

Editorial

We have included here both the minutes of the AGM, held at Aberdeen and the EGM, the proceedings of which complemented it. The next AGM will probably take place at the end of the current year.

We had a very interesting meeting on either side of the EGM on recent research on graphene, which anticipated a piece in The Times on the same subject. It's unusual, even in the so-called quality press, that one gets an account of a scientific topic that is as accurate and to the point.

May I draw your attention to this year's NanoteC07, meeting, a notice of which appears in this newsletter. As usual, this is a very strong and attractive programme and details to get further information are given.

The item on research into carbon in Portugal reached me some time ago but I hope that it is of interest. Various other items also appear: I am always grateful for any pieces of interest relevant to carbon that I can use.

I'm extremely grateful to Chris and Nicole (or Nicole and Chris-see the heading of their article) for writing the piece on women in science. We do get reminded from the IOP from time to time to look at the balance of the sexes in our group but their light-hearted but perceptive dialogue will perhaps put the matter in perspective. The RSC is also conscious of the problems (and opportunities, one might add) that women face in science and there is a Women Chemists' group run by the female members, with the support of the RSC, that does address these issues in a positive way.

Finally, we had intended to put together a meeting to discuss how coal might feature in a CO₂-free energy future. For various reasons, this fell by the wayside but I have set down my views on the subject and I hope that you will find them interesting. As Editor, I always welcome comment and criticism, so if you feel you want to challenge or respond to this article, feel free to do so. I warn you though, that anything you do say may be taken down and used as material in the next newsletter, which we hope will appear in 6 months' time or so.

Norman Parkyns

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NanoteC07

Nanotechnology in Carbon and Related Materials

www.hpc.susx.ac.uk/nanotec

University of Sussex at Brighton, 29th August – 1st September 2007

This is the ninth international NanoteC conference organised by the **British Carbon Group**, supported by the *GDR-E*, *European Women In Nano* network, and the *Royal Microscopical Society* with the aim of promoting carbon science at the nano scale as, for example, fullerenes, nanotubes, graphene, nanowires, sp^3 forms, etc.

The NanoteC conferences are renowned for their relaxed and friendly atmosphere, with emphasis on discussion and participation. We endeavour to achieve as much student participation as possible, and we anticipate that the keynote talks will be strongly influential on the next generation of nanotechnology scientists. The conference sessions start at 2pm on Wednesday August 29th, with registration in the morning, and end at 1pm on Saturday September 1st.

A very strong list of confirmed speakers at this year's NanoteC include:

Jean Christophe Charlier

Gyula Eres

Peter Harris

Anna Moisala

Elena Obraztsova

John Robertson

Toshiaki Enoki

Morinobu Endo

Andrea Ferrari

Pascale Launois

Rebecca Nicholls

Jieshan (Jason) Qiu

Kazu Suenaga

For further details on registration, submission of abstracts, and exhibition space, please visit the conference website www.hpc.susx.ac.uk/nanotec

NanoteC07 is organised by Malcolm Heggie, Chris Ewels, Nicole Grobert, and Gregory van Lier on behalf of the British Carbon Group (registered charity number 207890), which is sponsored by the Institute of Physics, Society of Chemical Industry and the Royal Society of Chemistry.



WomenInNano

THE BRITISH CARBON GROUP

MINUTES OF THE 2006 ANNUAL GENERAL MEETING HELD AT
THE ROBERT GORDON UNIVERSITY, ABERDEEN, 19th. JULY , 2006
AT 6.00 pm

PRESENT: Professor M.I. Heggie (Chairman), Professor J. W. Patrick
(Vice Chairman), 5 committee members, plus 7 members.

APOLOGIES FOR ABSENCE:

Apologies for absence were received from:

Dr. J. Fisher, Dr. P.C. Minshall, Dr C.J. Hindmarsh

MINUTES OF THE PREVIOUS MEETING

The minutes of the previous AGM, held on the 2nd September, 2005
at the University of Sussex at Brighton were approved as a true
record.

ACTIONS AND MATTERS ARISING (not covered in Agenda)

There were no matters arising.

CHAIRMAN'S REPORT (Professor M.I. Heggie)

From AGM 2005 to the AGM 2006.

The 2005 AGM was held at NanoteC05: our annual conference then
held in its traditional home, The University of Sussex. This meeting
was, as usual, well supported and successful, being truly
international with 90 participants, from the UK as well as Turkey,
Syria, Israel, Russia, Taiwan, Japan, South Africa and several
European countries..

“Ageing Management of Graphite Reactor Cores”, Cardiff, 28th – 30th November 2005: a 3-day specialist meeting organised by the BCG at the University of Cardiff, sponsored by the Health and Safety Executive (Nuclear Safety Directorate), British Energy (Generation) Ltd, The British Nuclear Group plc, Serco Assurance plc and Nexia Solutions Ltd. There were nearly 90 delegates and the proceedings formed an excellent, refereed volume ‘Ageing Management of Nuclear Reactors’ published by the RSC. In all it was a great success, for which we are grateful to the organiser, Dr Tony Wickham, and the proceedings editor, Dr. Gareth Neighbour.

