fusion

The Open University Physics & Astronomy Society

NEWSLETTER

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Contents

Beginning Bit

Hello all.

Welcome to the third digital only edition of the Fusion Newsletter.

We have plenty of interesting articles in the current issue of the Newsletter which I hope you will enjoy reading.

We are sad to report the death of Russell Stannard. Russell was a founding member of the newly founded Open University Physics Department of which he soon became a Professor. An enthusiast for his subject Russell wanted to make the important ideas of modern physics accessible to young children and so wrote his wonderful series of *Uncle Albert* books.

In case you are wondering what that curious yellow object is on the front page of this issue – it is the James Webb Space Telescope (JWST) under construction. In her article Jo Barstow talks about watching the launch of the JWST with her daughter ('Princess Anna of Arandelle') last Christmas and the necessary interruption to Christmas Dinner preparations! As well as telling us something about what it is hoped might be observed with the JWST Jo also tell us about her own interest in the telescope as an exoplanet scientist. We plan to have further articles on some of the observations made by the JSWT in future issues of the Newsletter.

Sam Henry has written a fascinating article on Underground Science which we are publishing in two parts. In the first part he tells us about experimental research into dark matter at the underground laboratory at Gran Sasso in Italy. In the concluding part – to be published in the next issue – Sam discusses the experiments into geomagnetism at the underground laboratory in Rustrel in France.

Finally I would like to offer enormous thanks to Jim Grozier who has done so much to help put the current issue of the Newsletter together. As well as contributing several articles – an obituary for Russell Stannard, a fascinating article on *Does* $E = mc^2$? and an interesting update on research into fusion – he has also gathered several other contributions to this issue of the Newsletter.

Dwyn has contributed an account on last year's Fusion Weekend/AGM and a quiz. And we also have another instrument to identify in *What is It and What is It For?*

At the moment we have a problem with the Fusion website which we are hoping to resolve soon. In the meanwhile if you want to contact Fusion then please email: fusionsocietyou@gmail.com If you have any comments you would like to make about the Newsletter or contributions then please email that address with the heading *Newsletter*

Russell Stannard OBE: 1931-2022

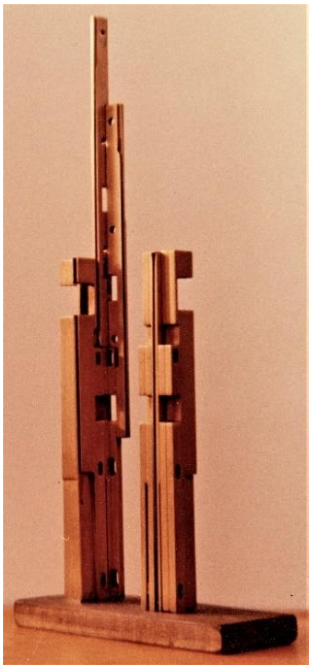
Russell Stannard began his physics career as an undergraduate at University College London in 1950, and gained his BSc in 1953. After graduating he took his PhD with the cloud chamber group under Eric Burhop, working on “Susie”, a high pressure cloud chamber (at that time the standard method for studying sub-atomic particles) in 1956-7. The chamber was on Mount Marmolada in the Dolomites in north-eastern Italy; access to the lab involved a 3 hour climb up the mountain, and the equipment itself was extremely dangerous; on one occasion he received an electric shock that was “eight times more powerful than what you would get from sticking your fingers in a 240 volt light socket. My body jack-knifed and I was involuntarily flung across the laboratory. There was the smell of burning flesh. I had been literally within an inch of being killed”.

After the completion of his cloud chamber work, Stannard moved to nuclear emulsion studies, investigating various particles including K mesons and sigma hyperons. This work was a collaboration with groups at Bristol, Brussels, Dublin, Milan and Padua.

In the late 1950s it became clear that the bubble chamber would become the dominant particle detector. Stannard went to the University of California at Berkeley in 1959 to learn bubble chamber techniques from Wilson Powell, and in the early 1960s he worked with UCL colleagues Fred Bullock, Alan Common, George Kalmus, Mike Esten and Cyril Henderson in a bubble chamber collaboration based first at the Lawrence Radiation Lab in Berkeley and later at CERN, and also on detectors at the Rutherford Appleton Laboratory and Bergen. During the 1960s he managed a team of scanners, whose job involved using specialist machines to examine the thousands of photographs produced by the bubble chambers in order to find interesting interactions. It was in that context that I met him in 2013-14, whilst preparing historical articles on the scanners and the UCL department.

Stannard left UCL in 1969 to help set up the physics department at the newly-founded Open University, and became a prominent member of the department there, becoming a professor in 1971, head of physics from 1971-92, and pro-vice chancellor from 1974-76. He was President of the Institute of Physics from 1987-91.

At the OU, he brokered a collaboration with the UCL physics department to teach a joint course in quantum mechanics, which was widely acclaimed.. His OU colleague David Broadhurst describes him as “an innovative teacher, always seeking to render what others considered as abstruse to be comprehensible to dedicated adult learners”. Another OU colleague, John Bolton, found the OU department to be “happier and more collegiate than others around us” under his leadership, while Bob Lambourne remembers his practice of giving copies of “Complete Plain Words”, Sir Ernest Gower’s essential guide to clear English, to all new academics. He continued his particle physics research at the OU, setting up an emulsion group there, and discovered one of the first three tracks from a charmed particle in nuclear emulsion while working at the OU.



