have contained a lot of water.

Absorption in the Near Infra-Red suggests existence of clays, which in turn indicates water.

In November 2011, The Mars Science Lab (MSL) (carrying the Rover) was launched from Cape Canaveral. It had 4 solid boosters and landed in the Gale Crater. It hit a landing ellipse of 7 by 20 km in August 2012.

The Curiosity Rover has 6 wheels. It has a laser to study absorptions. There is a robotic arm, as well as GC/MS, X-ray spectrometer and devices to study X-ray diffraction. Also, there are other environmental instruments. The daily power budget is about 100 Watts! It only operates after 11 am, after the planet warms up. So there is a daily pattern of data recording.

Curiosity Self-Portrait at 'Big Sky' Drilling Site. Credits NASA.

When approaching the surface of Mars, the lander was travelling at 6 km/second which then had to decrease to 0 km/s in 7 minutes. There is an online video of the landing, along with observations of the JPL team watching. There was a stage separation followed by a parachute descent.

Curiosity found layered mudstones on the surface, like during the Jurassic period in the UK. Below the surface, there were organics. X-ray diffraction uses Bragg's Law to determine the minerals. The Rover found clay, as predicted. They believe that river deposits led to the formation of a delta and that there was a long-standing body of water like a lake, which then led to mudstones. The MSL uses mass spectrometry to look for methane. Two mass spec absorptions may suggest different isotopes of carbon. GC/MS was combined with analysis by a tuneable laser spectrometer. Methane spikes were found on a seasonal basis, which begs the question: why? Perhaps there is a methane plume? The orbiter around Mars is able to look for methane plumes. The methane could have come from rocks and they are wondering whether it is released by microbes, but cannot be sure, and we need to be patient!

The MSL landed near the Bagnold Dunes and has been driven 18 km to the Vera Rubin Ridge, where it is currently located. The area of 18 km has been divided into smaller quadrangular zones, with names related to places on Earth e.g. there is a Scottish area with names like Oban. It is necessary to drive carefully because Curiosity is 'mortal'. For example, there has already been some damage to the wheels, which are made of thin aluminium plate, so the wheels on future rovers will probably be constructed from titanium.

The ExoMars was launched in October 2016. It had a trace gas orbiter called Schiaperelli to look for evidence of gases in the Martian atmosphere, particularly methane. The lander crashed due to timing issues with the parachutes. The ExoMars Rover will be launched in 2020. It will have a 2 metre drill

Following the lecture, there were a number of questions, which I will not elaborate upon here.

Jocelyn Bell Burnell

A Scientist of Remarkable Generosity

Nigel Patterson

Jocelyn Bell Burnell is probably best known for her key role in the discovery of pulsars (rotating neutron stars). It was an important discovery and one which was recognised in the award of a Nobel Prize. To her supervisor, Antony Hewish. She accepted this with remarkable equanimity and lack of bitterness.

Although proud of her role in the discovery of pulsars Bell Burnell considers her greatest achievement to be helping to found the Athena SWAN (Scientific Women's Academic Network) Charter Award. This was established in 2005 to recognise, and to celebrate, the advancement of gender equality in higher education and other institutions. It has since been extended to recognise gender equality in other areas. The OU School of Physical Sciences currently holds a Silver Award, and other STEM Schools hold Bronze Awards.

Bell Burnell has received numerous awards, has served as President of the Royal Astronomical Society and was the first female President of the Royal Society of Edinburgh and of the Institute of Physics (IOP). She was awarded a CBE in 1999 and appointed a Dame in 2007. Since 2018 she has been Chancellor of the University of Dundee.

She has had a long association with the Open University with whom she has worked in a variety of capacities since 1973. In 1991 Bell Burnell was appointed the first female Professor of Physics at the OU, a position she held until 2001. She has worked at several of the leading UK universities, at Princeton in the US and at the Royal Observatory in Edinburgh.

