fusion
The Open University Physics Society
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SRW Success at York

The Science Revision Weekend (SRW) at York last October was quite a success – there were around 240 students in attendance, we sold 54 Fusion T-shirts and gained several new members. Jim Grozier's Saturday evening talk (see opposite) was well received with over 50 in the audience (there are plans for more talks next year). Along with our colleagues in the Chemistry Society we are planning the SRW for 2006 which will be held at Yarnfield Park Training and Conference Centre, Stone, Staffs from 29 Sept to 1 Oct 2006. We need to ensure that courses are not left out because they haven't been covered before and therefore people don't expect them, so please let us know which courses should be added.

Wet and Windy Wales

Wales lived up to its reputation for the Fusion visit to Electric Mountain in Snowdonia. The day started bright and a few of us went for a walk up part of the Snowdon track by the side of the railway line. The steep climb was rewarded with a lovely view back down to the lake and views of the trains chugging further up the track to the summit. The size of the Electric Mountain project was quite awe inspiring, and for me well worth the immense cost for hiding such a huge power station in the midst of wonderful countryside. But on the tour itself there was very little to see, once you had grasped the size of the cavernous spaces created inside the mountain. The guide was full of facts and many figures of interest to some, but unfortunately for me lacking anything memorable, not even a dragon smouldering away!

Report and Photo by Lorna Pain

A Brief History of Magnetism

Above – Jim in full flow at the SRW

SRW talk summary by Jim Grozier

When I submitted the abstract for my lecture at the International Conference of Physics Students 2005 (on the last day of eligibility) I not only did not have the material for a talk, but I had no idea whether I would be able to put one together in time. I had chosen the title "A Brief History of Magnetism" because I was bored with talking about my research work and wanted to do something else. Since magnetism forms quite a large part of this work, it was not exactly a radical departure, but it did give me the freedom to look into the history and development of the subject, and a chance to investigate some of its more bizarre aspects.

Well, in the two months available, I did indeed manage to cobble something together, and discovered some interesting things along the way. I had been aware, like most people who have ever studied the subject, of the "schizoid" nature of the study of magnetism, inasmuch as it has been looked at from two entirely different viewpoints – first in terms of magnets and magnetisable materials, and then in terms of currents – and the fact that the former view never completely gave way to the latter has made it that much harder for a mere student to understand it. Indeed, the poor student, if religious, might even be driven to curse God for leaving all that magnetic rock lying around for people to experiment with, hundreds or even thousands of years before they would be able to produce an electric current!

One of the surprising things I learnt was that André Ampère, in the 1820s, was able to come out with a statement like *"A magnet ... is only an assembly of electric currents"* [1] which showed him to be decades ahead of his time; and that despite his efforts, his approach – explaining everything in terms of currents instead of poles – did not catch on in his lifetime, and his law of force between current elements did not achieve the prominence it deserved. This law is puzzlingly referred to in history of science books as "Ampère's Law", and I searched in vain for any reference to the Ampère's Law that physics students are taught nowadays, and which indeed appears on the Fusion "Maxwell" T-shirt (£8.50 inc p&p from all good OU physics societies) before eventually realising that that law is not, in fact, Ampère's at all but was first written down by James Clerk Maxwell, 18 years after Ampère's death! [2]

Ampère lived through magnetism's "golden age", which started with Hans Christian Oersted's discovery of the magnetic effect of an electric current. Oersted had been looking for some connection between electricity and magnetism for some time, initially by simply putting an open-circuited battery near a compass, and even when he realised that a current was required, he put the compass and wire at right angles, the one configuration where there is no force at all *(see picture below)*. His eventual breakthrough in 1820 led to extremely rapid developments in at least three laboratories, two in France and one in England. While Ampère designed and performed ever-more ingenious experiments on the force between currents, Biot and Savart simply refined Oersted's original experiment with the compass, making it quantitative; the resulting formula (for the magnetic flux density due to a current element) is, of course, in all the textbooks nowadays, while sadly you will struggle to find Ampère's in anything but a history book. Meanwhile in London, at the Royal Institution, Michael Faraday set to work, and within a year had discovered the motion of a conductor in a magnetic field, which of course is the principle behind the electric motor. It took him another ten years, however, to find what he was really looking for – electromagnetic induction – because, although we all know nowadays that a *change* in magnetic field is required for this, it was by no means obvious then. Hindsight is a wonderful thing!

Another fascinating story is that of the early scientific investigation of the forces between magnets. The quantitative evaluation of this force law, like the analogous one for the force between electric charges, had to wait for the invention of the torsion balance, and it is a well-established fact that Charles Augustin Coulomb built such a balance in the mid-1780s and used it to develop the electrostatic force law that bears his name. However, I was somewhat taken aback to hear a learned academic, Professor John Heilbron of Berkeley, USA, proclaim on Melvyn Bragg's *In Our Time* (one of the good things about being a full-time student is that you can bunk off when there is something interesting on radio 4!) that Coulomb had also discovered the inverse-square law for the force between magnetic poles. In my talk, on the basis of information obtained from the internet and also from Sir Edmund Whittaker's classic study, *A History of the Theories of Aether and Electricity* (1910), I had stated that John Michell, not Coulomb, had discovered this law, having also independently invented the torsion balance. Michell, a relatively-unknown Englishman, apparently also had time not only to invent the science of seismology, and design the famous gravity experiment later carried out by Cavendish, but also to postulate the existence of black holes (based on pure Newtonian theory of course) some 150 years before Einstein appeared on the scene!

In fact, Michell's paper, *A Treatise of Artificial Magnets*, which Whittaker quotes from extensively, was published in 1750, when Coulomb was only 14 years old. How could this be, that such a fundamental disagreement about historical "fact" could exist between a contemporary academic and a well-respected authority like Whittaker? Who was right? Well, I attempted to find out by emailing Heilbron and the other two "experts" on the programme (Whittaker presumably being by now unreachable even by cyberspace) but there was no reply from them, nor from the programme's online forum to which I'd posted a query, nor from the IoP's History of Physics group who I then wrote to in desperation. So much for the free exchange of ideas! Eventually John Gribbin cleared the mystery up for me: in his book *The Scientists*, Gribbin confirms that Michell did indeed discover the law, but "nobody took much notice". [3] OK, Michell was not a household name, and later abandoned a career in science to become a vicar. But why do some sections of the history-of-science fraternity continue to ignore him 250 years on?