He became interested in the interface between science and religion, and was for 12 years a trustee of the John Templeton Foundation, whose vision is "to advance our understanding of the deepest and most perplexing questions facing humankind". His son Adrian notes that this work "brought together two naturally opposing views in the church and science, [and] found a way to marry them and bring people together."

In the 1990s, he was commissioned by Cambridge University Press to write an updated version of George Gamow's "Mr Tompkins" popular-science books. He wanted to remove some of the sexist language and other outdated tropes, but had to do battle with the publishers for these changes before getting the go-ahead from Gamow's niece. He also published his own series of physics-related children's books, the "Uncle Albert" series.

He was a keen sculptor, and had some of his works on display at the OU. Some of his creations were inspired by pieces of physics equipment, such as a piece entitled "City Structures" which is based on part of a machine used for scanning nuclear emulsions.

In 1998 Russell Stannard was awarded the OBE for "contributions to physics, the Open University and the popularisation of science".

He is survived by his wife Maggi and his four children.

Jim Grozier

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Fusion Event And AGM 2021

Fusion was hoping to hold the annual Fusion event 2021 'in person' after the Covid restrictions put paid to our plans in 2020, but the ongoing problems meant that we again had to hold it online.

We had three talks - Greg Vaughan spoke about his experiences studying remotely with the OU, and several people joined to add theirs.

We had a talk from the OU Space Science Society– they are very active, with lots of online talks. They were awarded the UKSEDS Branch of the year 2021, after only being in existence since 2020 - how fab is that!! Their website is www.ouspacesciencesociety.org.

Lee Patrick spoke to us about his research on 'the lives of massive stars and how to find them before they explode'. He is based at the observatory on Las Palmas in the Canary Islands, and is seconded to the OU. This was an especially topical subject due to the then recent eruption of the Cumbre Vieja volcano, which has disrupted his research.

The Fusion AGM is part of the annual event.

All members of the committee were returned with no objections. Two people, Greg Vaughan and Jim

Grozier, who were previously both committee members offered to rejoin the committee – Greg as secretary, following the recent sad death of Michael Taylor.

We really need some new committee members, with new ideas. We hold 3/4 committee meetings each year. In better times one of these is at MK, but in the present circumstances they all are online– so you don't even have to get out of bed to attend!! If you are interested in joining the committee contact Dwyn - fusionsocietyou@gmail.com.

Dwyn Padfield

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James Webb Space Telescope (JWST)

On Christmas Day last year - despite the critical importance of timing when it comes to a good roast dinner - I temporarily abandoned turkey, roast potatoes and sprouts to stand in front of the TV with my then-4-year-old daughter and watch, fingernails digging into my palms, as the James Webb Space Telescope lifted off from Kourou atop its Ariane 5 launch vehicle. This was the moment astronomers had waited for, for what sometimes seemed like forever – the original launch date was projected to be between 2007 and 2011. Various delays due to the need for redesign, testing failures and of course a global pandemic extended the timeline by more than a decade.

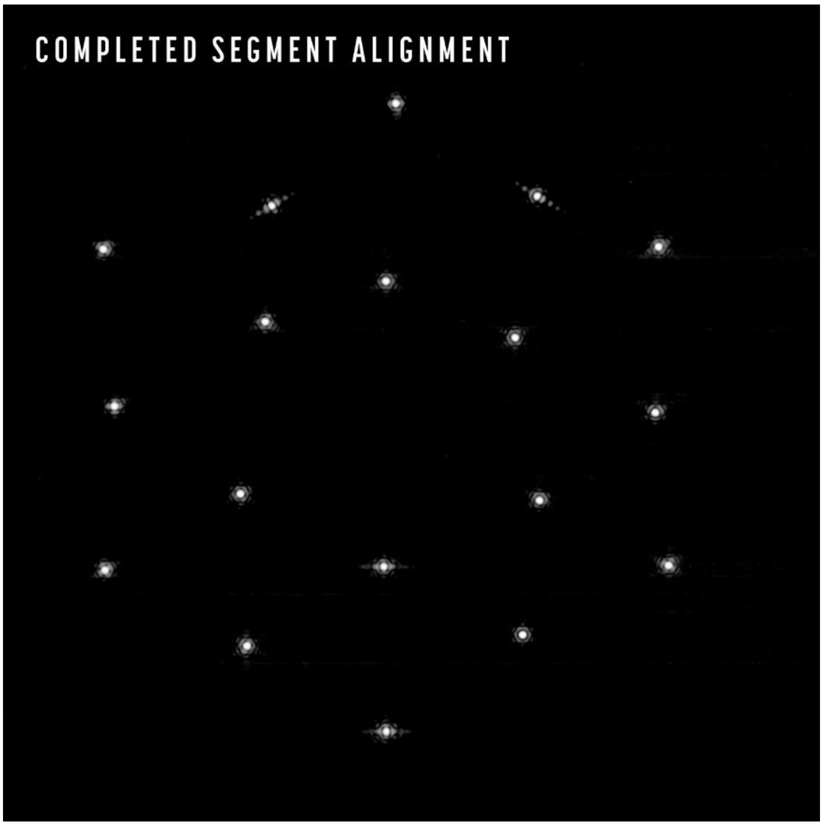
A successful launch, while cause for celebration, certainly wasn't the end of the telescope's challenges. The James Webb Space Telescope (JWST) has a 25 square metre primary mirror, the largest on any space telescope yet, and because it will observe at infrared wavelengths it has a large sunshield to ensure the low temperatures required for operation. In order for it to fit inside the Ariane 5 fairing, these key spacecraft components had to be folded and later deployed during the mission's cruise phase. There were over 300 potential single point failures – mission-critical deployment steps with no alternatives or back up options – that had to be successfully overcome during the weeks following launch.