In 2018 Bell Burnell she was awarded the Special Breakthrough Prize in Fundamental Physics. The Prize was worth $3 million (£2.3 million). A not inconsiderate sum. She donated the entire sum to help fund women, minority groups and refugees to become researchers in physics through the Bell Burnell Graduate Scholarship Fund which is administered by the Institute of Physics.

Dame Jocelyn Bell Burnell accepts Special Breakthrough Prize. Credits: IOP

In 2019 Bell Burnell visited the Open University to give a talk on her discovery of pulsars – *An Accidental Discovery* – as part of the OU's 50th birthday celebrations. You can watch her talk here.

She deserves admiration for her work in astrophysics. And she deserves just as much admiration for her principles and her generosity.

A Brief History of Dimensions
Part 1

Jim Grozier

This article is based on an article published in the newsletter of the History of Physics Group of the Institute of Physics in December 2016 (issue 34), with the permission of the Editor.

Dimensions are usually dealt with in an extremely rudimentary way in physics textbooks – the sole purpose being to prepare the student for dimensional analysis. This is a shame, because, behind the standard half-a-page treatment, there is a rich history, much of which is in danger of being forgotten altogether, at least by physicists; this despite the fact that, in a sense, it is still going on.

In this article I will survey the history of dimensions from the 17th century to the present, and examine an oft-quoted thesis that the number of dimensions can or should only reduce with time.

A Note on Nomenclature: Base Units and Fundamental Units

Norman Campbell, in his classic book *An Account of the Principles of Measurement and Calculation,* published in 1928, defined "fundamental measurement" as "measurement which involves no previous measurement". It is thus a natural step to think in terms of "fundamental quantities" as those quantities that allow of fundamental measurement (though Campbell preferred to call them *magnitudes*), and of the units in which they are measured as "fundamental units". The term favoured by the BIPM (International Bureau of Weights and Measures) in its definitions of the SI units, however, is *base unit*. This is unfortunate, since the concept of dimension lends itself very readily to the formalisms of linear algebra, so that a set of dimensions can be represented as a vector space, in which the term *base quantity* or *base unit* then has a very special meaning [see e.g. Subramanian (1985)]. The main problem here is that, while the BIPM clearly prefers to identify *specific* units, once and for all, as base units, dimension spaces can be transformed into one another, so that the base units, in the vector space sense, change too. In this article I will refer to *fundamental* units rather than base units, to avoid this ambiguity.

Early Concepts of Dimension

The concept of dimension, in the sense in which it is used today in dimensional analysis, goes back at least to the 17th century. Descartes, in 1629, extended the familiar concept of spatial dimensions so as to include other quantities such as weight and speed: "length, breadth and depth are not the only dimensions of a body; weight too is a dimension ... speed is a dimension ... and there are countless other instances of this sort" [Roche p189]. For Descartes, a dimension was simply a "measurable property".

John Wallis, writing in 1684, echoes Descartes' classification: "besides the three dimensions LBT (Length, Breadth and Thickness) it hath acquired a fourth Dimension ... of Weight ... And if to those four dimensions we super-induce the fifth of Celerity: the Force arising LBTWC, is a Magnitude of five Dimensions" [Wallis p94-95]. For both Descartes and Wallis, dimension is thus a *qualitative* concept only: a way of classifying the various kinds of measurable properties.

In 1822, Joseph Fourier, in his *Analytical Theory of Heat*, added a *quantitative* aspect, assigning, to each term in his equations, an integer representing the dimension of that term *with respect to a given unit*. Fourier was concerned that equations should not be affected by the choice of a particular system of units. In order for this to be the case, it is necessary for a change in the unit of any one fundamental quantity to bring about a proportionate change in *every* term in the equation; Fourier expresses this by requiring that "every term ... have the same total exponent" with respect to a given quantity [Fourier, Art. 161]. He expands on this as follows: "suppose ... the unit of length to be changed, and its second value to be equal to the first divided by m. Any quantity x which in the equation ... represents a certain line *ab*, and which, consequently denotes a certain number times the unit of length, becomes mx, corresponding to the same length *ab* ... thus the dimension of x with respect to the unit of length is 1" [*ibid.*].

