fusion
The Open University Physics Society
Newsletter • Winter 2001/2002 Volume 1 • Issue 4

Einstein, Millikan and the Photoelectric Effect

One of Einstein's early successes was his interpretation of the photoelectric effect in terms of energy quantisation. But the reality is a lot more complicated, as RICHARD KEESING of York University explains.

My interest in this subject was awakened as an undergraduate when I found that I could not get a simple experiment to measure Planck's constant using the visible photoelectric effect to work. As you probably know this experiment measures the photocurrent versus voltage in a vacuum photo-diode which is illuminated by monochromatic light. The object of the exercise is to find the retarding voltage at which the photo-current 'cut off' occurs as a function of the frequency of the light. It is well known that Einstein predicted that the energy E of emission of electrons from a metal illuminated with monochromatic light of frequency ν is governed by: $E = h\nu - f$, where f is the work function of the metal.

I noticed that a reverse photocurrent existed, (due to photo-electrons being emitted from the anode) and try as I might I could not get rid of it. As a result the apparent 'cut off' simply occurred when the forward and reverse currents were equal and opposite. Needless to say I failed to get a value of Planck's constant. Several years later I was demonstrating in our first year lab here and found that the apparatus we had for measuring Planck's constant had similar problems. As a consequence I decided to build a photo-diode which I hoped would not suffer from this problem, had it built and after a few modifications produced a tube which had a forward to reverse current ratio of about 106 in the red and ~104 in the near UV[1]. And this is where my troubles really started!

My first disquieting observation with the new tube was that the *I/V* curves had high energy tails on them and always approached the voltage axis asymptotically. I had been brought up to believe that the current would show a well defined cut off, however my curves just refused to do so. What on earth was wrong with my apparatus; why were my results so different from those in all the text books? After considerable soul searching it suddenly occurred to me that there was something wrong with the theory of the photoelectric effect which one finds in elementary treatments. The problem with this theory is that it conflicts with some fundamental aspects of physics. The most important of these, at least to me, is the condition that mathematical functions which can be applied to the physical world are generally continuous in amplitude and gradient. A discrete cut off implies a discontinuity in gradient and immediately makes one very suspicious about the function.

The second problem is that the conduction electrons in a metal (the source of the photoelectrons) have an energy distribution which possesses a 'thermal tail'. This causes the (Fermi-Dirac) energy distribution function to approach the energy axis asymptotically: as it should because it is a well behaved physical function. The third problem is that in any real apparatus, even if the temperature were absolute zero and there were consequently no thermal tail, the photoelectrons must leave the photo-cathode over a finite range of angles. Unless the retarding

(continued on page 4)

Well, it's a very short editorial for this issue, as we need to tell you all about our forthcoming *Fusion Day* and *AGM*. And talking of membership, look out for our spring renewal offers and get ready to welcome all those new *FUSION* members who will be joining as a result of our flyer in the current course mailings.

Fusion Day and Annual General Meeting, OU, Milton Keynes

Saturday 2nd February 2002
Central Meeting Room 11

- 10.30 Coffee and Biscuits.
- 11.00 Talk on quantum computing by Dr Andy Greentree.
- 11.45 Laboratory visits, including the cold atom/quantum optics laboratory.
- 12.30 Lunch (free to members)
- 13.30 Annual General Meeting of Fusion – The Open University Physics Society (*FUSION* members only).
- 15.30 Coffee and Biscuits.
- 16.00 Talk on *Nucleus, a trip to the heart of Matter* by Dr Ray Mackintosh*.

The *AGM* is your chance to raise any questions and have your say about how the Society is run and what you would like it to be in the future. All members are welcome and we would love to see as many of you there as possible.

All posts will be up for election at the *AGM*, so if you would like to get involved in running the Society, or even just join the Committee and come along to our meetings, please let us know.

Notices, incorporating maps and directions, are being sent out by email or post. If you would like further travel or overnight accommodation advice, please call *01279 718781 or* email *eleanor@oufusion.org.uk*.

For those who want to stay on afterwards for an informal get together, we are organising an early dinner at an inexpensive pub or restaurant in Central Milton Keynes.

**Ray will be signing copies of his new book, 'Nucleus, a trip to the heart of Matter' after the AGM.*

Goodbye Julia!

JULIA MADDOCK (nee Rose) has left the *Institute of Physics* after three years as *Student Liaison Officer.*

Julia took over the job of running *NEXUS*, the Institute's busy student wing, after graduating from Durham University in 1998. She has helped to make *NEXUS* a household name amongst the Institute's 7,000 student members, and has been responsible for a plethora of events incorporating all sorts of social, career-building and networking activities, and even the odd bit of physics! She also edited *Nexus News*, the termly student magazine.

She is taking up an appointment as a Press Officer at the Swindon-based Particle Physics & Astronomy Research Council (*PPARC*), working to get more particle physics and astronomy news into the relevant press markets.