In my talk, partly to brighten up a perhaps rather dull subject, and partly because it just seemed such a wicked idea, I played the audience a recording of a song about Ampère's Law, written by Walter Smith and Marian Mckenzie and performed by the band "Broadside Electric", in which they had clearly made the obvious, but erroneous, assumption that Ampère had written it. I will spare you that pleasure on this occasion (and besides the Fusion newsletter does not have a sound channel just yet) but I will just share with you, in closing, the contents of my "Conclusions" slide:

1. Don't believe everything you read in textbooks.
2. Physics songs can be cool but are not always accurate.
3. Physicists don't like change. *(An allusion to the reluctance not only to give up the pole model but also to adopt SI units.)*
4. You can learn some good physics from history books. *(Whittaker, for instance, gives a brilliant explanation of Magnetic Vector Potential, recommended for anyone who, like me, feels totally baffled by the concept.)*
5. God hates physicists.
6. Doing a talk is good for you.

Of these, the last piece of advice is the most important. It's a hackneyed saying, but it's nevertheless very true that the best way to learn something is to have a go at teaching it!

[1] A. Ampère, *The Mutual Action of Two Electric Currents*, 1820.

[2] O. Darrigol, *Electrodynamics from Ampère to Einstein*, OUP, 2000.

[3] J. Gribbin, *The Scientists, Random House*, 2003.

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Happy Birthday!

We would like to congratulate the neutrino, which celebrated its 75th birthday in December. Pauli postulated its existence in 1930, but it was another 26 years before it was discovered experimentally. So, if you missed it, 2006 will see another chance to celebrate as it is the 50th anniversary of Reines and Cowan's discovery. Party on!

Departmental News

From Lindsey Shaw-Greening

Since the summer issue there have been a number of staffing changes in the department. We are pleased to welcome Emma Taylor, a new lecturer in hypervelocity impact physics, Stephen Lewis, our second RCUK fellow who models planetary atmospheres, Jemina Gorfinkiel a new lecturer in electron molecule interactions and Professor Glenn White, previously at the University of Kent who will be continuing his work on star formation and astrochemistry. We have also recently been joined by staff who are part of the new CETL (Centre for Excellence in Teaching and Learning). Two members of the team have recently started, Diane Ford, CETL secretary and Kevin Mayles, CETL centre manager. With all these new members of staff the department is expanding into new offices soon! Plans are currently underway for National Science Week events that the department will host and CEPSAR (Centre for Earth, Planetary, Space and Astronomical Research) events for next year.

Physics Web Links

Physics from Wikipedia, the free encyclopedia can be found at *en.wikipedia.org/wiki/physics* and Gerard t'Hooft's "How to Become a Good Theoretical Physicist" is at *www.phys.uu.nl/˜thooft/theorist.html*. This is a web site for young students, and anyone else, who are thrilled by the challenges posed by real science, and who are determined to use their brains to discover new things about the physical world that we are living in. In short, it is for all those who want to study physics, but in their own time.

Congratulations

John Small presented a recent version of the ideas he is working on at CASYS'05 (*www.ulg.ac.be/mathgen/chaos/casys.html*) and when he got home from ICPS, which ran over the end of CASYS'05, he found that he had been awarded the prize for best lecture. The paper behind his lecture will be published in the American Institute of Physics conference proceedings on CASYS'05. We are hoping he will do an article for Fusion as well!

Planetary Evening

Report by Lorraine Robinson

Fusion's first lecture evening was held on 18th November 2005 on the OU campus in Milton Keynes. With talks by Colin Pillinger and Andrew Ball this proved to be a marvellous evening. The second lecture, given by Professor Pillinger, described in detail the early stages of the building of Beagle 2 and the story of how it was eventually put into space.

It started as a result of work done on Martian meteorites in the 1980s. Researchers were hoping to prove that the Martian surface could contain evidence of organic life. US Scientists saw a tiny fossil in one of the meteorites, but others objected that the 100nm object was not large enough to contain a strand of DNA. The question built momentum ... 'Are we alone in the Universe?' ... Professor Pillinger decided to find out.

What was needed was to send some type of 'lander' to the surface which was capable of analysing the rocks. He had no money, no history of spacecraft building, but he did have instruments capable of distinguishing between carbonate and organic matter. His wife suggested that they start a campaign and named the lander 'Beagle 2'. He campaigned hard to sell the mission to NASA and the European Space Agency (ESA).

First he had a laboratory full of spectrometer and analysis equipment including cameras which had to be shrunk to 5.5 kg. This had never been done before. The finished product achieved the greatest ratio of science payload to systems mass of any space mission and also paved the way for mobile spectrometers to be used in hospitals.

Beagle 2 was built like a pocket watch and with parachutes and heat shields weighed in at just over 33 kg. It had to be capable of travelling at 12,500 mph toward the surface of Mars and slow down sufficiently to land.

Mars Express carrying Beagle 2 was launched. In June 2003, at 250 million miles, checks were carried out and everything seemed to be working well. On 19 December it was ejected by a spring mechanism from the back of Mars Express to the surface.

But something happened ... Mars Express was not listening to Beagle 2 after it was launched. Others tried to listen for it, Jodrell Bank Observatory listened for a signal for 12 days, but all had gone quiet and the fate of Beagle 2 was unknown. Did it crash on Mars? It was protected by gas filled bags, but in experiments on Earth it is only the first bounce that you can really test for, since subsequent bounces become random.

Expeditions of this type are evaluated by the number of single-point failures which could occur and therefore jeopardise the whole mission. Beagle 2 had just 40 which is not high, considering that other expeditions with over 100 single-point failures had succeeded.

The big question that is being asked now is whether there will be another expedition to Mars to try again to land a new Beagle and so continue the search for life.

At the ESA Council Meeting at ministerial level held on 5 December 2005 the following was decided: Aurora is the continuation of the Space Exploration programme initiated in 2001 and consists of two elements, representing a balance between mutual dependence and non-dependence for Europe within an overall international architecture. It contains a core programme, which will take place over the years 2006-2009, of initial work for the definition and building of future robotic and human exploration missions, in particular to the Moon and also to Mars. The programme will also participate in the development of enabling technology activities for raising the awareness of European citizens with respect to space exploration.

Exo Mars will be a spacecraft composite of an orbiter and descent module with an independent data relay and telecommunication function. The descent module will include a high mobility rover which will contain a static package of geo-physics, meteorology and environment instruments. The purpose of the Exo Mars mission will be to search for traces of past and present life and characterise the biological environment of Mars. The Exo Mars mission will be launched in 2011.

Dr Andrew Ball's lecture was about the Huygens probe and a description of the operation of the PSSRI's sensors on Huygens, including the Surface Science Package.

On Titan's surface the gravity is 1/7 that of on Earth and the atmospheric pressure is one and half times higher.

Methane (CH_4) reacts with Nitrogen, catalysed by sunlight. There is a cascade of reaction molecules drifting down through Titan's atmosphere. There is evidence for liquid methane having flowed on the surface, but so far only limited evidence of present-day surface liquid.