The "1" here is the exponent of m in the overall expression; had the factor by which x changed been m^2 or $1/m$, he would have said the dimension was 2 or -1 respectively, and so on. Notice that Fourier is referring to *length* as a generalised spatial dimension, rather than the distinct *length, breadth* and *depth/thickness* mentioned by Descartes and Wallis. This is because his argument is based around units, and he is clearly assuming that the three spatial dimensions will be measured in the same units.

Two other names which are often associated with the development of dimensional analysis in the 19th century are Gauss and Weber. Both were involved in defining new "absolute" units for electrical and magnetic quantities, which would be defined in terms of the units of the "fundamental" quantities, mass, length and time. This was not just an academic issue: reliable standards of electrical quantities like resistance were needed by telegraph engineers, particularly in the latter part of the century, when problems with undersea cables presented a major challenge.

A system of absolute units is coherent, and dispenses with the so-called "useless coefficients" required to convert, say, from gallons to cubic feet. From the dimensional formula for a particular quantity, one can simply read off the appropriate derived units – e.g. since energy has dimensions ML^2T^{-2}, its unit in the cgs system would be g cm^2 sec^{-2} (later named the erg).

Maxwell's absolute units and the problem of electromagnetic quantities

The next major contribution to the subject was by James Clerk Maxwell. In his *Treatise on Electricity and Magnetism* (1873) Maxwell introduced dimension as a property of *units* rather than quantities. He spoke of "ascertaining the dimensions of every unit in terms of the three fundamental units” and stated that “When a given unit varies as the n^{th} power of one of these units [i.e. fundamental units] it is said to be of *n dimensions* as regards that unit” [Maxwell (1873) Art. 2]. Maxwell’s dimensional formulae consisted of products of powers of quantities M, L and T, which he described as the units of mass, length and time [*ibid*. Art. 3-5]. He provided a table giving the dimensions of all known electrical quantities, many of which featured, somewhat controversially, fractional powers of M, L and T.

James Thomson, however, objected to this talk of “powers of units”. In 1878, he wrote that “much of the nomenclature and notation hitherto used is very confusing and unsatisfactory”. Thomson was responding, not just to Maxwell, but also to J D Everett, who had proclaimed that the “the unit of acceleration varies directly as the unit of length, and inversely as the square of the unit of time”. Thomson argued that we have no right to speak of such things as “the square of the unit of time”, since units are not numbers, but entities derived from physical standards, and cannot be multiplied by one another, although they can be added, and hence multiplied by a number.

626.] *Table of Dimensions.*

	Symbol.	Dimensions in Electrostatic System.	Dimensions in Electromagnetic System.
Quantity of electricity	e	$[L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-1}]$	$[L^{\frac{1}{2}} M^{\frac{1}{2}}]$.
Line-integral of electromotive intensity	E	$[L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}]$	$[L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}]$.
Quantity of magnetism Electrokinetic momentum of a circuit	m p	$[L^{\frac{1}{2}} M^{\frac{1}{2}}]$	$[L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-1}]$.
Electric current Magnetic potential	C Ω	$[L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}]$	$[L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}]$.
Electric displacement Surface-density	$\mathfrak{D}$	$[L^{-\frac{1}{2}} M^{\frac{1}{2}} T^{-1}]$	$[L^{-\frac{3}{2}} M^{\frac{1}{2}}]$.
Electromotive intensity	$\mathfrak{E}$	$[L^{-\frac{1}{2}} M^{\frac{1}{2}} T^{-1}]$	$[L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-2}]$.
Magnetic induction	$\mathfrak{B}$	$[L^{-\frac{3}{2}} M^{\frac{1}{2}}]$	$[L^{-\frac{1}{2}} M^{\frac{1}{2}} T^{-1}]$.
Magnetic force	$\mathfrak{H}$	$[L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-2}]$	$[L^{-\frac{1}{2}} M^{\frac{1}{2}} T^{-1}]$.
Strength of current at a point	$\mathfrak{C}$	$[L^{-\frac{1}{2}} M^{\frac{1}{2}} T^{-2}]$	$[L^{-\frac{3}{2}} M^{\frac{1}{2}} T^{-1}]$.
Vector potential	$\mathfrak{A}$	$[L^{-\frac{1}{2}} M^{\frac{1}{2}}]$	$[L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}]$.