"I've enjoyed working at the Institute and meeting so many people", she says. "I think this is about the right time for me to move on to a fresh challenge and I'm sure *Nexus* will benefit from having a more recent graduate bring fresh ideas in".

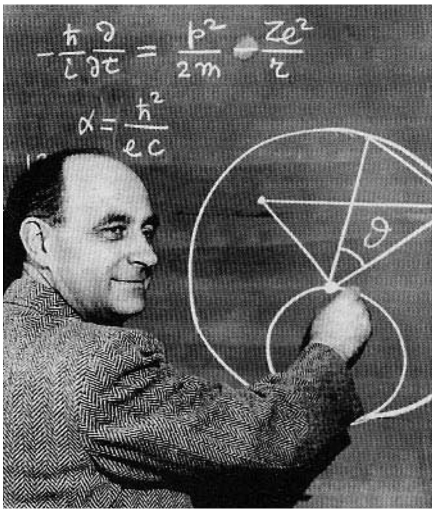
Julia was instrumental in helping us to set up *FUSION*, and has seen the society grow from strength to strength. We thank her for that, and wish her well in her new post. She hands the *IoP* baton on to Sam Rae, who graduated from Nottingham University in Physics and Philosophy this summer.

Fermi Trivia

Enrico Fermi, the famous physicist, was on the interview panel assessing a PhD thesis at the University of Chicago. Fermi sat through the entire interview without opening his mouth, and so, as it drew to a close, the chairman turned to him and said, "Are there any questions you would like to ask, Professor Fermi?"

"OK", Fermi replied, and, turning to address the student, "How many piano tuners are there in Chicago?"

Now, you may think, what on earth's that got to do with physics? Certainly the student thought so, and he sat in stunned silence, unable to answer. But what Fermi was actually trying to get him to do was demonstrate his ability to make an order-of-magnitude estimate, of the kind physicists are often required to do. You know the sort of thing - so many households in Chicago, so many percent of them have a piano, a piano-tuner can tune so many in a day, etc etc. Try it - it's good practice for the real thing!



We all know about Einstein's greatest blunder. But what about Fermi's? Well, one day he wrote the formula for the fine-structure constant on the blackboard, and got it wrong - inadvertently interchanging h and e. Well, we all do that, of course, but unfortunately for Fermi, this happened to be on a day when he had his photo taken - a photo which, decades later, was used in a commemorative US stamp, thereby distributing thousands of copies of his mistake across the nation.

Wolfgang Pauli proposed in 1931 the existence of a small, electrically neutral and possibly massless particle to explain an apparent lack of conservation of energy and angular momentum in nuclear beta-decay. He suggested the name "neutron". Two years later, Fermi published his theory of beta-decay which indeed incorporated such a particle. Unfortunately, in the meantime, the name "neutron" had been given to a completely different particle - well, a considerably heavier one anyway - which was discovered by Chadwick in 1932. Fermi suggested instead "neutrino", which, in his native Italian, means a "baby neutron". In what connoisseurs of particle physics will recognise as a break with tradition, the name stuck.

Overheard

OU students don't have to go to many lectures - some would say "just as well!" - but then again we miss the lighthearted little asides; for instance (heard at a 3rd year undergraduate physics lecture):

"This experiment requires an initial temperature of 0.01K. This was actually achieved by means of nuclear adiabatic demagnetisation, but for the purposes of this course you can regard it as magic."

Congratulations ...

... to BOB LAMBOURNE of the *OU*'s Physics & Astronomy Department, who, with Michael Tinker of Reading University, has been awarded the 2001 Bragg Medal & Prize by the *Institute of Physics*, for contributions to physics education, particularly the development of the Flexible Learning Approach to Physics (*FLAP*). Bob, who is a member of *FUSION*, takes over as head of the Department in February. We look forward to working with him.

... to BARRIE JONES, the current Head of the Physics & Astronomy Department, who has been awarded a Personal Chair in Astronomy (i.e. not the Chair vacated by Jocelyn Bell-Burnell, which is still vacant at the time of going to press) We would like to take this opportunity to thank Barrie for the help he has given us over the past year with setting up and publicising Fusion.

... to Fusion's PAUL RUFFLE whose team won the business game "The Project Masters" at the *Young Physicists' Conference* in Oxford in November.

Dark matter and cryogenic detectors

Many people think that "Dark Matter" is pie in the sky, but some take a more down-to-earth view, like Sam Henry, a PhD student at the University of Oxford.

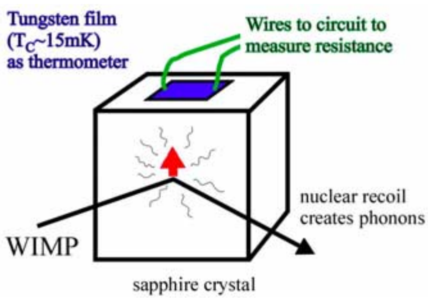
Fundamental research into areas such as particle physics and astronomy is often justified to politicians as essential to provide the theory to drive applied physics and the resulting technology. However the process is circular, as developments in applied physics are necessary to provide the instrumentation required to do fundamental research. A good example of this cycle is the search for dark matter, which is providing the main motive for developing cryogenic particle detectors.