Cassini was launched in 1997 and arrived at Saturn in 2004. Cassini is still in orbit around Saturn. The Huygens probe was launched from Cassini on Christmas Day 2004. Communication with Huygens was switched on four hours before entering the atmosphere and was able to send back pictures from an altitude 10 km.

For more detailed information check out the 8 December 2005 issue of Nature magazine.

Making Ice Cream and Scientific Thinking

A true story about a thinking student

by Tamás Jávor

What do you think about this question: If you take two containers, fill them with equal volumes of a liquid, one hot and the other cold, and put them into the freezer at the same time, which will freeze first? You might think that the editor confused my manuscript with that of a primary school physics book. We indeed are going to see students and things about children in the article, but I do not suggest that you give a confident answer to the question!

In the 1960s, there was a schoolboy named Erasto B. Mpemba in Tanzania, Africa. At his school the pupils loved to make ice cream. They bought some milk at the market, boiled it, mixed it with sugar, and put it into the refrigerator of the school. There was not much space in it, so the boys always tried to quickly obtain a place for their ice cream.

One day, as Erasto was boiling his milk, he noticed that another boy was putting his milk into the refrigerator without boiling it. He did not want to miss the space and, hurrying, he did not wait until his milk cooled down to room temperature, but put it into the freezer hot (even at the risk of ruining it).

One and a half hours later they went back, and found that his ice cream was ready, while his friend's was not yet completely frozen. Erasto found this unusual and asked his physics teacher at the school why this happened. The teacher answered: "You were confused, that cannot happen." Then he believed this answer, and did not bother to try the experiment again (even when, in his next holiday, he met some ice cream selling friends who told him that they also start freezing the cream while hot, because that way it is ready quicker).

Some years later Erasto Mpemba became a high school student. The first topic they were dealing with in physics was heat. When hearing about Newton's law of cooling, Erasto Mpemba asked the teacher: "Please, sir, why is it that when you put both hot milk and cold milk into a refrigerator at the same time, the hot milk freezes first?" The teacher replied: "I do not think so, Mpemba." But the student stated that he had seen it himself. The teacher said: "The answer I can give is that you were confused." And when he insisted on his opinion, the teacher told him: "All I can say is that that is Mpemba's physics and not the universal physics." (And later on, the whole class would criticise all his mistakes saying "That is Mpemba's mathematics" or whatever it was.)

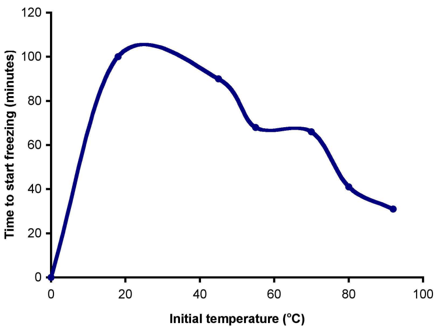
Mpemba did not want to leave this case at that. One day, as he found the biology laboratory of the school open and empty, he quickly went in, filled two beakers with hot and cold tap water and placed them into the freezer. As he returned one hour later, he found that neither of them had frozen yet, but there was more ice in the originally hot water. However, this was not conclusive, so he decided to continue to deal with the topic.

Later, Dr Denis G. Osborne, professor at University College Dar es Salaam (then capital of Tanzania) visited their school. He gave a lecture to the students and after that they were allowed to ask questions. Erasto Mpemba took courage and asked: "If you take two similar containers with equal volumes of water, one at 35°C and the other at 100°C, and put them into the refrigerator, the one that started at 100°C freezes first. Why?" The professor did not ridicule the student. He recalls: "I confess that I thought he was mistaken but fortunately remembered the need to encourage students to develop questioning and critical attitudes. No question should be ridiculed. [...] everyday events are seldom as simple as they seem and it is dangerous to pass a superficial judgment on what can and cannot be." He answered the student: "The facts as they are given surprise me, because they appear to contradict the physics I know. But I will try this experiment when I am back in Dar es Salaam." And he encouraged the questioner to repeat the experiment himself, too.

Mpemba became an anti-hero at his school. His classmates told him that he had shamed them, and that his aim was to ask a question which the professor would not be able to answer, others asked him: "But Mpemba, did you understand your chapter on Newton's law of cooling?" [1]

But he did continue experimenting at the school. His results were just the same. He showed everyone what happens. When the head teacher of the physics department heard that it worked, he said: "It should not." (But added: "I will try it this afternoon." And found the same results.)

Meanwhile, Dr Osborne, back at his workplace, also let a young technician test the facts. He reported that in the first trial the hot water froze first, and added: "But we will keep on repeating the experiment until we get the right result!" They indeed repeated it. The results are plotted in the figure below where the curve has a maximum at about 30°C.



Results of Dr Osborne's detailed experiments.

Articles were published, experiments were repeated everywhere. The latter is not an easy task, because there are many factors influencing what exactly happens (like the geometry and the material constants of the objects – the freezer, the container and the liquid -, the ratio of the top surface area and the volume of the liquid, etc.) Under some conditions the effect does not even occur: the cooler liquid freezes first.

We shall see some theories which attempted to explain this phenomenon. It is important to know that even today there is no proved or accepted explanation!

1. Some thought that the hotter glass had melted the frost layer in Mpemba's refrigerators, and this way it got into a much better contact with the freezer (because frost is a bad thermal conductor). In some experiments it might have happened, but eliminating this effect does not stop the phenomenon.

2. During the cooling evaporation also occurs. Evaporation needs heat and removes mass from the liquid – both let the cooling be faster. Of course in the hotter liquid these effects are stronger. However, from theoretical calculations and experiments eliminating evaporation we know that this explanation is insufficient.

3. Above 4°C, the density of water increases as temperature decreases. As the top layer (where cooling is the most intensive) has transmitted heat to the environment, it becomes cooler, hence denser. It starts to sink down to the bottom of the beaker, from where warmer water is arriving to the top. These convection currents established by temperature gradient are more intensive in the initially hotter liquid, which makes heat transmission at the top faster. The temperature gradient undoubtedly exists, but these currents have been neither theoretically described nor thoroughly experimentally observed.

4. Some investigators stated that gases dissolved in the liquid can play a role in causing the effect. Of course there is less dissolved gas in the hot water, and dissolved gases might change the thermodynamic constants of the solvent, but there is no exact theory to explain why and how they do.

5. Finally, supercooling can give an answer. It was observed that the initially warmer water can be supercooled less. (But there is only a very complicated and not undoubtedly valid explanation why this happens.)

We can say that the faster freezing of the initially hotter water is most probably the result of several effects at the same time.