627.] We have already considered the products of the pairs of these quantities in the order in which they stand. Their ratios are in certain cases of scientific importance. Thus

Maxwell’s table of dimensions [Maxwell 1891]

He suggested an alternative approach which recalled Fourier’s method, based on changing the sizes of units. Thomson’s *change-ratio*, the factor by which the unit is reduced, was identical to Fourier’s factor *m*. Being a pure number, the change-ratio can be subjected to algebraic manipulation, whereas magnitudes and units are not pure numbers and hence cannot be so manipulated. [Thomson (1878) p452].

What Thomson’s modification amounts to is redefining the terms appearing in Maxwell’s dimensional formulae – M, L and T and products of powers thereof – as change-ratios. Thus, if the unit of mass is reduced by a factor M, that of length by a factor L, and that of time by a factor T, the *numerical value* of an expression representing energy, for example, will increase by a factor ML^2T^{-2}.

Maxwell’s dimensional formulae had two major drawbacks. One was that the formulae he arrived at for the electrical quantities were not unique, and depended on whether one worked in the electrostatic or the electromagnetic system of units. These systems arose, of course, from defining electric charge in such a way that the constant in Coulomb’s Law took the value unity, and defining magnetic pole strength in such a way that the constant in the corresponding magnetostatic equation was unity; this was fine as long as electrostatics and magnetostatics were seen as two entirely separate disciplines, but of course it transpired that they were not; one had to choose one or the other of these defining equations, and each then gave rise to a separate system of units and dimensions.

The other problem with Maxwell’s formulae was the presence of fractional powers. Clearly, if one defines a unit of charge so that Coulomb’s Law takes the form XXX for the force between two charges q_1, q_2 separated by a distance r, with mass, length and time as the fundamental quantities, if the fundamental units are reduced by the usual factors, the quantity q_1q_2 must increase by a factor ML^3T^{-2}; this means that we are forced to conclude that charge has dimensions $M^{1/2}L^{3/2}T^{-1}$. In the electromagnetic system of units, however, the dimensions of charge are $M^{1/2}L^{1/2}$. And in both systems, almost all electrical quantities turn out to have dimensions which are fractional powers of M, L and T, with few exceptions, among them resistance – which has dimensions $L^{-1}T$ in the electrostatic system and LT^{-1} in the electromagnetic.

These fractional dimensions implied that the corresponding units would also be fractional powers of the fundamental units – but it was by no means clear what this might mean. In contrast, the dimensions of resistance appeared to be the same as those of velocity (or the reciprocal of velocity, depending on which system of units one used). A debate ensued about whether resistance, in the electromagnetic system, could in fact be regarded as a velocity in some sense; experiments were even devised which could read off the value of a resistance in units of velocity, by measuring a real velocity [see e.g. Mitchell pp 73]. John Roche quotes William Thomson as announcing to a meeting of electrical engineers in 1883 that “we are going to learn [that] electrical resistance ... is a velocity” [Roche p202]. Daniel Mitchell, however, questions whether Maxwell or Thomson really believed that resistance (in the electromagnetic system of units, or its reciprocal, now known as *conductance*, in the electrostatic) was a velocity, rather than a quantity that was *expressed* as such in the particular experimental conditions of their thought-experiments, concluding that they “never tried to claim” that it was [Mitchell p76].