In addition the Group co-sponsored the Nanostructured Materials Symposium within the IoP Condensed Matter and Materials Physics in April, and the 4th IEE International seminar on advances in carbon electronics (18 Nov 2005, London).

We hold this AGM at what has become arguably the best international carbon conference held in Europe to date, and certainly the biggest. Carbon2006 which we are holding in July in Aberdeen (www.carbon2006.org) attracted some 560 attendees and 60 or so accompanying persons. We all owe a debt of gratitude to the strenuous efforts of the BCG committee which constituted the organising committee and especially to Prof. Mark Thomas (Programme Chair), Prof. Bob Bradley (Local Chair), Dr Chris Ewels (Webmaster) and Dr Tony Wickham (Conference Manager).

TREASURER’S REPORT

A report for the calendar year 2005 was prepared by the Honorary Treasurer, Dr. C.J. Hindmarsh, and presented by the Chairman. The meeting concluded that the report was not sufficiently detailed and it contained obvious inaccuracies and inconsistencies. The report was not accepted. It was decided that a more thorough report, appropriately audited and signed, be presented to an Extraordinary General Meeting of the group and also circulated in the Newsletter.

ELECTION OF OFFICERS AND COMMITTEE MEMBERS

At this the 2006 AGM the Chairman, Vice Chairman, Treasurer and Secretary had to offer themselves for re-election.

In addition Dr. S. Mikhalovsky and Dr. A. Westwood had to retire and were not eligible for re-election for the next year. They leave with the gratitude of the committee for their valued efforts in debate and in conference organisation.

The retiring officers were nominated for re-election. In addition Dr. C.P. Ewels was nominated for election to one of the vacant committee posts.

In order to encourage new committee members it had previously been decided to seek a nomination for the other vacant committee post from the floor of the AGM. A nomination was received: Dr Ian Kinloch.

The following officers and committee members were elected unopposed.

Officers:

Chairman:	Professor. M.I. Heggie (University of Sussex)
Vice Chairman:	Professor J.W. Patrick (University of Nottingham)
Honorary Treasurer	Dr C.J. Hindmarsh (DSTL Porton Down)
Honorary Secretary	Dr. J. Fisher

Committee Members:

Dr. C.P. Ewels
Dr. Ian Kinloch

The following were notified as representatives of the sponsoring bodies:

SCI representative University)	Professor R.H. Bradley	(Robert Gordon
RSC representative	Dr. A.J. Wickham	
IOP representative	Dr. J. Goss	(University of Newcastle)

Any Other Business

There being no other business previously notified the meeting was closed at 18.45.

BRITISH CARBON GROUP

MINUTES OF THE EXTRAORDINARY GENERAL MEETING HELD AT THE INSTITUTE OF PHYSICS, PORTLAND PLACE, LONDON, 14th. DECEMBER , 2006 AT 3.00 pm

PRESENT: Professor M.I. Heggie (Chairman), Professor J. W. Patrick (Vice Chairman), Dr. C.J. Hindmarsh (Honorary Treasurer, Dr. J. Fisher (Honorary Secretary), 7 committee members, plus 7 members.

The extraordinary meeting had been called by the British Carbon Group committee to receive the 2005 group accounts and to carry out the election of a new Honorary Treasurer.

PRESENTATION OF 2005 GROUP ACCOUNTS

The 2005 British Carbon Group accounts were presented to the meeting by Dr. C.J. Hindmarsh.

These were accepted by the meeting as a true and accurate financial account of the period.

ELECTION OF GROUP TREASURER

Dr. Hindmarsh had decided to retire from the position of Group Honorary Treasurer at the end of 2006.

Professor Heggie, on behalf of the group, thanked Dr. Hindmarsh for his efforts as treasurer since his first election in 2002. His time in office had coincided with the hectic period during the organisation of Carbon 2006.

Dr. A.J. Wickham was elected unopposed and unanimously as the new Honorary Treasurer of the British Carbon Group. Dr. Wickham's term of office will start on January 1st. 2007.

Any Other Business

No other business being allowed the meeting was closed at 3.30 pm

John Fisher,

Honorary Secretary, British Carbon Group
December 14th. 2006

Vacancy for post-doctoral research

We have been asked by Prof. Beguin to make this position widely known, so we hope that it is not too late for some prospective candidate

Proposition of Post-Doctoral stay

Place : Centre de Recherche sur la Matière Divisée, CNRS-
University,
Orléans, France

Duration : 2 years
Expected starting date: May 2007
Subject : Optimization of nanoporous carbons for supercapacitors in
organic
medium
Citizenship: European

Profile : the candidate should have a background in materials
chemistry, and
if possible on carbon materials. Basis of electrochemistry would be
highly
appreciated.