1|Princess Anna of Arandelle (Jo's daughter) watches the JSWT launch

Now safely ensconced in its orbit around the L2 Lagrange Point, sunshield open and mirrors undergoing the careful final adjustments that will ensure a perfect focus, JWST is getting ready to study the stars. Due to a perfect launch with minimal course corrections required, leaving plenty of fuel manoeuvring, we could be making use of the observatory for 20 years – twice its nominal lifetime. With observing programmes planned to look at everything from Saturn to distant galaxies, groundbreaking results are anticipated across astronomy.

My personal interest in JWST is for the study of transiting exoplanet atmospheres. More than half of the currently known exoplanets were discovered by watching for periodic dips in the amount of light coming from their parent stars, caused by the planet passing in front of the star from our viewpoint and blocking some of the starlight. When this happens, a tiny fraction of the starlight is filtered through the planet's atmosphere. Because different gases in the atmosphere will absorb particular wavelengths of light, this starlight has the planet's atmospheric composition imprinted onto it. I generate computational models of the passage of light through an atmosphere, and compare the outputs to transit observations from the Hubble Space Telescope, Spitzer and ground based telescopes to determine the properties of exoplanet atmospheres. This technique for studying exoplanet atmospheres is called transit spectroscopy.

Transit spectroscopy is best suited to hot, gas giant exoplanets orbiting close to their parent stars. These hot Jupiters have fluffy atmospheres that produce the largest wavelength-dependent variations in the amount of starlight that is absorbed by the atmosphere. Especially with Hubble, we have been able to use this technique to make great strides in understanding hot Jupiter atmospheres over the last few years. We've detected water vapour, clouds made of silicates and other minerals and metal oxides in gas form; we've also seen molecules start to break apart and be ionised on the very hottest planets, some of which have temperatures equivalent to that of a cool star.



By looking at the light coming from the system either side of and during the eclipse of a planet behind its star, we can also study the thermal emission from the planet itself, which allows us to investigate the atmospheric structure – how the temperature changes as a function of altitude. For the most favourable targets, we can even observe the minute changes in the total amount of light from the system as the planet completes an orbit around its star, which allows us to map temperature and sometimes gas abundance as a function of planet longitude.

These measurements are at the very limit of what Hubble is able to achieve. JWST, however, with a much larger mirror and designed to probe further into the infrared, is ideally suited for transit and eclipse spectroscopy of exoplanets. In particular, we hope that JWST will enable us to study smaller and cooler planets in the same way we've been able to observe hot Jupiters. We now know of several small rocky planets, some of them temperate, whose atmospheres should be accessible to JWST, including the 7 planets of the TRAPPIST-1 system. These planets are in close orbits around a nearby cool star, with likely temperatures ranging from around 150 K for the outermost planet to 400 K for the innermost, meaning that they may well cover Mars-, Earth- and Venus-like scenarios. Simulations suggest that a more Earth-like atmospheric composition for one of these planets would be distinguishable from a carbon dioxide dominated atmosphere with JWST.

Paradoxically, the significant launch delays have worked out very well for exoplanet scientists. Had JWST launched 10 years ago, we would have known of perhaps 700 planets, many of which were unsuitable for this kind of follow up as they either did not transit, or orbited relatively distant stars. We now have a list of almost 5000 confirmed exoplanets, several of which have been discovered by the TESS spacecraft and its census of nearby, bright planet hosts. Key targets, such as the TRAPPIST 1 planets, have only been discovered in the last few years, and modelling tools for interpretation of spectral observations have also developed significantly over the last decade. As a community, we are in much better shape to make good use of JWST at this point in time than we would have been had it launched as originally planned.

JWST was expected to begin scientific observations in the late spring or early summer 2022, and transiting exoplanets including members of the TRAPPIST-1 system will be among the first targets. In the next 18 months we can expect to learn a lot about these and other worlds. We may be in for some surprises – because JWST will provide much more precise observations than Hubble, it may prove false some assumptions we made in our interpretation of previous results. Whether it proves us wrong or confirms our previous findings, I'm very excited to see what JWST can tell us about other worlds.

And just in case you were wondering - Christmas dinner was a triumph.

Jo Barstow

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Does *E* equal *mc*^{2}?

A few years ago, whiling away the time at a friend's house, I picked up a popular science book about black holes, and was leafing through it when I came across an account of special relativity (SR) which claimed that when a stationary body is heated up its mass increases. This I found astonishing, and not at all consistent with the relativity I had learnt on the OU course S357 (*Space, Time and Cosmology*) that I'd taken a few years before.

The claim was, of course, based on Einstein's "most famous equation":

$$E = mc^2$$

so that, if you add energy to a body, then, since mass and energy are linked by that equation, and *c* is a constant, the mass must increase too. The author did go on to say that this mass increase has not actually been detected in the laboratory – it would require the mass to be measured with a precision of one part in a trillion (10^{12}) and that is not achievable – or at least, not yet. So this result is merely a prediction.

When I got home, I went straight to my S357 course unit to check that I had remembered it right and the popular-science book was wrong; but I was even more astonished to find that the same example appeared in the OU book, with the same conclusion! On S357 (and presumably on whatever course superseded it) the equation we learnt was

$$E^2 = p^2c^2 + m^2c^4$$

In the example, however, since the body being heated was not moving in the observer's frame of reference, its momentum *p* in this frame was zero, so that (2) collapses to (1) with the same result.