People also began to look for earlier references in literature. It turned out that this phenomenon could have been a common idea. (Remember the ice cream sellers!) But by official science it was forgotten until 1969. Some historic statements: Ren Descartes (1637): "Experience shows that water which has been kept for a long time on the fire freezes sooner than other water." Francis Bacon (1620): "Water slightly warm is more easily frozen than quite cold." Giovanni Marliani, medieval physicist dealing with heat: in a debate (c1461) stated that he had taken four ounces of boiling water and the same volume of non-heated water, placed them outside in a cold winter day, and had found that the boiling water froze first. He quotes an even earlier source: Aristotle (c350 BC): "The fact that water has previously been warmed contributes to its freezing quickly; for so it cools sooner. Hence many people, when they want to cool water quickly, begin by putting it in the sun..."

This phenomenon was named the Mpemba effect after this brave student. The story is a parable for everybody forever, not to undervalue the observations of uneducated people, and not to state too quickly that something is impossible. The story warns us that it is worth reflecting on this: Do not we often have serious prejudices in discovering nature? Can we really observe our world clearly and without bias? Like Erasto Mpemba did, and like children do. Can we wonder at the interesting, beautiful things around us? (The younger a child is, the more they do so.) An interesting statement is recorded from Jesus Christ: "Unless you become like little children, you will never enter the kingdom of heaven." It seems so, that important things in life can be correctly, really understood with "a child's mind". Open-hearted and putting aside prejudices. I hope we can all learn to observe the world this way!

Dr Osborne and Mpemba never became famous, their names cannot

[1] Newton's law of cooling states that the rate of cooling is proportional to the temperature difference between the object and the cooling environment – under some simplifying assumptions.

be found in any biography collection. I would welcome any information about their later destiny.

Tamás Jávor is a student at Budapest University of Technology and Economics in Hungary. This article is based on a lecture given by the author at ICPS 2005, Coimbra, Portugal.

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Mastering Science?

by Norrette Moore

After completing a Natural Science with Physics BSc with the OU, in an effort to quench an addiction to study and supplement my 2.2 result, I have spent the last few years completing the OU's MSc in Science (F12). This is currently the only part-time master's level distance learning on offer from the OU which has any amount of Physics content.

I will blame my 2.2 result on my hatred of exams; good news for fellow sufferers is that for an MSc there is NO exam. Each course is structured with around 6 TMAs, a poster, plus a substantial examinable mini-review. Interesting to note that including assignments and the examinable component, a body of work amounting to over 65,000 words is submitted over 180 points. The cost of a 60-pointer is £925 in 2006 – However, I would expect this to rise in accordance with the country-wide increase in tertiary education costs.

To obtain the degree the student must attain 180 points from the following courses, split into two strands : Science Studies and Frontiers in Medical Science.

Topic	Course	Points	Next Start	Strand
Science and the public	S802	60	Jan 2006	Studies
Communicating science	S804	60	Jan 2006	Studies
Molecules in medicine	S807	60	Jan 2006	Medical
Imaging in medicine	S809	60	Jan 2006	Medical
Radiotherapy and its physics (new offering from 2007)	S819	60	Jan 2007	Medical
Issues in brain and behaviour	SD805	60	Feb 2006	Medical
Contemporary issues in science learning	SEH806	60	Jan 2006	Studies
Explaining cognition: damaged brains and neural networks	DS871	30	Nov 2006	Medical
The project module	S810	60	Jan 2006	Either

I began my studies with S804, Science Communication. Believing it to be a firm grounding for some publishing intentions, I was disappointed to find it didn't really suit this Physics grad. Admittedly one learnt the basics of research, referencing and 'how the science community works', but the course is frankly an out-and-out Social Science course, with accompanying socio-babble. Mandatory First Class conferences were very interesting – current issues are discussed and debated. But the end of course assignment was a *media study* of a current scientific issue, and I found this work less than inspiring. Ordinary assignments are submitted using the online method – this means you can submit right up to the cut-off date.

The Imaging course (S809) is an extension of the medical imaging studies started in the splendid undergraduate course, Images and Information (ST291). The course is divided into blocks for each of the main modalities – Ultrasound, X-ray/CT, MRi – some lesser-known methods and safety issues are included. Also explored is the logistics of maintaining such a large amount of data on a hospital system and speedy retrieval of patient information – image compression techniques are covered and in general the course was very interesting. However, one is left with the feeling that only an overview of the topic can be covered in a 60 point course. Other universities offer complete MScs in medical imaging so an equivalent full-time 60 pointer could be gained in, say, just MRi.

After taking a year off, and with still no immediate sign of the radiotherapy course I ventured into the Molecules and Medicine territory, rather than suffer the slings and arrows of outrageous sociology again. Any hopes of catching up on biochemistry knowledge in the early days of the course were foiled by the course materials arriving only at the last minute. A warning to those non-chemists contemplating this course, get the set books and study them the previous winter. The course is based on the development of new drugs and one is eventually given the opportunity to focus on a drug and/or disease of choice from a range including HIV, cancer, etc. Fortunately for me, there was not too much focus on the detail of chemical structures – and some of the computer tools provided were fun to use and enabled one to produce impressive chemical structures in various 2D and 3D formats.

All MSc courses provide the student with an Athens Password, giving on-line access to a large number of scientific journals. This is invaluable, providing the world of academic publishing at the end of your internet connection. I shall miss it sorely.

In the last few months of my degree the new radiotherapy course was announced for 2007. S819 covers the application of physics to the techniques of radiotherapy, which plays an important role in the treatment of cancer. The core materials apply the principles of basic physics to radiotherapy in dosimetry, external and internal treatment methods, treatment planning and radiation protection. This will round out a coherent medical physics MSc.

The project course S810, in respect of a medical physics focus, is available for those who have access to facilities or who work in a hospital – I got the sense that literature reviews are discouraged for this topic.

It is to be noted that nearly all graduates of F12 do **not** share my disappointment in the course content – it may be the shock of moving from 3rd level undergrad topics such as the Schrödinger equation to a media study in the early days of this degree that has led me to this sense of incoherence. If physics students were to learn from my mistakes and avoid the Studies strand and to focus on radio-imaging and radiotherapy, they may end their studies with more of a sense of becoming a Master. By supplementing these with a good project course then perhaps the degree can be renamed from the tautologous MSc in Science to that of MSc in Medical Physics.

Visions for Discovery

Berkeley Conference Report *by Professor Russell Stannard*

Russell Stannard is Professor Emeritus in the OU's Physics and Astronomy department and is well remembered by many OU physics students for appearing at various ages in the course videos for "S357 – Space, Time and Cosmology". However, his main preoccupation these days is being a trustee of the John Templeton Foundation, an American charitable organisation which distributes $40 million per year mostly to promote better understanding between science and religion, and character-building among young people. The Foundation organised the Berkeley Conference which was purely about physics. Despite being nearly 74 years old Professor Stannard also keeps pretty active giving talks all round the UK.