Dark matter is one of the biggest problems in contemporary physics and astronomy. In order to explain the motion of stars in our galaxy, and in other galaxies, there must be a great deal of mass in addition to that made up by all the luminous stars. Measurements of the velocities of stars show that the galaxy appears to be imbedded in a halo of dark matter. Stronger evidence comes from cosmology. Measurements of the rate of expansion of the Universe *(Hubble's constant)*, suggest that we live in a flat universe – where the rate of expansion will ultimately be balanced by gravity. However all the visible matter in the universe can make up only 5% of the critical density required to produce a sufficiently high gravitational attraction.

Exactly what makes up the remaining 95% is still not fully understood. At one time it was thought it could be explained by objects such as planets, black holes and brown dwarves. However it is now clear that these objects can account for at most 20% of dark matter. The remainder appears to consist of something much more exotic.

The majority of dark matter is believed to consist of exotic particles. While some of this could consist of known particles such as neutrinos, the principal particle candidates for galactic dark matter come from theories beyond the standard model of particle physics, which have yet to be verified by experiments.

These particles are generally known as *WIMPs (Weakly Interacting Massive Particles)*, they are massive enough to account for galactic dark matter; but so weakly interacting that we have never detected them. However so far they are only hypothetical, there is no direct evidence that *WIMPs* exist or that the theories that predict them are correct. Therefore there are numerous experiments around the world trying to detect *WIMPs*, explain dark matter, and provide evidence for further theories of particle physics.



Searching for *WIMPs* basically involves building a particle detector, and waiting for a *WIMP* to hit it. As the interaction rate is so low – believed to be only one or two events a day in a ten kilo detector – this requires very sensitive, low threshold detectors. The other problem is background radiation, as any particles from background radioactivity or cosmic rays will also trigger a detector. Therefore *WIMP* searches are located in deep underground sites with extensive shielding.

Dark matter experiments include the UK dark matter collaboration, based in a Yorkshire salt mine; my experiment, *CRESST* based in the Gran Sasso underground laboratory in Italy; and the *CDMS* group in California. All these experiments have detector development projects. In *CRESST* we use cryogenic calorimetric detectors made from sapphire crystals. When a particle strikes a crystal atom, its energy is dissipated as phonons - tiny vibrations which propagate through the crystal and hit a superconducting phase transition thermometer (*SPT*) on its side, this is a thin film of a superconductor material held at its transition temperature. The phonons become trapped in the film, and thermalise causing a tiny increase in its temperature, this changes the film from its superconducting to its conducting state, and the relatively large change in resistance can be amplified and read out.

Cryogenic calorimeters are in many ways the ultimate *WIMP* detectors with excellent sensitivity. Experiments using cryogenic detectors typically use only a few kg of absorber, whereas searches using other methods such as scintillation detectors require huge absorber masses. These detectors have been developed for dark matter searches and similar experiments, but they are now finding applications in other areas of science including x-ray astronomy and spectroscopy. One of the fascinating aspects to this project is that it involves research in many different, but equally exciting areas of physics: cosmology, particle physics and superconductivity.

We are currently upgrading the *CRESST* experiment from a 1kg to a 10kg detector, and also adding some background discrimination to distinguish *WIMPs* from beta or gamma radiation. We should start taking data again this year. The *DAMA* experiment, also based at Gran Sasso, have claimed for some time to have found evidence for *WIMPs*. However their claim is still controversial, and the *CDMS* collaboration say their data largely excludes this result. The upgraded *CRESST* experiment should be able to test this claim within a few months.

Over the next few years, the various *WIMP* searches will reach the sensitivity where most theoretical models suggest the particles exist. So if *WIMPs* do exist within the galaxy we should find out soon.

EINSTEIN, MILLIKAN AND THE PHOTOELECTRIC EFFECT

(continued from page 1)

device is a point source at the centre of a sphere, this will cause a finite energy resolution and this in turn causes the current-voltage function to approach the energy (voltage) axis asymptotically (as it should because physical systems obey the first condition). For these reasons one would not expect an observable cut off. This being the case how on earth did Robert Millikan[2] obtain the results he published in 1916, for they appear highly unphysical?

Before starting this investigation I had read Millikan's 1916 papers in a rather cursory way but had not read Einstein's[3] 1905 papers at all. I now returned to these papers with an earnest intent.