It should be pointed out of course, that the symbol "*m*" does not have the same meaning in equations (1) and (2): in (1) it is the relativistic mass while in (2) it is the rest mass. Both these terms are now regarded as somewhat archaic, since, in the words of the course unit, "we follow the modern convention according to which *m* is simply the mass of the particle". In other words, it is the same as the rest mass, and we do not use the term "relativistic mass" which is related to the rest mass by the factor γ which depends on relative velocity.

But the problem here is not just a mathematical one, or even a definitional one. The body that is being heated has an internal structure: it is composed of billions upon billions of atoms or molecules which are all jiggling around, and this jiggling, which of course is what we call heat, corresponds to a non-zero *momentum* at the scale of individual molecules, so at the molecular level, the p in (2) is not zero. The addition of heat from an external source increases the jiggling, and hence p will change, meaning that (2) no longer reduces to (1).

And this leads us to a crucial realisation – the bodies on which Einstein based his derivation of special relativity are far too simple to represent actual bodies in anything but a most rudimentary way; in particular, they have no internal structure, and so are simply *incapable* of heating up. We cannot apply equations derived from such a model to a real-life body which has properties absent in the model.

This is not something that is peculiar to relativity. I can remember being very confused, when I was doing applied maths at school, that in some collisions, called *elastic* collisions, both linear momentum and kinetic energy were conserved, while there were other collisions, called *inelastic* collisions, where one of these conservations does not apply, and ……to be honest I spent an awful lot of time trying to remember which one it was. It was kinetic energy of course – linear momentum is always conserved – but under certain circumstances you could have a collision, say between two lumps of putty, where the two lumps coalesce and kinetic energy is not conserved. Of course there is permanent deformation of one or both bodies, and this produces heat, so the *overall* energy is conserved. But the important thing to realise is that *you cannot predict this behaviour from anything intrinsic to the model* – you have to have some sort of additional information, such as that one body is made of putty. And the models we used for these sorts of problem were effectively idealised billiard balls, which do not really correspond very closely to anything real; rather like Einstein's "rigid bodies", in fact.

Principle Theories and Constructive Theories

This problem with SR can be stated in a somewhat different way by describing it as a *principle theory* as opposed to a *constructive theory*. Principle theories are based on principles, from which other things can be logically derived. (Do not be confused by Einstein's use of the term "thought experiment"; these were simple logical deductions, and no actual experiments were done). Constructive theories predict the behaviour of macroscopic objects in terms of their microscopic constituents (atoms). The archetypal example of this is the physics of gases. Thermodynamics is a principle theory, based on certain laws, and describes the bulk properties of macroscopic volumes of gas. Kinetic theory, on the other hand, seeks to explain thermodynamics in terms of the motions of gas molecules; it is a constructive theory, which underpins the seemingly arbitrary assumptions of thermodynamics, and explains it.

But there is no constructive theory to underpin special relativity. Einstein was aware of this; as early as 1908, he wrote that "a physical theory can only be satisfactory when it builds up its structures from elementary foundations". Of the idealised measuring-rods and clocks from which special relativity was derived, he later said that strictly speaking they should be "represented as solutions of the basic equations (objects consisting of moving atomic configurations), not, as it were, as theoretically self-sufficient entities." But to my knowledge, nobody has yet done this.

Philosophers of science are aware of this problem. Harvey Brown has written widely on the topic, notably in a 2005 paper entitled *Einstein's Misgivings about his 1905 Formulation of Special Relativity.*

But Brown's main concern here seems to be with considerations of aesthetics and completeness; he does not seem to regard a constructive theory as an essential component so much as a merely desirable one. And Dennis Dieks has written about "bottom-up" (constructive) and "top-down" (principle) approaches to SR in the context of *pluralism* – he says that it is a matter of pragmatics, and "there is no uniquely best way of explaining the relativistic effects".

How, though, would we go about building a constructive theory of relativity? I take it that we would need to regard the Lorentz transformations – the equations that relate measurements by different observers to one another – as true only of elementary particles (atoms? electrons? quarks?) and then build a slightly more complicated model consisting of two particles bound together (a molecule) and work up from there. (Even this would be verging dangerously on over-simplification, since an atom can absorb a mechanical impact by a process of excitation, which, for completeness, should also be built into the model).

But hold on a minute. Can we even assume the Lorentz transformations hold for atoms? The classic derivation involves one observer sending a light signal to another observer, moving at a constant speed relative to the first observer, and the second observer reflecting the signal back to the first observer who then records the time at which the reflected signal arrives. But you can't just "reflect" light from individual atoms or electrons – the incident photon will transfer momentum to the "observer", which is then no longer moving in the same inertial frame, and it is not clear that the photon will simply "bounce back". In fact you probably need to involve quantum mechanics. So this would be a decidedly non-trivial exercise.

And yet one thing we can be fairly sure about is that SR *does* work at the sub-atomic scale. The effect of time dilation (a consequence of the theory) on the lifetimes of muons has been well researched, and found to be consistent with SR – in fact it was probably the first experimental verification of the theory. But I for one would want a lot more convincing that we can justify the applicability of the full theory at this level.

Relativity, Momentum and Energy

Special relativity – which was announced to the world by Einstein in a paper in 1905 – tells us that two observers moving relative to each other will disagree on their measurements of lengths and time intervals. It is a short step from there to realising that if one of the fundamental laws of physics, the conservation of linear momentum, holds in the reference frame of one of these observers, it will not, in general, hold in the other. This must have been rather embarrassing for Einstein, since it immediately conflicts with the Principle of Special Relativity on which the theory was based.