The Strong View; Dimensional Analysis

This idea that resistance “is a velocity” – that, in other words, there is something more to two quantities having the same dimensions than simply being measured in the same units – brings us to what Roche has called “the strong view of dimension” and Mitchell refers to as a “physicalist” view: the belief that dimensions reveal the “essential” or “ultimate” nature of a quantity. This recalls the early work of Descartes and Wallis, in which dimensions were regarded as qualitative properties. W.W. Williams was a subscriber to this view; in an 1892 paper, he said that “the dimensional formulae may be taken as representing the physical identities of the various quantities, as indicating, in fact, how our conceptions of their physical nature (in terms, of course, of other and more fundamental conceptions) are formed”. He saw this view as “more comprehensive and fundamental” compared with the interpretation of dimension as “merely a change-ratio” [Williams p237].

Percy Bridgman, writing in 1922, had little time for the strong view. He pointed out that “when there are so many kinds of different physical quantities expressed in terms of a few fundamental units, there cannot help being all sorts of accidental relations between them, and without further examination we cannot say whether a dimensional relation is real or accidental” [Bridgman p91]. A “real” dimensional relation between two quantities would, for Bridgman, imply a *physical* relation between them. Against this view, Bridgman argues that “the mere fact that the dimensions of the quantum are those of angular momentum does not justify us in expecting that there is a mechanism to account for the quantum consisting of something or other in rotational motion” [*ibid*]. The quantum – Planck’s constant – is usually called the quantum of *action*, since it has the dimensions of [energy] $\times$ [time], or ML^2T^{-1} ; but angular momentum is also described as having these dimensions. Another pair of apparently dissimilar quantities which are regarded as having the same dimensions are torque and energy (both ML^2T^{-2}). Interestingly, Williams saw this very dimensional correspondence between distinct quantities – or rather, “the fact that difficulties are felt” in respect of it – as evidence *for* the strong view: if the formulae are to express nothing more than numerical dependence on the fundamental units, “we are not entitled to feel any difficulty in the matter” [Williams p238].

Bridgman’s book, *Dimensional Analysis*, is described by Roche as “the first book devoted entirely to dimensional analysis”. This emerging discipline formalised and built on Fourier’s dictum that every term in an equation should have the same dimension with respect to each of the fundamental quantities, which enabled physicists to narrow down the range of possible formulae for a given quantity, and provided a means of checking formulae for consistency. It proved particularly successful in fluid mechanics.[1]

By the late 19^{th} century, it was established that heat was a form of energy, and hence had the same dimensions (ML^2T^{-2}) so that, with the dimensions of electrical quantities also being expressed in terms of mass, length and time, there was a perception that *all* quantities had mechanical dimensions. This view is sometimes referred to as “mechanical reductionism”. It is well known that Maxwell had a mechanical model to explain electromagnetic phenomena (though whether Maxwell himself saw this as a literal explanation or simply an analogy, is an open question).

However, even at the height of the “mechanical reductionist” era, there were those who regretted the “suppression” of electrical and magnetic dimensions. A. W. Rücker introduced electrical and magnetic constants *K* and μ, respectively, of unknown dimensions, and produced a table giving dimensions of various electrical and magnetic quantities in terms of

[1]Note that the dimensional formula for a given quantity may take different forms depending on what it is being used for. Maxwell’s primary motivation was to “[ascertain] the dimensions of every unit in terms of the three fundamental units” – in other words, to find the appropriate absolute unit for a given quantity. But in Bridgman’s book many of the formulae are given, not just in terms of the fundamental quantities, but sometimes also include derived quantities, such as velocity and force, because the nature of the problem at hand leads us to suspect that these derived quantities will be present in the formula.

M, L, T and either *K* or . He based this on a table which he says Maxwell had given, "in which the dimensions of each of the electrical and magnetic units are given in terms of M,L,T and either electrical quantity or the strength of a magnetic pole" [Rücker p109].[2]

Williams developed this idea, and found possible dimensions for *K* and which led to "intelligible, natural and connected" dimensions for these quantities, which did not involve fractional powers; note, though, that neither Rücker nor Williams introduced a fourth fundamental quantity – Williams' postulated dimensions for *K* and were still expressed in terms of the mechanical quantities M, L and T.