One of the most significant events marking Einstein Year was a conference at UC Berkeley, 6-8 October 2005. Entitled *Visions for Discovery*, it was aimed at looking at the future of physics – what the big questions still facing us appear to be. Of course the target is a moving one. As we make discoveries, new questions arise, and the emphasis changes. But how do things look to us at this present time?

The conference was attended by 900 physicists, including 18 Nobel laureates – 20 by the end as Glauber and Haensch's awards were announced. It was organised by the John Templeton Foundation, of which I have been a trustee for the past 12 years. Recently we have been branching out to cover certain pure science topics – provided one is dealing with really fundamental questions. Two years ago we held a conference in Princeton, in honour of John Wheeler – devoted to cosmology. This Berkeley event was the second such venture, and was in honour of Charles Townes' 90th birthday. Charles won the Nobel Prize for the maser/laser principle. He was also the first to discover complex molecules in the interstellar medium, and the first to measure the mass of the black hole at the centre of the Milky Way Galaxy.

Now to the conference itself: It was partly looking at where technology is likely to go – as this impacts on what discoveries one can make in physics. I will say a little about that as we go along, but let's get to the main questions facing physics. Rather than sum up what each speaker said, which would lead to a lot of overlap, I have tried to collate what various speakers contributed under subject headings – and I have numbered the main questions from 1 to 30.

Astronomy and Cosmology

Origins of the Universe

1. What can be said about the very beginning of the universe – are we really dealing with a singularity?

Normally when we get a singularity, it means the breakdown of the physics you are using. Hawking suggests there was no $t = 0$. Time melts away – and becomes imaginary. So no boundary. That gets rid of a cause of the Big Bang and also the question of what were the initial conditions and how they were fixed. In fact, the question 'What caused the Big Bang?' probably has no meaning anyway. We think of the Big Bang as marking the coming into existence of space – which then carries on expanding and carrying the galaxy clusters apart. But if time is welded to space to form a 4-D spacetime, the Big Bang will also mark the origin of time. But did the Big Bang mark the beginning of time?

2. How far back can we experimentally probe?

The further out one observes the further back in time one is probing because it takes time for the light to reach us. So can we hope to see back to the Big Bang itself? No, not with electromagnetic (EM) radiation. We can get back to about 300,000 years after the Big Bang, but then encounter radiation fog. Before the formation of atoms, the universe was bathed in radiation. But with neutrinos we could hope to get back to 1 second, and with gravitational waves could go back to the very beginning – in principle. That brings us up against the technological question of how much one might eventually be able to improve our detection techniques to make use of such forms of radiation.

3. Was there inflation, and if so, which model is correct?

Inflation is a period of super-fast expansion soon after the Big Bang, invoked to explain the flatness of space and the homogeneity of the universe. We do not know what drove inflation. There are several versions of the theory. How do we distinguish between them? A study of the details of the Cosmic Microwave Background radiation might help. CMB has structure at different angular scales. How do we understand these? Initially there were small inhomogeneities in density. These got magnified by gravity, making denser regions even more dense. But then photon repulsion increases, so one would tend to get a rebound. Some structure is due to gravitational collapse, some to gravity competing against photon repulsion which causes the rebound, and some from collapse, followed by rebound, followed by re-collapse. These competing effects give rise to structure on different scales. So we need to study these and see what would have been expected from competing inflationary theories. Also there is a need to study polarisation patterns in the CMB – which is the new frontier in CMB studies.

Contents of the Universe

5% baryonic matter (4% as free hydrogen, 0.5% in stars); 25% dark matter; 70% dark energy

4. What is dark matter?

Dark matter is invoked to explain the speed of rotation of a galaxy and the movement of galaxies within their cluster. It is known not to be baryonic, so what is it? It cannot be massy neutrinos. Such neutrinos would have to have a mass of 50ev and experimental limits put it at less than 1ev. Could we be dealing with supersymmetric particles? Most versions assume a neutral particle called a neutralino with a mass that might be between 10 and 1000 Gev. It has a weak interaction with an expected cross-section with quarks of 10^{-36} cm^2. One possible way of looking for indirect evidence for it is to examine high energy neutrinos coming from the posited annihilation of pairs of neutralinos in the sun. In addition, experiments are being carried out to try to detect a wind of dark matter passing through the laboratory. The density of this wind is expected to be equivalent to half a proton per cc (but is not made up of protons).

5. What is dark energy?

Saul Perlmutter was at the conference describing his discovery that the expansion of the universe is accelerating. It had been expected to be decreasing because of the gravitational attraction between the galaxy clusters, but it is not. This has given rise to the notion that space is permeated with a dark energy which exerts a pressure rather than an attraction. So, is this Einstein's notorious Lambda (Λ) cosmological constant? Einstein assumed the universe was static so gravity's attraction between the galaxies would have to be countered by an equal and opposite repulsion which meant he had to introduce into his equation a constant, lambda, to represent the repulsion. This he later regarded as his biggest mistake (he could have predicted the expansion) – but now it looks as though he had been right.

Is there any connection between the on-going repulsion due to dark energy, and the early repulsion associated with inflation? An open question.

Does the density of dark energy remain constant? One idea is that it might increase with time. If so, the repulsion will become noticeable over smaller and smaller distances. First, galaxy clusters will be torn apart, then the galaxies themselves will disintegrate, then the solar systems, the stars, atoms, and nuclei. This is called the Big Rip.

6. Why is Λ so small?

In other words why is there so little dark matter? Λ comes out to be 10^{-120}, which is either 60 or 120 orders of magnitude (according to your theory) smaller than what one might expect based, say, on vacuum fluctuations. In other words one would have expected either a very large Λ or none at all. Perhaps we have almost complete cancellation of large contributions from different mechanisms, but this almost complete cancellation is still a mystery.

7. Why is there so little anti-matter in the Universe?

What is the precise mechanism for producing matter in favour of anti-matter?

8. What can we learn from the study of exoplanets?

The first planet found going round another star was 10 years ago. To date 168 of these exoplanets have been found, including a triple planet system and several other multiple planet systems. The lightest planet so far found has a mass 7 times that of the earth. Something like 10% of the stars so far searched have been shown to have planets. There are to date three ways of discovering them. (i) Examining the star wobbling as it goes round the system's centre of gravity, using ground-based interferometers; (ii) from the dimming of the light of the star during a transit of the planet; and (iii) from blocking out the light of the star so as to see the light from the planet itself – this being in the design stage at present.

9. ET?

The search for extraterrestrial life continues and is being expanded in both the radio waves and optical wavelengths – especially being alert to the possibility that ET is trying to communicate using powerful laser beams.

Once one can detect light from a planet by blocking out the light from the star, one might infer that there was life on it by looking for variable colour patterns related to seasons and perhaps indicating vegetation. In addition, spectral analysis of light from the exoplanet could give us its chemical composition – especially looking for oxygen – as an indication of at least primitive life forms – also water, ozone, and CO_2.