But Einstein had already turned the whole concept of absolute space and time on its head, so he was not unduly fazed by this. Instead he looked for some quantity that might be conserved in all reference frames moving at constant speed relative to one another (aka *inertial* reference frames), and which might become indistinguishable with classical momentum at low speeds. And he found it.

Classical momentum is just mass times velocity, or mv. The more mass a speeding object has, the more momentum; and the faster it's going, the more momentum. If someone throws a heavy medicine ball at you it might knock you over; but a tennis ball travelling at the same speed will not. Nevertheless, a tennis ball travelling much faster will hurt you a lot more. The more momentum the thing has, the more you will feel it.

In special relativity, the distances and time intervals that different observers measure are related by a factor called γ, which depends on the relative speed of the two observers:

$$\gamma = \frac{1}{\sqrt{(1 - v^2/c^2)}}$$

It has the value 1 when the two observers are at rest relative to each other, but increases very gradually as the relative speed (v) increases. When this speed approaches that of light (c), γ becomes very large. Now, if you multiply the classical momentum by the same factor γ, you find that the resulting quantity, $mv\gamma$, is conserved in all inertial reference frames, and becomes equal to the classical momentum at low speeds. So the conservation of linear momentum is not infringed – it's just that we have to modify our definition of momentum a little.

However, Einstein did not, for some reason, want to redefine momentum; he wanted it to still equal mv. Hence he took the only other option available: he redefined *mass*. He effectively replaced it with *relativistic mass* $m_0\gamma$, with m_0 dubbed the *rest mass.* Hence momentum (p) becomes $m_0v\gamma$ or mv, as before. And if you substitute $p = m_0v\gamma$ in (2) and relabel the m in the second term as m_0, you end up with (1).

This new "relativistic mass" had some strange properties. Measurements of it varied according to the speed of the observer; if this was a large fraction of the speed of light, the mass would be correspondingly greater – for instance, a body travelling at 80% of the speed of light would appear 67% more massive. Even stranger, it seemed to be linked to the energy of the body in some way. Einstein derived the formula $E = mc^2$ in which the m is this new relativistic mass. It seemed to have a 1:1 relationship with energy, suggesting that mass was perhaps no more than a *form* of energy; from that, of course, flowed the idea that mass might be converted into energy, and hence the concepts of atomic power and the atomic bomb.

Later in life, however, Einstein had second thoughts about this. In 1948 he wrote to a friend that "it is not good to introduce the concept of [relativistic mass] of a moving body for which no clear definition can be given. It is better to introduce no other mass concept than the `rest mass'". And indeed, special relativity as it is taught today – and as I learnt it, for instance, in 1997 – does not speak of relativistic mass at all, except as a historical curiosity. Momentum is defined as simply $mv\gamma$, where m is now the same as the rest mass – in other words, the classical, non-relativistic mass.

Interconvertibility and Concomitance

The decision whether or not to employ the concept of relativistic mass effectively creates two different ways of interpreting special relativity. These are known as the *concomitance view* and the *interconvertibility view*.

The concept of relativistic mass leads to $E = mc^2$ and an identification between energy and mass. This gives rise to the concomitance view: energy and mass are *concomitant*, they are *the same thing* (give or take the constant c^2). But if you reject relativistic mass and take the modern approach, this leads to the interconvertibility view, in which mass and energy can be *converted* into one another: mass to energy in nuclear fission or fusion reactions, energy to mass in particle colliders.

To advocates of the concomitance view, nuclear explosions take some explaining. They cannot, after all, say that mass is being converted into energy, since in their interpretation both mass and energy are conserved at all times. All they can say is that the mass/energy is being "rearranged". On the other hand, concomitance, which entails relativistic mass, is useful for explaining the impossibility of travelling at the speed of light. This is forbidden by the form of the equation – when *v=c* the denominator is zero – but for a more “physical” explanation we might want to say that as the object accelerates its mass increases, so it gets harder and harder to accelerate, or, what amounts to the same thing, it takes more and more energy to accelerate it by a given amount.

Although the interconvertibility interpretation is favoured nowadays, and is the version taught at first degree level, what we often find is that the two are very frequently mixed up and may appear together in the same textbook or newspaper article, or even – in the case of the “Relativity Mugs” sold in the Science Museum shop – on the same piece of crockery!

Relativity mugs bearing both concomitance and interconvertibility “soundbites” : *the small print says both “this formula suggests that tiny amounts of mass can be converted into huge amounts of energy” (conversion) and “matter and energy are really different forms of the same thing” (concomitance).*

So far, so good. I see nothing wrong with there being two rival “paradigms” regarding mass and energy in SR (although the muddling up of the two concepts is a bit unfortunate). Thomas Kuhn would no doubt have been upset by this state of affairs, because he said that old paradigms disappear when their adherents die out and textbooks get rewritten. What he failed to take into account is that university teaching is not always done by the book; lecturers can choose to set students selected parts of textbooks, or even none at all, and may even just regurgitate the physics they themselves learnt decades earlier. Although, to be honest, it does seem that most physicists take the interconvertibility approach, while concomitance is more popular among philosophers and the general public. (I remember reading a press article several years ago which asked whether loading books onto a Kindle makes it heavier, as one is (presumably) adding energy. Tellingly, the newspaper’s science editor, who wrote the article, consulted a computer scientist about this, but no physicists!)

One should not poke fun at popular science, however – especially as physicists themselves don’t always get it right. In fact I was alerted to this fascinating phenomenon by a friend who is a retired physics teacher, who sent me an extract from a physics textbook in which both these incompatible views were espoused *on the same page*!