Einstein's actual statements on the Photoelectric Effect

It is worthwhile reviewing exactly what Einstein wrote in his 1905 paper. Quoting verbatim from the English translation:

'...According to the concept that the light consists of energy quanta of magnitude $R b\nu/N$ (i.e. $h\nu$) however one can conceive of the ejection of electrons by light in the following way. Energy quanta penetrate into the surface layer of the body, and their energy is transformed, at least in part, into kinetic energy of electrons. The simplest way to imagine this is that a light quantum delivers its entire energy to a single electron; we shall assume that this is what happens. *The possibility should not be excluded, however, that electrons might receive their energy only in part from the light quanta.*' (I have highlighted this last sentence, Einstein did not.)

Einstein then goes on to derive the photoelectric equation by considering the emission of photo-electrons from a body having a work function f which is at a positive potential P surrounded by earthed conductors. He argues that we can make the potential of the photo-emitter sufficiently positive just to stop current reaching the earthed conductors. Under this condition:
$eP = h\nu - f$, where e is the electronic charge.

In this Einstein seems to be assuming, that there are no other sources of energy for the electrons. Thus he actually makes the prediction that there is a maximum energy of photo-emission although he covers himself against all eventualities with the condition I have highlighted above.

Millikan's investigation of the Photoelectric Effect

In his day Millikan was determined to perform experiments which would confront the most modern theories and have a real impact on the course of physics. This he did. To this end he spent about ten years investigating Einstein's predictions for the photoelectric effect which culminated in his several papers of around 1916. It is important to realise that although Millikan was using state of the art vacuum equipment, monochromators, light sources and electrical measuring instruments these were somewhat rudimentary in comparison with today.

His investigations of photo-emission from billets of vacuum cast sodium, potassium and lithium having freshly cut surfaces give one the impression that the surfaces he examined were the alkali metals from which the billets were cast. However his vacua, although good for 1905, were only 10^{-5} torr and would allow complete contamination of a surface in the order of one second. He noted that after freshly cutting his surfaces in vacuum the photo-currents and contact potentials were very unstable and it was his practice to increase the pressure in his systems to 10^{-2} torr to allow these to stabilise before experiments could be performed.

The work on Lithium: Using a mercury arc lamp and Hilger monochromator to isolate the spectral line at 433.9 nm Millikan measured the photo-current collected in a flared oxidised copper cylinder as a function of retarding potential. The *I/V* curve he obtained is reproduced from his paper as I in Fig 1 below. It will be noticed that it has a ~ 1eV tail which approaches the energy axis asymptotically. After a deal of experimentation Millikan convinced himself that this asymptotic tail was entirely due to the presence of short wavelength light scattered in his monochromator which he removed by 'interposing a filter of aesculin in a glass trough' . He reported that the asymptotic tail completely disappeared leaving curve II of fig 1. As this filter reduced the saturation photo-current by about a factor of four, from 2,595 to 591 units, he removed it and so subsequently collected *I/V* curves with these long asymptotic tails in situ.

Quoting Millikan; 'Hence after it has been established that the flat 'feet' of the curves are due to stray light, it is perhaps just as well to reduce these feet as much as possible, without the use of filters, that is, by having all transmitting and reflecting surfaces as clean and as perfect as possible and all absorbing surfaces as black as possible and then simply to cut the feet off'.

Millikan repeated on many occasions that the effect of the optical filter was to cause the asymptotic tail to disappear completely and allow him to observe the current plunging into the axis. On page 369 Millikan makes the following statement:

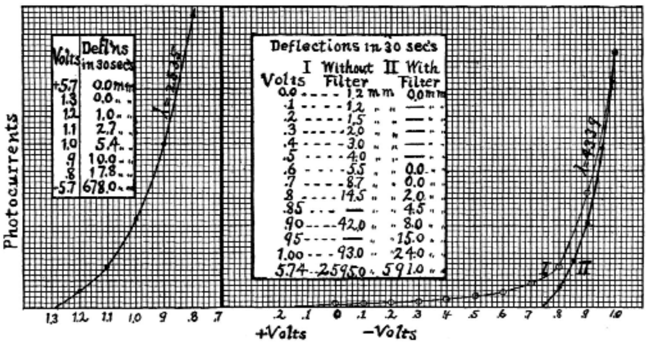


Fig 1. Millikan's graphs of photocurrent vs retarding potential for Lithium with and without his aesculin UV filter showing the asymptotic tail and the tail removed.

by Richard Keesing of York University

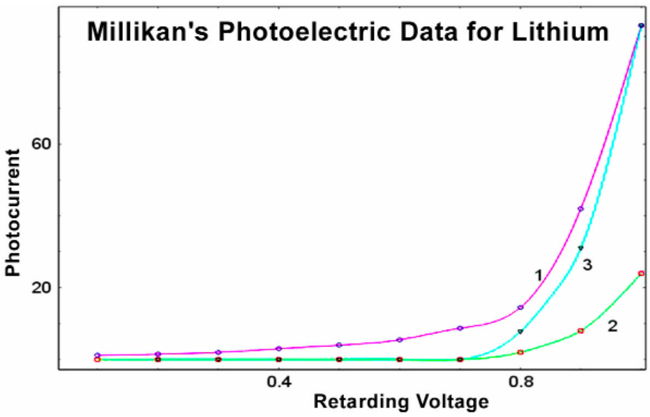


Fig 2. Curves 1 and 2 show Millikan's data taken from the tables of Fig 1, replotted on the same current scale. Also included is his scaled curve II for reference. The data points on all three curves have been connected with simple splines.