10. The formation and development of galactic black holes?

There is a black hole at the centre of the Milky Way galaxy with a mass of 3 million stars as judged by the motion of stars within 10 light-hours of the centre. These are measured using infra-red radiation as optical wavelengths are no good for probing that area. Black holes have been found at the centre of other galaxies – one weighing in at 3 billion stellar masses. How these develop over time is an active area of study.

11. Does the Universe spin?

Goedel has shown that theoretically it could. If it does, one could journey far from the earth and return before one had set out (time-travel). But tests show that the rate is less than 10^{-5} radians during the lifetime so far of the universe.

Relativity

12. What is the status of Spacetime?

According to Ed Witten, space and time might be doomed. Maybe space is an emergent concept of something that is yet more fundamental. Could time also be emergent and not fundamental?

13. Does general relativity break down under conditions of very strong gravity?

We have already alluded to worries over whether the Big Bang began with a singularity as one might expect from the straight application of general relativity. Could it be that we are also wrong in thinking that at the centre of a black hole – another situation of intense gravity – there is a singularity?

Multiverses

14. Is our Universe alone?

Certain versions of inflationary theory lead to the belief that when one gets symmetry breaking, it might occur differently in different regions. This would give rise to domains where the laws of physics would be different to our own.

Alternatively one might think that if the Big Bang gave rise to our universe why might not other big bangs give rise to other universes where the laws might be different, and indeed the number of dimensions might be different to ours?

Such questions are closely linked to the problem of the Anthropic Principle. Over the past 30 years or so it has become increasingly recognised that our universe appears to have been extraordinarily suited to the development of life. Change any of a number of physical constants and conditions by only a small amount and the development of life anywhere in the universe would have been impossible. This recognition prompted Fred Hoyle to declare 'A simple interpretation of the facts indicates that a super intelligence has monkeyed with the physics.' Or, as Freeman Dyson has declared 'The universe knew we were coming.' This suggests that either a God has deliberately designed a universe with us, and perhaps other forms of life, in mind, or there is an infinite number of universes, most of them hostile to life but a few freak ones happen to be OK – and we being a form of life must of course find ourselves in a freak universe. If there *are* other universes, then it is difficult to see how we might prove that they are there, they by definition not being reachable by us as they do not belong to the universe we observe. But might there be some indirect evidence of their existence we might call upon?

Quantum Physics

15. Is it the ultimate description of nature?

The perennial Bohr-Einstein debate. Bohr insisted that it is a theory of observations of the world rather than a description of the world as it actually is in itself – and that is as much as we shall ever have. Or was Einstein right that the ultimate goal of physics is to come up with a theory of the world as it actually is in itself – preferably a description which gets rid of the uncertainty aspect of present-day quantum theory?

16. Does it make sense to talk of the wave function of the universe?

There is an idea of trying to account for the Big Bang as being a quantum fluctuation. Just as a virtual electron pops into the world as a result of such a fluctuation, the electron being described by a wave function, can we so regard the universe as an object behaving in the same way and possessing a wave function of its own. One worry about that is that the wave function is the way in which an external observer describes a physical system. But in the case of the universe – all that exists – who or what is supposed to be the external observer?

17. How are we to understand quantum entanglement?

The EPR experiment: 2 electrons collide, separate to a great distance, and you measure the spin of one electron in a particular direction and that instantly fixes what a second experimenter will find when he measures the spin of the distant electron. This appears to be faster-than-light communication. Bohr gets round the problem by stating that we are not dealing with two separate 1-electron systems with communication passing between them, but with a single 2-electron system such that a measurement on one electron is actually a measurement on the whole 2-electron system. But if that is so, what is the nature of the bonding between the two electrons in the absence of any physically recognisable force such as electric or gravitational. This is called quantum entanglement – and is deeply mysterious. Is this something we just have to live with and that we are to be denied any more satisfying solution? In any case, is there a way of exploiting quantum entanglement such as in quantum communication or quantum computing?

High Energy Physics

18. The Higgs particle?

The Higgs particle has long been proposed as the solution as to how the elementary particles acquire their masses. It must be over 115Gev in mass, and it is widely expected to be less than 200 Gev. In which case when the large hadron collider (LHC) at CERN becomes operational it should be found. If it is not found, we shall be shaken considerably.

19. Why the pattern of particle masses?

The pattern of masses of the particles strikes us as very strange. The top quark has 58,333 times the mass of the up quark. That seems such an enormous range of masses. Likewise it seems odd that the mass of the neutrino is almost, but not quite, zero.

20. How are we to understand QCD?

In particular why are the strong interactions CP invariant whereas the electroweak interaction is not. The most elegant solution is to postulate the existence of the axion, but does it actually exist?

21. Is the proton stable?

Is baryon number conserved? Or to put it another way, are diamonds really for ever? We know experimentally that the lifetime of the proton must be greater than 10^{32} years, but how much further can we push this limit?

22. What of string theory?

In this type of theory, particles are not represented by points, but as tiny vibrating strings. Is this likely to hold the answer to the question of how to unite quantum theory with general relativity? There are competing types of string theory, some requiring 6, 7, or more extra dimensions. So which one, if any, is the correct theory?

23. Grand Unification?

This is the hope that we shall one day be able to demonstrate that the strong, weak and electromagnetic forces can all be shown to be manifestations of the one unified force. According to current thinking all these forces should come to have comparable strength at an energy of 10^{15} Gev. One problem is that we are never going to be able to realise such energies in the laboratory – the accelerator would have to be too large. The highest we are able to manage gets us only as far as 10^{3} Gev – 12 orders of magnitude short. So we have to rely on indirect indications – the instability of the proton being one such low-energy by-product – the theory predicting that the proton should decay slowly to a positron and π^0. Of course, such a high energy regime was achieved in the past at the time of the Big Bang. At 10^{-32} second, the temperature was 10^{27} K which means the particles were moving about with 10^{15} Gev. At that time the forces were united – before spontaneous symmetry breaking took place. So, if we were able experimentally to probe back to that era – using gravity waves, who knows, such investigations might be a window onto that high energy regime. But then again this can sound a bit fanciful.

24. Supersymmetry?

According to this idea, the exchanged particles that act as transmitters of force (gluons, photons, W's and Z's) and the particles that do the exchanging (quarks and leptons) are not as different in their properties and roles as is commonly supposed. Is supersymmetry true? In particular does the neutralino, which it predicts, exist (postulated as a possible component of dark matter).

The Laws of Nature

25. Are the physical constants really constant?

There is some indication that the fine structure constant has changed over time, but this is controversial and far from established.

26. What is the status of mathematics?

The language of physics is mathematics. But does mathematics exist in its own right to be discovered, or is it a human invention?