Rival Interpretations

In his paper *Interpretations of Einstein's Equation* $E = mc^2$, Francisco Flores identifies six distinct positions on this question, which he believes constitute "all of the leading and influential interpretations of Einstein's equation in the literature". He then applies to each of the six three tests, which, he argues, a successful interpretation ought to satisfy. These tests then rule out five of the six, and Flores concludes that the remaining interpretation is the only viable one.

Flores divides the six interpretations into two sub-groups. The first four he describes as *property* interpretations; the last two are *ontological* interpretations.

The property interpretations are possible answers to the question "do energy and mass describe the same, or distinct, properties of a body?" If the latter, a subsidiary question comes into play: "can one of these properties be converted into the other?" Flores identifies positions he describes as "same-property"; "different-properties, no-conversion", and "different-properties, conversion". He also highlights one view which he describes as "one-property, no-conversion", in which only mass is regarded as a *property* (and hence there can be no conversion).

The last two interpretations, which Flores does not distinguish from one another very clearly, are described as "ontological" because he says they concern "the fundamental stuff of modern physics". Both depend on the assumption that "there is no distinction between mass and energy as properties", and hence they belong, in a sense, to the "same-property" camp.

My first worry about this contest is that he does not include an option analogous to "None of the Above" or "RON" (Re-Open Nominations) as sometimes used in elections and surveys. If one were to ask a random sample of physicists "how would you interpret the equation $E = mc^2$", one would be likely to find the response "I wouldn't" among the most popular. Since the equation is usually presented to physics students as itself an option – and, furthermore, one that modern physics generally avoids – it would be difficult to know how else to answer the question. Luckily, the interpretations that Flores discusses will equally well do duty as interpretations of the rôles of, and relationship between, mass and energy in special relativity – a topic on which all physicists and philosophers of physics are likely to have a view.

The first test Flores applies is described as "the familiar goal of philosophical interpretations of physical theories", namely, that the theory is required to answer the question "what would the world be like if this theory were true?" In other words, the theory must make predictions about the world (and, though Flores does not say as much, we would surely hope that they were *testable* predictions). Secondly, he requires that "an interpretation I of a given physical theory T does not appeal to hypotheses outside T or theories other than T". The third criterion tests the theory for what Flores calls "philosophical uniformity": it asks whether the theory treats "elements in the mathematical formalism of T that are similar in type" similarly, or explains why these elements should be treated differently.

Rest Mass and Relativistic Mass

Flores is careful to establish at the outset that he "will focus exclusively" on rest mass as opposed to relativistic mass in the paper. This is a sensible decision, not least because no other type of mass is recognised by most physicists nowadays. However, it does restrict the applicability of the equation $E = mc^2$ to measurements made in the rest frame, and strictly speaking, as Lev Okun has pointed out, the equation should then be written in the form in which Einstein introduced it:

$$E_0 = mc^2$$

where E_0 is the energy measured in the rest frame, and m is the rest mass [Okun p31].Yet at least one of the interpretations that Flores investigates – that of Bondi and Spurgin – makes it equally clear that the authors are considering *relativistic* mass, *no*t rest mass: they claim that the equation holds in "all frames of reference" [Bondi & Spurgin p62] and use the symbols m, m_0 to denote relativistic and rest masses respectively, so that, for them, $E = mc^2$ is an equation relating energy to relativistic mass. [1] Flores does not mention this.

Another interpretation – that of Wolfgang Rindler – also clearly treats the equation as relating energy to relativistic mass. Rindler opts for a definition of relativistic momentum to coincide with the non-relativistic case, in other words, $p = m\mathbf{v}$. This choice of definition then commits him to relativistic mass. For instance, he states that "if a momentum of the form $m\mathbf{u}$ is to be conserved, then the mass m must be of the form $m = \gamma m_0$" [Rindler p80]. This is somewhat more serious, since Rindler's "different-properties, conversion" interpretation of the equation is the one singled out by Flores as the only viable one.

Units and Dimensions

One of the interpretations discussed by Flores – the "same-property" interpretation – rests heavily on an argument involving units and dimensions. This interpretation is associated with Arthur Eddington and R. Torretti. It is one of many claims made by certain physicists (among whom Eddington features prominently) on the basis of the assumption that, if a fundamental physical constant (such as c) is represented by a numerical value (and usually that value is 1) it becomes dimensionless. Clearly, if we make such a substitution in the equation $E = mc^2$, we appear to have equality between energy and mass, which Eddington and Torretti then interpret as evidence that energy and mass are the same property.

Since the philosophy of measurement is a field largely neglected by most physicists (and many philosophers), misunderstandings about units and dimensions abound in the literature, as I have shown elsewhere [see e.g. Grozier (2020)]. Eddington's mistake is to assume that, when "working in" a particular system of units in which c has the value 1, we can write Einstein's equation as simply $E = m$ and hence deduce that they are the same property. Apart from a worry about what happens when we move from that particular system of units to a system in which c does not have the value 1 (does it make sense to say that two properties are the same, but only when we are working in a certain system or systems of units?) we might reasonably object that, if we want to use a particular system of units, we must give those units names. It is legitimate to say that, in a certain system of units, the speed of light is "1 einstein" (where the "einstein" is my name for the unit of velocity in Eddington's system) but it is not

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[1] Hence Bondi and Spurgin do not even appear to be restricting this statement to *inertial* frames, which is usual when considering special, as opposed to general, relativity.

legitimate to just say that c is a pure number with the value 1. Flores treats Eddington and Torretti's argument somewhat uncritically; he rejects it, but for different reasons. He does not seem to be aware of the particular problem I have just outlined.