To be continued ……

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[2] Rücker does not, however, give a reference for this. Daniel Mitchell explains that Maxwell introduced a magnetic constant in a piece (co-authored with Fleeming Jenkin) entitled *On the Elementary Relations Between Electrical Measurements*, published in 1865, but removed references to this constant in a later edition published in 1873. [Mitchell, personal communication].

Identify the Physicists

Answers

1 Paul Dirac
2 Albert Einstein
3 Peter Higgs
4 Michael Faraday
5 Isaac Newton
6 James Watt
7 Erwin Schrodinger
8 Richard Feynman
9 Marie Curie
10 Christopher Huygens
11 Werner Heisenberg
12 Niels Bohr
13 Rosalind Franklin
14 Max von Laue
15 Enrico Fermi

A New Qualification and New Modules

This year the OU is introducing a new single honours named degree: BSc (Honours) Physics.

The existing degrees still remain. You can still follow either the Physics or Astronomy and Planetary Science Pathways through the BSc (Honours) Natural Sciences and to take the BSc (Honours) Mathematics and Physics comprising half the modules provided by the School of Mathematics and Statistics and the other half by the School of Physical Sciences. This chart shows the main physics and astronomy and planetary science pathways.

There also remain broader qualifications so BSc (Honours) for those who want to include a range of the Sciences in their degree, the BSc (Honours) Combined STEM for those who want to include other STEM subjects, such as Computing and Technology, as well as the BA/BSc (Honours) Open degree.

During the past few years the School of Physical Sciences and the School of Mathematics have been refreshing or rewriting their curriculum. New modules have new been written at Levels 1 and 2. This year SXPS *Remote experiments in physics and space* replaced SXPA288 and for the forthcoming academic year the Astronomy module S282 will be replaced by the completely new S284. New modules SM380 and SM381 will replace the Quantum Physics and Electromagnetism modules in 2021. It is presently intended that the level 3 Astrophysics and Planetary Science modules will be replaced by new modules in 2022. The project module SXP390 will also be reviewed during the next year or so.

Things to do During the Lockdown

It looks as if we are going to spend a lot of time in doors at home during the next few months as a result of covid-19 or coronavirus. So here are some suggestions of things to entertain you during that time.

The School of Physical Sciences has a very useful Physics, astronomy and planetary science Study Home website. The site is well worth exploring since it contains many interesting things. The bottom item of the 'Menu' tab is Inspiring physics lectures. There you will find links to recordings of some 15 talks on many different aspects of the physical sciences – physics, astronomy and planetary science. These include lectures held IOP lectures held jointly with the IOP as well STEM OpenTalks and much else besides.

A recent IOP/OU lecture and which is not yet included in the *Inspiring physics lectures* page was given by Dr Floor van Leeuwen, University of Cambridge, on *Details of the Hertzsprung-Russell diagram as revealed by the 2nd Gaia data release*.

Dame Jocelyn Bell Burnell's lecture *An Accidental Discovery*, which she gave as part of the OU's 50th birthday celebrations, can be found here .

Emeritus Professor Russell Stannard has given an interesting talk on *The Early Years of The OU* which you can find here. Stannard joined the OU near the very beginning when he was appointed as Professor of Physics in 1971.

Professor David Rothery regularly hosts *Planets and Moons Chats* together with a different guest. The chats are broadcast live and then put up on YouTube. Recent chats include:

- with Judith Croston Oct 2019
- with Rachael Hamp March 2019
- with Helen Frazer and Nisha Ramikissoon Nov 2018
- with Monica Grady Nov 2017
- with Ian Wright March 2017
- with Manish Patel December 2016

There are many OU webscasts of lectures on a variety of different subjects and held at the OU Berrill Lecture Theatre which you can watch here .

Finally, what is Stephen Hawking doing on the front cover of the Newsletter? Shortly before his death Hawking was invited by his friend Brian Cox to star in a Monty Python sketch and at the same time sang the Python's *Galaxy Song*.

Happy viewing!