'These curves and a great many similar which I have taken seem to me to establish beyond question the contention that there is a definite, exactly determinable maximum velocity of emission of corpuscles from a metal under the influence of light of a given frequency'.

Millikan was aware that the presence of these distinct maximum energies implied that the source of the photoelectrons could not originate in a thermal distribution and so concluded that the photo-electrons had to come from the atoms themselves.

Let us for the moment accept that Millikan's photoelectrons were monoenergetic or at least had a distinct maximum energy. In order to observe a discontinuity in the *I/V* curve Millikan's retarding field analyser would have to have had an infinite energy resolution. The sole geometry which has this property is a point source at the centre of a perfect sphere, the collection efficiency of which is unity for all energies. Millikan's geometry was clearly not this.

Reading Millikan's papers leaves one somewhat perplexed. Having performed experiments on photoemission and modelled the process in planar and spherical diodes and found that one can understand the phenomenon quantitatively one is faced with Millikan's results. For his results to be physically meaningful his experiment would have to have suppressed the energy spread of his photoelectrons, suppressed the finite energy resolution of his energy analyser, and in doing so violated the requirement that physical functions should be continuous in amplitude and gradient.

Millikan fortunately included tables of data with his photocurrent vs retarding potential curves and I have replotted his curves again in figure 2 above. Curves 1 and 2 are plots of the actual data from the tables through which I have fitted simple splines. It is clear that there is no discernable cut off in curve 1 or 2 although Millikan claims otherwise. Interestingly though Millikan's curve II is not a plot of his actual data. It has in fact been scaled by multiplying by a factor of 93/24 so that it passes through the point at 1.00 volts.

I have shown this as curve 3 the points being joined by a simple spline. Millikan claimed that his curve II plunged into the energy axis at an exactly definable point. My curve 2, which is a plot of his actual data clearly does no such thing and is manifestly asymptotic to the energy axis. The numbers he quotes in his tables represent actual physical measurements and these cannot violate the continuity of functions, and clearly do not, no matter how often Millikan claims to the contrary. Why then, you might ask, does Millikan's curve II appear to plunge into the energy axis? For all he appears to have done is scale all the points by a constant, which would seem to be an entirely legitimate procedure. And here lies the rub: all the points up to a retarding voltage of 0.7 are recorded as being exactly zero current. Thus if one multiplies them by any finite constant they remain zero and the zero current point at V= 0.7 effectively pins the curve to the energy axis. Millikan then projected his curve II into the energy axis from the currents at 0.9 and 0.8 volts. Had Millikan measured the current at 0.7 volts more precisely one feels sure that he would have found it to be finite and not zero and this really would have put the cat amongst his pigeons.

Once Millikan had convinced himself that curve II plunged into the energy axis he felt justified in cutting off the tails from all his other curves and published the results shown in fig 3. This is the figure which is often mistakenly published in textbooks as undoctored experimental observations.

The moral of this story? Don't fiddle your data!

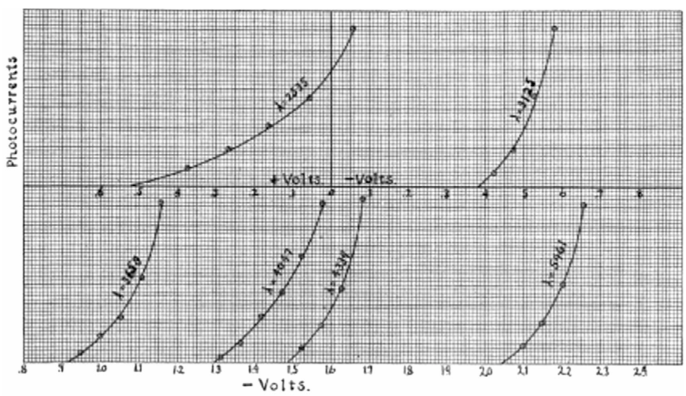


Fig 3. Millikan's curves of photo-current vs retarding potential in sodium with the asymptotic tails cut off: the data often reproduced in text books.

References: (1) R G Keesing, Eur. J Phys. 2 (1981) 139-149. (2) A Einstein: (A B Arons & M B Pepperd) Am. J. Phys.(1965) 33,5,367-374. (3) R A Millikan: Phys Rev (1916) VII, 3, 355-388.

Richard Keesing's research interests include resonance tunnelling of charged particles through layered structures of atomic dimensions.