Flores rightly points out, following Einstein, that special relativity is a *principle* theory as opposed to a *constructive* theory, and that such theories "do not afford bottom-up explanations" [Flores p259]. However, he fails to appreciate the full implications of this distinction. For instance, in one of the interpretations considered by Flores – that of Marc Lange, who argues that energy is not a real property because it is frame-dependent (hence "one-property [mass], no-conversion") – Lange requires the fundamental mass-energy relation of special relativity

$$E^2 = p^2c^2 + m^2c^4$$

to hold simultaneously at the macroscopic and microscopic levels, and concludes that mass is not additive – a result which he uses to back up his argument that there is no conversion of mass to energy because the "mass defect" is a fiction based on the assumption of the additivity of mass. But how do we know that the equation holds for fundamental particles? Flores rejects Lange's interpretation, but for a different reason.

Mass, Energy and Pluralism

Does it actually matter, though, which is the "correct" interpretation of the relationship between energy and mass in SR? Presumably not; it was, after all, perfectly possible that more than one of the six interpretations might pass Flores' test, or that none would pass it: he was not necessarily looking for a single answer. Maintaining a pluralistic approach, and selecting a model that is appropriate to the problem in hand, seems a sensible, pragmatic way for philosophers and physicists to behave. And instead of worrying about which model is "true", a better use of one's time and energy would perhaps be to challenge the many inconsistencies and contradictions about mass and energy that one finds in the press, popular science books, physics textbooks, and philosophical literature.

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Jim Grozier

Underground Science – Part 1

Exploring deep underground laboratories and the physics done there.

One dark night in 1901, Scottish professor C.T.R. Wilson ventured into the Caledonian railway tunnel near Edinburgh with an early particle detector. His goal was to find out whether the mysterious new phenomenon of radioactivity was coming from the Earth, or from space. His results were inconclusive—the answer is not simple as there are many sources of radiation. However, this was just the start of underground particle physics experiments. By 1912, the existence of high energy cosmic rays, coming from space, was established. It was soon realised that they could hinder other measurements. They were not stopped by a simple lead shield, but could punch their way through rock and penetrate hundreds of metres underground. The signal in a detector big and sensitive enough to detect the ghost-like neutrinos, or search for the weakly interacting massive particles believed to explain Dark Matter, would be swamped by the noise from cosmic rays unless that experiment were built deep underground.

This was the motivation for building deep underground laboratories—research facilities in mines and tunnels, kilometres beneath the surface of the Earth. These research environments have since attracted the attention of researchers from other fields, including geophysicists looking for a low-noise place to monitor the Earth's magnetic field or study the movement of groundwater.

Gran Sasso, Italy – Dark Matter

Drive north-east of Rome, along the A24 autostrada, and once outside of the urban sprawl surrounding the capital and past the green pastures of Lazio, you enter Abruzzo, where the landscape becomes mountainous. The mountains turn to steep cliffs and the motorway goes into a long tunnel. Halfway through this, there is a special underground exit, which leads to a pair of high metal doors, which slowly swing open to reveal an extensive laboratory complex built right in the heart of the mountain. A large electronic message board alerts us in bold red capital letters that we are entering the *Laboratori Nazionali del Gran Sasso.* It may feel like we are invading the underground base of a James Bond supervillain, but in many ways, the purpose of the laboratory is stranger than fiction. I first went to Gran Sasso in 2001 to work on a dark matter search experiment with the name *CRESST* (*Cryogenic Rare Event Search with Superconducting Thermometers*). The *Rare Events* were the dark matter particle interactions we aimed to detect. *Cryogenic Superconducting Thermometers* were the chosen technology to do this. At the heart of the experiment are crystals cooled to a low temperature. Any particle hitting one of the crystals causes a tiny rise in the temperature. This heat input is less than a millionth of a degree, but it can be detected with a super-sensitive superconducting thermometer.

We have to go through a ritual before we can see the detectors. The experiment was built inside a "Class 100" cleanroom, which means we must remove our boots and outer clothes, and dress in full body white hooded outfits, put on face masks and hair nets, then pull latex gloves over our fingers before wiping them clean with alcohol. Like all living creatures, our bodies contain radioactive atoms, as we breath air that has been irradiated by cosmic rays. A single sweaty fingerprint or shed skin cell could contaminate the detectors.

The detector is surrounded by a wall of lead bricks. The two sides of the shield roll back on rails—very slowly as they weigh over a tonne. As the lead bricks themselves are slightly radioactive, contaminated with the isotope Pb-210, there is another shield made of copper, which can be purified to a very high level and does not contain any radioactive isotopes.

Eventually the final shield is removed and we can see the detectors—the crystal heart of this three-storey high apparatus, hidden behind so much support infrastructure. The clean room, lead bricks, and one kilometre of rock overburden, is all to provide the right environment to run these crystal detectors, which you can hold in your hand.

The CRESST experiment has now been running for over twenty-five years. It hasn’t seen dark matter. There was a brief excitement in 2011 when they saw an unexpected excess of events, but it turned out to be due to an overlooked radioactive background. Meanwhile other dark matter search experiments have been constructed at Gran Sasso. The XENON experiment consists of a tank containing several tonnes of liquid xenon. Particle interactions in the liquid creates flashes of scintillation light. When smaller experiments failed to find dark matter, this technology proved to be the easiest to scale up to the tonne-scale required to continue the search. XENON has not found dark matter either, but the null result of the latest search has let them set the world-leading limit on the interaction rate.