27. Are the laws of nature calculable?

David Gross (Nobel laureate for his work on asymptotic freedom) claims that it is his dream that one day we shall be able rationally to work out what the laws of nature and the values of the physical parameters *had* to be. I tackled him afterwards, pointing out that because the language of physics is mathematics what we are trying to do in formulating a theory of everything (ToE) is to find the particular mathematical structure that models the working of the universe. And because of that, even before we know what the ToE is, we can deduce certain things about it from the general properties that all mathematical structures must obey. For example, there is Goedel's incompleteness theorem. But even more important than that, it is known that from within a mathematical structure one cannot justify the initial choice of axioms on which that structure is built. The axioms of the structure that models the universe (and us) are the laws of nature. Hence we, being within that structure, will never be able to justify the initial choice of laws. David had no answer to this, but was still unconvinced. I told him he could dream on but I didn't give much for his chances!

General

28. Physics and free will?

It has always been difficult to reconcile our conscious sense of being free to act as we wish, with what is going on in the physical brain – whether we think the physical correlate of the mental decision is governed by classical determinism or quantum uncertainty. Our truly basic data is our raw mental experience, and we could argue that all science does is to try and bring order and sense to those mental experiences. So, if our physical theories cannot account for our free will, then there must be something deficient about the theory we have devised! Perhaps quantum entanglement comes into this in some way. After all, if the simplest system of two electrons that once fleetingly interacted in the past, but do so no more through physical forces – if they cannot be described as behaving like two isolated particles, what of the brain with all its multiple connections? Or do we have to conclude that our basic data is at fault and free will is an illusion?

29. Physics and consciousness?

Some people harbour the hope that one day we shall be able to account for the phenomenon of consciousness purely in physical terms. Is this a misguided hope? Certainly there is a close connection between what consciously happens in the mind and what goes on in the physical brain, but that is not to say that, on the basis of the physics alone, one ought to be able to predict that these happenings would be accompanied by conscious experiences.

30. The end of physics?

How will the study of physics end? When we have discovered everything and have a complete theory? Or will we ultimately fall short? One possible reason for such a failure is that our brains – which were after all fashioned by natural selection to assist us to survive by finding food, mates, and shelter – was never originally intended to do physics for its own sake. We might regard it as miraculous that we have made the progress we have with an instrument not designed for that purpose. It does not follow that we have the mental capacity to work out all of nature's intricacies.

But you might think, we can extend our thinking processes indefinitely with the aid of computers. Moore's Law shows that the power of computers doubles about every year – this has held for decades. At present, computers have the mental capacity of an insect. Carry on extrapolating Moore's law into the future, then computers will have the capacity of mice by 2020, monkeys by 2030, humans by 2050, and by 2070 we shall be ruled by robots. But is this a fair extrapolation? No. The reason for the increase in power is predominantly due to the miniaturising of the silicon chips. But by extrapolation, that means the process breaks down around 2020 when we shall be requiring chips to consist of no more than a dozen atoms, the following year, 6 atoms, 3 atoms, etc.

Another technical limitation might be over the size of the particle accelerator needed to put in the last piece of the jigsaw puzzle. OK, the LHC finds the Higgs. But what other discoveries and problems will it throw up? After all, every time we have built an accelerator to explore a higher energy regime, new things have been found which could not have been anticipated from what we knew of the lower energy physics. Perhaps one does need to get up to 10^{15} Gev to get vital clues as to what is going on. There is no reason why this universe should have been built in such a way that it was completely open to discovery within the gross national product of planet earth!

That more or less concludes what I have to say about this conference. You might be interested to know that it was an occasion for announcing a new initiative of the Templeton Foundation. They have set up a *Foundational Questions Institute (FQXi)*, run by Max Tegmark of MIT and Anthony Aguirre of UC Santa Cruz, for awarding grants to people who want to work on foundational questions projects that are not normally funded by other agencies. It has been set up with an initial grant of $8 million. You can find more information on what sorts of projects they will consider by visiting *www.fqxi.org*.

Muon Catalysed Fusion

by Tommy Moorhouse

Dr Lara Howlett's article (Vol 5 Issue 2) brought to mind a subject that captured my interest about 10 years ago. The article described the cooling of muon beams for the production of beams of neutrinos, and the interaction of muon beams with hydrogen. These processes are central to muon catalysed fusion (which we will abbreviate to μ-CF for most of this article), a source of much excitement on and off over the past half century or so. My aim is to indicate in fairly nontechnical (and possibly slightly inaccurate) terms what μ-CF is and, hopefully, encourage other *Fusion* members to delve further.

My amateur interest in μ-CF stems from the fact that the field brings together a wide range of ideas from modern physics, particularly quantum theory and physical chemistry. μ-CF is not currently thought to be a viable means of producing significant amounts of energy but there is still much research into this field. Who knows, one day soon the problems, outlined in this article and in the references, may be overcome and the dream of practical energy production through fusion may become reality.

The fusion of light nuclei is by now a well known means of releasing large quantities of energy from matter. One normally thinks of fusion occurring in extreme conditions of temperature and pressure, for the simple reason that in order to fuse the nuclei must overcome the large Coulomb repulsion between the protons to get close enough to react. As we shall see, muons can allow the reacting nuclei to get close enough to fuse even at or below room temperature. Once a muon has assisted in the fusion of one pair of nuclei, it can go on to assist others. This is a beautiful example of catalysis.

As an introduction to the main ideas we consider the mechanism of nuclear fusion, what muons are and how they can catalyse fusion, in more detail. This account is based largely on the review in Rafelski et al. (1991)[1].

Nuclear Fusion

It is useful to begin by thinking in purely classical terms. In this article, and the field of μ-CF generally, the focus is on the fusion of the isotopes deuterium (D) and tritium (T). When two light atoms initially separated by a large distance approach each other, the force between them varies in a way dictated by the Coulomb potential (as modified by effects such as spin-orbit and relativistic effects which we will neglect for the moment). At large distances the nuclei are screened by the electrons and the force is very small. As the atoms get closer the electrons interact and, if the speeds are relatively low, chemical binding can occur. The electrons fall into molecular orbitals with a release of energy corresponding to the binding energy of the molecule. At higher collision speeds the nuclei penetrate the electron screen, and the repulsive Coulomb force between the protons becomes dominant. At very high speeds, such as occur in hot plasma, the nuclei are essentially independent of the electrons and can get close enough for the strong interaction to overcome the Coulomb repulsion,when fusion can occur. At this stage quantum effects such as tunnelling become important.

The conditions inside stars are typical of the extremes of density and temperature required to sustain fusion. The problems of keeping fusion going in a hot plasma, such as containment of the plasma, have been the subject of much work ever since the potential for harnessing vast quantities of energy were realised.