S281 – Astronomy and Planetary Science

There are many components to this popular course, which covers one of the most romantic and inspiring fields of scientific enquiry, and also one of the fastest-moving ones. The course texts are backed up by the excellent book *Images of the Cosmos*, which contains many detailed photographs of planets, moons and galaxies; it has a yearbook, to ensure that students are kept up-to-date; and there are 15 video sequences and 8 TV programmes, which are an essential resource for such a visual subject.

There is a tendency, in the videos and many of the photographs, to use original, unsimplified images, from which the student is often required to identify certain features, but I felt this was expecting rather a lot – a bit like expecting a first-year medical student to see as much in an X-ray as an experienced radiologist. The principle is fine, but I think at this level we do need some simplification, or at least some helpful computer graphics to guide us around the complicated bits.

The TV programmes are easy to miss – many courses have abandoned this particular medium in favour of 100% prerecorded videos, and it's easy to forget to set the video, or get up at 6:30 to watch them! Do try to, though, as some of them are worth their weight in gold. They are slightly less rigidly linked to the course material than the video sequences, and contain some material that goes beyond the course – an essential component, I believe, and one that not all *OU* courses provide. My favourites were a programme on preparations for the *Cassini* mission to Titan, Saturn's largest moon, and the reminiscences and philosophising of Adriaan Blaauw, veteran Dutch astronomer who was in at the birth of radio astronomy. I was also pleased to see that the final programme, *Cosmology on Trial*, does accept that there are some scientists who don't agree with the "Big Bang" orthodoxy.

Astronomy is a practical subject, like most sciences, but unfortunately there is no summer school and so practical opportunities are limited. There are projects, involving observation of both the night sky and the sun, which the student is encouraged to do, and indeed, one of the *TMA* questions involves a project write-up. The cut-off date for this was in May, and a problem I encountered was the lack of any suitable clear skies, both at night or in the daytime. My advice would be to start on the projects immediately the course mailing arrives, so as to give yourself a sporting chance of actually being able to do them! Of course, many people, especially women, are reluctant to go out alone to the sort of dark, remote places where observation is possible, so perhaps the *OU* could help by organising some group observing sessions, possibly in conjunction with local astronomy societies?

Having said that, I felt that the project I chose to write up had a distinctly "Blue Peter" flavour to it, and treating such a wishy-washy exercise with the rigid discipline imposed by a standard project report did seem just a little absurd!

Hardened science students may be a little surprised by the style of presentation, which in places is very wordy and descriptive. In fact, at one point the authors declare their intention to avoid becoming too "biological"! Students of biology may find this OK; but I was just a little fazed by the discovery that four different words used in the same chapter all referred to the same phenomenon! The language used in the *TMAs* is also rather odd in places – the cause of much discussion on the *First Class* conference!

I found the standard of tutorial support to be very high – in fact, significantly higher than that provided for most of the other courses I have done – although of course this may vary from region to region.

S281 tries to please everyone, and therefore, it has to be said, ends up disappointing some people. For me, it was the lack of maths, and even basic science in some places, that frustrated me; others, with little or no maths and science experience, find themselves out of their depth even at this modest level. I did, however, like the gentle approach adopted for the questions, many of which begin with the words "Can you suggest..." or even "Can you remember..."!

S281 is soon to be replaced by a 60-point course, *S208*. Hopefully this will give the writers a chance to remedy some of the weaknesses of the current course. If I were to suggest just one improvement, it would be permission to take the *Course Handbook* into the exam – so that the latter becomes a test of understanding rather than just memory.

– Jim Grozier

POET'S CORNER

Cole's Lost Soul

There was a young fellow named Cole
Who ventured too near a black hole
His dv by dt
Was quite wondrous to see
But now all that's left is his soul

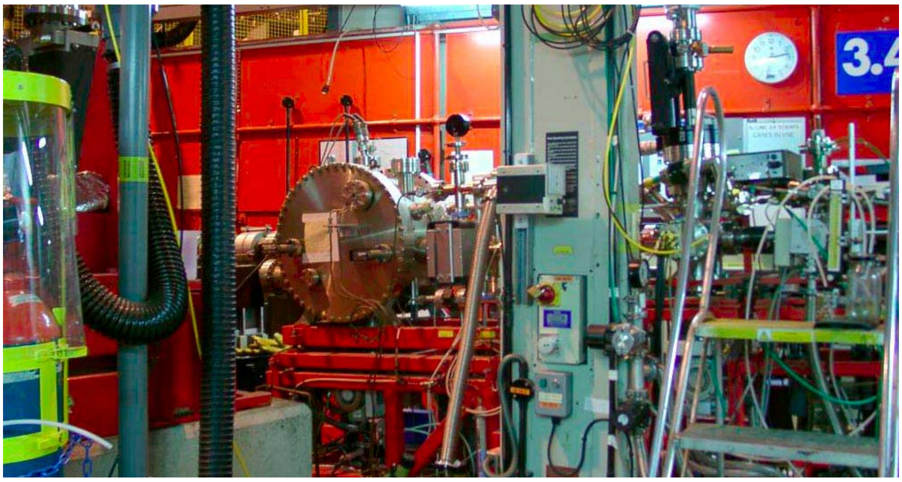
The Condensed Story of Ms Farad

Miss Farad was pretty and sensual
And charged to a reckless potential
But a rascal named Ohm
Conducted her home -
Her decline was, alas, exponential

The Relative Time of Ms Bright

There was a young lady called Bright
Who could travel faster than light
She went away one day
In an Einsteinian sort of way
And returned the previous night!