Dark Matter remains one of the biggest unsolved mysteries in modern science, and a mystery that has grown over the last decades as experiments have failed to detect a signal, but the evidence from astronomy for this invisible component of the universe has continued to grow, and the idea that it is a new type of particle remains the leading hypothesis.

After decades of searching, dark matter experiments could now be approaching the end game. The detectors are now so large that they will soon be limited by the background solar neutrinos—a type of radiation that cannot be shielded, even deep underground. Unless dark matter particles show up soon, this could be the last result from these deep underground detectors, and we will need to find other ways to test the dark matter hypothesis.

However, even if dark matter searches come to an end, there are many other researchers interested in underground facilities.

Samuel Henry

Fusion Research Breakthrough

Results announced recently by scientists working on the Joint European Torus (JET) have been described in a press release as “the clearest demonstration worldwide of the potential for fusion energy to deliver safe and sustainable low-carbon energy”.

Researchers from the EUROfusion consortium – 4,800 experts, students and staff from across Europe, co-funded by the European Commission – more than doubled previous records achieved in 1997 at the UK Atomic Energy Authority (UKAEA) site at Culham, near Oxford, using the same fuel mixture to be used by commercial fusion energy powerplants.

JET produced a total of 59 Megajoules of heat energy from fusion over a five second period (the duration of the fusion experiment). During this experiment, JET averaged a fusion power of around 11 Megawatts.

The record and scientific data from these crucial experiments are a major boost for ITER, the larger and more advanced version of JET. ITER is a fusion research mega-project supported by seven members – China, the European Union, India, Japan, South Korea, Russia and the USA – based in the south of France, to further demonstrate the scientific and technological feasibility of fusion energy.

Dr Bernard Bigot, Director General of ITER, said: “A sustained pulse of deuterium-tritium fusion at this power level – nearly industrial scale – delivers a resounding confirmation to all of those involved in the global fusion quest. For the ITER Project, the JET results are a strong confidence builder that we are on the right track as we move forward toward demonstrating full fusion power.”

Jim Grozier

Fusion Quiz

I – The singer Olivia Newton-John is the grand-daughter of which physicist?

2 – Paul Dirac was at primary school with which Hollywood legend?

3 - What did Tycho Brahe lose in a duel?

4 – Which two equations appear in Westminster Abbey?

5 - Which 20th/21st physicist was born on the 300th anniversary of the death of which 16/17th century one?

6 - Where are some of Eugene Shoemaker's ashes scattered?

7 - According to legend, which physicist could fit into a quart mug when he was born?

8 – The comment ' beer is proof that God loves us and wants us to be happy' is frequently, but erroneously, attributed to Benjamin Franklin. But he did make a similar comment about which drink?

9 - Which two physicists/astronomers were granted the Danish chivalry award the Order of the Elephant?

10 – In 1905 five muskrats from the US were introduced into Prague. What phenomenon did scientists use to monitor their spread?

11 – Which two physicists, buried in Westminster Abbey, have the same inscription on their graves, one in English, the other in Latin?

12 - What was unusual about Leonardo's handwriting?

13 – Whose image appears on the Fields medal?

14 – What unit was originally called the galvat, and then the weber?

What is it and What is it For?

Fusion Quiz Answers

1– Max Born.

2 – Cary Grant.

3 – Part of his nose.

4 – The Dirac equation, and the Hawking equation for the entropy of a black hole.

5 – Stephen Hawking DOB 08/01/1942, Galileo DOD 08/01/1642.

6 – On the moon. He was hoping to travel to the moon, but a medical condition prevented this.

7 – Newton.

8 – Wine – 'Behold the water that falls from the heavens upon our vineyards; there it enters the roots of the vines to be changed into wine; a constant proof that God loves us and loves to see us happy'.

9 – Tycho Brahe and Niels Bohr.

10 – Brownian motion.

11 – Stephen Hawing and Newton. 'Here lies what was mortal of Stephen Hawking/Newton'.

12 - It was backward.

13 – Archimedes.

14 – The ampere -the unit for electric current.

What is it and What is it For?

It is it a remote observation telescope for observing something across the room. Vertical movement measurable.

Fusion Online Event 10th September 2022

0900 – 1000 – Jim Grozier (Fusion) – Attribution and award in the age of big science.

1000 - 1045– Jonathan Nylk (OU) – Fantastic beams and how to make them: Structured photonics for biomedical imaging.

1100 -1200 – Mark Jones (OU)– The OU MPhys degree and new modules.

1200 – 1300 – Ian Knowles (OU) – What are the big questions in particle physics.

1300-1345 – lunch break.

1345-1445 – Carole Haswell (OU) – OU planet discoveries in context

1500 1530 – Greg Aldam – A physicist in finance.

1530 1600 – Julian Guassardo (IOP) - What the IOP can do for you.

1600-1700 – AGM

To join the meeting please click here.

Or, in ‘longhand’: https://teams.microsoft.com/l/meetup-join/19%3ameeting_ODg3NzkxZmMtYTljNC00YTk1LThmYWUtY2MzMTQ4YmJkMDhm%40thread.v2/0?context=%7b%22Tid%22%3a%220e2ed455-96af-4100-bed3-a8e5fd981685%22%2c%22Oid%22%3a%222a9371fb-ca63-45f5-a9b0-62ae0c5e7181%22%7d

Although the online event starts at 9.00 the Teams ‘room’ will be available from a little before 8.45 to give you the chance to check your connection.