Muons

Muons are point particles like electrons in every way, except that they are about 200 times heavier and can decay into lighter particles. Like electrons they come in positive and negatively charged varieties (or, if you prefer, the negative muon has a positively charged antiparticle). They live, in an average sense, around 2×10^{-6} seconds. Although this seems a short time, in terms of the timescale characteristic of nuclear reactions (about 10^{-12} to 10^{-23} s) it is a very long time. The story of the discovery of muons is fascinating in its own right (see, for example, Pais 1986[3]), as is the theoretical description of their place in nature, but here we shall only concerned with their ability to increase the probability of two nuclei fusing.

μ-CF has been 'discovered' several times, possibly most famously by Alvarez et al. (see Jackson 1999[2]) who were investigating a mysterious particle labelled the μ'. The events leading to the 'detection' of this particle were found in fact to be the signature of μ-CF. This discovery lead to much work on a simple 'direct' picture of μ-CF, and it was found that the muons, in this picture, could only catalyse a handful of fusion reactions before being lost.

'Direct' μ-CF

The 'direct' model can be illustrated in a very simple classical picture: a neutral molecule sitting at a point in space is approached by a negative muon. The muon can react 'chemically' with the molecule, kicking out an electron to form a bound state with the muon in orbit around one of the atoms. This reflects the fact that the binding energy of the ground state of the muonic atom (as we call it) is, as a first approximation, proportional to the reduced mass of the bound particle, and the system prefers the lower energy state.

Once inside the atom the muon has another effect: the muonic system has a Bohr radius (what we normally think of as the size of the atom) approximately 200 times smaller than the ordinary atom. It is this effect that make fusion much more likely to occur.

The muonic screening is effective to much smaller nuclear separations. In fact, the nuclei have a significant probability of approaching closely enough to make the nuclear force between them significant, and the nuclei can undergo fusion. The fusion, being a violent event, kicks out the muon, which can then go on to 'infect' another atom. This is the sense in which the muons catalyse nuclear fusion. We are familiar with the idea of catalysis in chemistry, where a substance can alter the rate of a chemical reaction without being consumed in the process, and the role of muons in this fusion cycle is clearly exactly analogous.

Muons can be lost from the cycle in several ways, the most important of which is 'sticking' to the alpha particle produced in the reaction and therefore being unable to bind to another deuterium or tritium nucleus. Also important is the weak decay of the muon into an electron and neutrinos.

A revival of interest

The discovery that the muon capture rate in a deuterium tritium mixture is greatly enhanced by the existence of a resonance reignited interest in practical applications of μ-CF. The resonant states are the 'ordinary' DT molecule and an excited state of muonic DT having very similar energies. When the muonic state forms it very quickly cascades to the ground state, and ejects an electron (the Auger effect) which carries away the liberated energy. Now fusion can take place on a short timescale, and the muon is usually liberated. Sticking is much less of a problem in D-T fusion because the alpha particle recoils strongly as a neutron is ejected from the reaction. The reaction scheme is:

$(\mu\ \mathrm{TD}) \rightarrow \alpha + \mathrm{n} + \mu.$

Detailed calculations of the various reaction times, together with experiments (Rafelski et al. 1991[1], Ishida et al. 2003[4] and references therein), indicate that a single muon can catalyse over 150 fusion reactions before sticking or decaying. Unfortunately this is still not enough to make the method viable on a large scale (and other caveats are presented in Rafelski et al. 1991[1]). It may be possible to reduce sticking by stripping muons from the alpha particles after reaction, but practical methods of doing this are not yet available. The production of muons is quite costly in energy terms, and the most common isotope of hydrogen is not suitable for energy production by this method. Tritium, the most effective isotope for this purpose, is radioactive and brings its own set of problems. If the process is made viable in terms of energy balance then these other issues will have to be addressed.

Further issues

If muons can be used as a catalyst for fusion one might ask: why not other heavy particles? There is a heavier version of the muon, the tau, which presumably would enhance the reaction rate even more. The problem, of course, is that its lifetime is much too short to even allow the formation of tau atoms. Even if they were relatively stable there would also be the energy cost of producing beams of taus. No other particles are strong candidates. For example, if one asks: what about pions? The unfortunate answer is that pions are extremely short lived, react strongly with nuclei on a short timescale and would be lost before catalysing any reactions. It seems that the muon's characteristics, remarkably, make it alone a viable fusion catalyst.

Ishida et al. (2003)[4] discusses the sticking problem, and indicates that the theoretic and experimental investigation of μ-CF is still very much alive.

As a final observation, the electron has been suggested as a fusion catalyst in unusual environments such as hydrogen adsorbed onto a paladium substrate. This has been a very controversial subject, and proponents of μ-CF have largely distanced themselves from this field of 'cold fusion'.

Conclusion

Very many technical details have been overlooked in this article, but the interested reader will find all of the gaps plugged in the main references and articles cited there. The Open Library has links to many of the articles cited below and in the references, and there is a wealth of material on the web.

Afterword

Mike Loughlin of UKAEA agrees: "Andrei Sakharov and F. C. Frank predicted muon catalysed fusion before 1950 and the concept is very elegant ... research continues today but, according to current understanding, μ-CF will not be a power source".

References

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[3] Pais A., Inward Bound, 1986 (paperback first issued 1988), Oxford University Press.

[4] Katsuhiko Ishida, Kanetada Nagamine, Teiichiro Matsuzaki, Naritoshi Kawamura, Muon Catalysed Fusion in Journal of Physics G 29, 2003 (IOP Publishing Ltd).

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EVENT HORIZON

Fusion Day and AGM, OU Campus, Milton Keynes

Saturday 28 January 2006

11.00 Opening remarks
11:15 Lecture – 'Cosmic Chemistry'
12:15 Lab tour and fun experiments
13.00 Lunch in Christoloudu Rooms
14.00 Fusion AGM
16.00 Coffee
16.30 Telescope tour and talk
17.30 Break
18.00 Dinner at the Hilton Hotel
19.30 Lecture – 'Out at the Edge'
21.00 Socialise in the Hotel bar!

Please contact *agm@oufusion.org.uk* if you wish to attend lunch (free) and dinner (charged). Full details on our web-site. Special OU rates available at the MK Hilton Hotel (01908 694433).

Jodrell Bank Observatory (JBO)

Friday 24 February

(for those wishing to arrive the night before the JBO tour)
7.30 Dinner at pub near JBO
9.30 After dinner talk – Ian Morison

Saturday 25 February 2006

11.00 Tour of JBO – Ian Morison
13.00 Lunch in the JBO visitor's centre
14.00 Two talks by JBO astronomers
16.00 Conclusion

Culham Science Centre, Abingdon, Oxfordshire

7 April 2006 2.00-5.00pm

The visit comprises an introduction to fusion and tours of the two fusion experiments on site, the JET and MAST.