CLRC Daresbury



On a cold dark morning at the beginning of November, my alarm clock went off at 4:30 am. What on earth was going on? Then I remembered, it was the *FUSION* visit to Daresbury. Nine hours later, the visit began. People came from all over the UK, from Brighton to Glasgow to see this fascinating laboratory.

We were given a very interesting talk by one of the resident physicists, Hywel Owen in which he described how the synchrotron radiation is generated and some of its many applications.

When charged particles are accelerated, they give off radiation, for the electrons in the synchrotron ring at Daresbury this is most intense in the soft X-ray region, with wavelengths of around 4 x 10^{-10}m. They are also highly collimated into a very tight cone. The physicists at Daresbury use *Undulators* or *Wigglers* when they need to increase the energy of the photons.

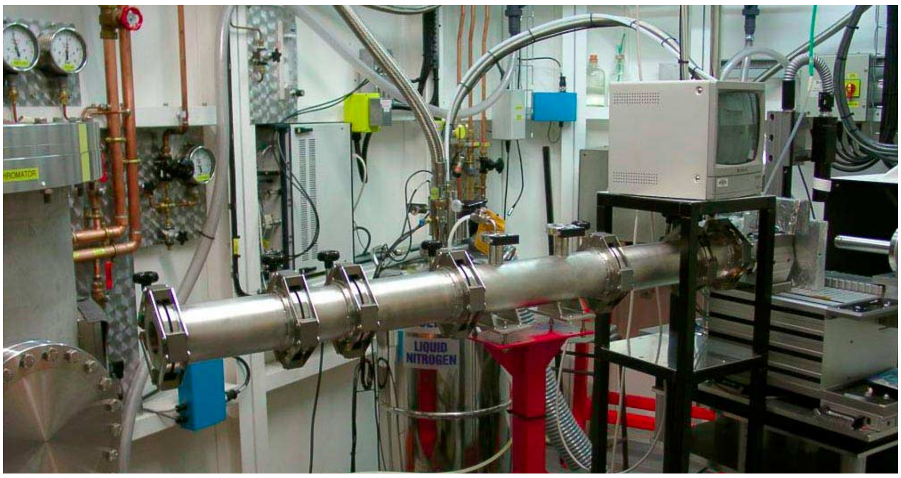
Undulators are a periodic array of permanent magnets with alternating north and south poles which gently wave the electron beam into a sine-like path through the magnets' length. Synchrotron light results from each undulation, and constructive interference between these emissions gives a very bright and narrow light beam.

A *Wiggler* uses superconducting magnets, the high fields generated cause the stored electon beam to effectively take a hairpin bend, a huge acceleration generating very short wavelength light.

The radiation is transmitted from the storage ring to the experimental areas via evacuated beam lines, many containing focusing optics to concentrate the synchrotron light at the location where it will be used.

The photons are in high demand at Daresbury; time at the 27 experimental areas is oversubscribed by a factor of three. Often the areas are in use round the clock.

The facilities have been used to look at the structure of proteins, stress on aircraft wings, fabrication processes of ancient ceramics and most importantly what it is that makes chocolate taste so good (apparently it depends on the crystalline structure). Indeed some of the experiments at Daresbury led to the award of a *Nobel Prize*. In 1997 Dr. J. Walker received a share in the *Nobel Prize for Chemistry* for work on the enzymatic process used to synthesise *ATP* in cells.



Our tour of the lab was fascinating. As an *OU* student, I'm used to doing experiments for one week a year, usually on standard equipment and repeating some of the landmark discoveries in physics. This was completely different, as you can see from the photographs, the lab is a mass of pipes, cables, sealed rooms, giant magnets and detectors. This is because there is such high demand for the synchrotron radiation, as many experiments as possible are fitted into the limited floor space.

Before an experiment starts, there are elaborate safety precautions, and in fact there are three full-time safety officers on site. Experimental areas are sealed off before activation to prevent radiation exposure. We were a little disconcerted when some liquid nitrogen started spurting out of a tap, but apparently this is fairly normal.

The excess heat of the laboratory is removed by water drawn from the nearby canal and returned 10°C higher in temperature, something the nearby ducks like in winter.

The trip was rounded off with coffee and biscuits in the science centre, where there is a 'hands on' exhibition and we all took home some fascinating literature on the science at Daresbury and its applications. We wished our hosts well and presented them with *FUSION* T-shirts.

Eleanor Cowan

EVENT HORIZON

Organised by Eleanor Cowan.
Forthcoming *FUSION* events include:

CERN, Geneva

27th - 30th June 2002

We will be travelling as part of the Nexus group, so there will be lots of other students, We have booked 10 of the 50 available places for *FUSION* members. The trip leaves on Thursday 27th June and returns the following Sunday. Please let Eleanor know as soon as possible, if you are interested.

Culham Science Centre

Sunday 21st April 2002

We will see *JET*, the world-famous nuclear fusion research facility (which will be familiar to anyone who studied *S272*) and also *MAST* (Mega Amp Spherical Tokamak), and hear the latest news on the quest for commercial fusion power. Culham is in Oxfordshire, near Didcot. The visit starts at 10am.

British Engineerium, Hove, Sussex

Sunday 2nd June 2002

This is a Victorian pumping station. We will have a guided tour and actually be able to see the old steam engines working as they did one hundred years ago. There is also a chance to see the tunnels used to bring coal into the station as well as the *Museum of Domestic Appliances*, which is on the same site. The visit begins at 11am and costs £4.25 per person.

Other Events

Don't forget that the *Institute of Physics* also arranges lectures and visits, so check their website for the latest information. If you wish to attend any of the above events, email *eleanor@oufusion.org.uk* or leave a message on the *FUSION* web site or call *01279 718781*. Also please check the *FUSION* web site for any last minute changes.

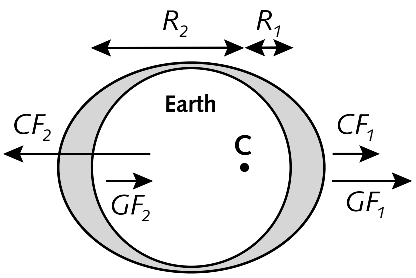
Ocean Tidal Bulges *by Mustafa Jaffari*

In one of our local Astronomical Society meetings, a member asked the reasons for there being two tidal bulges at the opposite sides of the Earth. I volunteered a short explanation, which was that the common centre of mass of the Earth-Moon system was 1,700 km inside the Earth and that the dance of these two about this point was causing an imbalance of forces which is corrected by an additional bulge on the far side of the Earth from the Moon's position. The side nearest to the Moon would of course, have a bulge from the mutual attraction of the Earth and the Moon, but why is there a bulge on the far side?

The Earth and the Moon are in a gravitational lock with each other and the Earth-Moon system is in a similar gravitational lock with the Sun. There are other forces also acting within the Earth, such as thermal movement of the ocean and atmosphere, causing currents and other more complex mechanisms. Tidal bulges also occur in the body of the Earth as well as in the atmosphere. However, to explain tidal bulges, we can just consider gravity with Kepler's and Newton's Laws. We will also ignore the effect of the Sun' s gravity on the Earth, which is around a quarter of the Moon's gravitational pull.

Two objects in space possessing mass will always orbit their common centre of mass. Now the Earth is spinning on its own axis and every part of the Earth, including its oceans and atmosphere, is bound by Earth's gravity as opposed to being flung out by the centrifugal force *(CF)* caused by the Earth's spin[1]. But we also have

Tidal Bulges: Net Force Equals CF + GF



C = Centre of mass of Earth-Moon system

an additional *CF* caused by the Earth and Moon rotating about their common centre. This *CF* has an angular movement of 1/27.3 of 360 degrees per day[2]. The formula for *CF* is $m\omega^2R$ and the distance R from this common centre to the surface of the Earth is 1,700 km on one side and 11,100 km to the other side (roughly).

This additional *CF* on the mass of ocean at the Earth's surface near the Moon is less than that experienced at the far side of the Earth. But the gravitational forces *(GF)* are greater on the Earth's side nearest to the Moon[3]. It is this difference in the totals of these two forces *(CF + GF)* that causes the second ocean tidal bulge on the Earth's far side. Thus there are two ocean tidal bulges in line with the Moon (slightly lagging in fact, due to friction). Of course, the Sun's gravity causes additional forces which add to or reduce the lunar tides depending upon the relative positions of the Sun-Earth-Moon.

This friction of the Earth moving below its tidal bulges slows the Earth's rotation roughly at a rate of half an hour every ten million years. This loss of momentum causes the Moon to spiral outward at about 3 cm per year. The Earth's rotation on its axis will finally slow down to the same pace as the Moon's orbit, that is once a month, so if you were standing on the Moon, you would see the same face of the Earth, just as we see the same face of the Moon from Earth.

References: See FAQ 75 by Phil Plait on NASA's web site and S330 Oceanography volume 4 page 43. (1) Centrifugal force is often described as a fictional force as it is only experienced within a rotating reference frame. (2) The Earth-Moon system rotates once every 27.3 days. (3) Earth's gravitational force is ignored in this model as it is the same (more or less) at all points of the Earth's surface.

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