Contacts:
Prof. F. Béguin, ++33 2 38 25 53 75
beguin@cnrs-orleans.fr
Dr. E. Raymundo-Pinero, ++33 2 38 25 53 61
raymundo@cnrs-orleans.fr

The unknown element

Prof. R. V. Jones had a rather splendid story that dated from the later 1940s. Following his valuable contribution to scientific intelligence during the Second World War, he was retained in some senior capacity or other as advisor to the Armed Services. At that time there was a tremendous amount of speculation about Unidentified Flying Objects (UFOs), which had attracted a number of observations by more or less reliable witnesses, as well of course by the lunatic fringe of the Great British Public. There was a lot of speculation about UFOs: did they exist at all and if so were they of extra-terrestrial origin or even from behind the Iron Curtain?

One day, there arrived on Jones' desk an urgent request for him to come and give his expert opinion on a crisis that had arisen. Apparently, an object had fallen out of the sky, out of the blue as it were, on an airfield and because of the general paranoia of the time, it had been rushed to the RAE, Farnborough for a report on its constitution. Among the details of the report was a chemical analysis that had caused a sensation. No doubt the analyst had couched his results in the usual terms but the report had then been filtered through the Civil Service and by somebody who was not a scientist, one presumes. This person had seized on the chemical analysis and had published a version that had caused an uproar and panic to sweep through Whitehall. What it said was that the object consisted of x % Si, y% Al z % Fe and so on but the phrase that had caused such a tumult was the statement that more than 99% was of an

unidentified element. An unidentified element! What could this be? Were we in the realms of science fiction with technology totally unknown to the human race? Please would Prof. Jones come at once and give his advice as to how the British Government should handle this alarming affair.

Jones however saw no reason to leave his office. He phoned Farnborough and asked them how this analysis was carried out. UV emission by spark excitation, he was told. With graphite electrodes, he enquired? Of course, that's the way we normally do this analysis. Probably the analysts who wrote the report made the natural assumption that everyone would know this and would realise that carbon would not be reported as a constituent. However, someone had completely misinterpreted this and panicked. So, carbon was the unidentified element and that was the end of the affair. The mysterious object was nothing more than a lump of coke although it does raise the question, how did it fall out of the sky like that, if indeed it did.

What's in a name?

Those of you living in Britain may well have been amused to read in the papers a few months ago about a butcher in Wales. It seems that he made an excellent sausage that was sold under the name of Welsh Dragon sausages. Now, even most Englishmen are aware that the Red Dragon is a very active symbol of Wales and there was no argument but that the goods being sold were indeed sausages of high quality. Why then, did he fall foul of the local authority? His crime, if crime it was, lay in the name he had given to his product. The local trading standards authority, ever vigilant to uphold the rights of consumers, argued that this was a misrepresentation, since it was clear that the sausages contained not a single gram of dragon meat, such comestible being in very short supply, despite being utterly fabulous. The poor butcher was very bemused by all this, since it had never entered his mind that anyone should be led to suppose that his sausages were made of anything other than the usual animals that run about the hills and valleys of the Principality. I don't know what the outcome was. One hopes that the literal-minded officials were rightly laughed to scorn for their misplaced zeal.

Just before Christmas, my wife and I attended an open evening at a local delicatessen where all manner of tempting delights were available for us to sample. Among them, my wife noticed that charcoal biscuits were being offered for sale. Now, I remember a

couple of issues ago, that Chris Ewels wrote a piece on possible toxicity of nanocarbons, in the course of which he mentioned that children in France were formerly fed with a spoonful of charcoal a day for the good of their health. These biscuits were indeed very dark: not only that, they were hexagonal in shape, which looked suggestive of what might be in them but on enquiring from the owner of the delicatessen how much charcoal they contained, he averred that they were totally free of any form of the element we all know and love.

Women in Carbon Science
Nicole Grobert and Chris Ewels
Chris Ewels and Nicole Grobert

We all know that diamond is a girl's best friend, but what about the other carbon allotropes?

Nicole: One issue that regularly comes up is gender balance in science, and the British Carbon Group had been approached by its host organisations on this subject. A resolution was passed at the last BCG committee meeting calling for an article for the newsletter. Immediately I was picked for the job, as the only female participant in that group.

I tried to pass it off onto various male colleagues, but the group felt it was up to me. So I begged for a male co-author as it's an issue which needs to be addressed by both sexes, and as Chris failed to duck fast enough, he got the job.

Chris: Women in science is a tricky subject and writing about it sometimes feels a bit like walking on eggshells, particularly as a male author. It'd be easy to paint myself into a stereotypical corner; "What has women in science got to do with me? I'm a bloke!" plays well as an introduction to a walk through the issues but doesn't really reflect my take on things. Equally it's difficult to write about issues of prejudice and discrimination against women when I can clearly never have been on the receiving end. We were starting to move well outside of my usual comfort zone.

Nicole+Chris: How can the article be written without us being judged, or misjudged, by what we say? Several questions came to mind.

Nicole: First of all it was difficult to write about as I felt I was asked to write about my own situation, and as a result would get comments on the theme of “of course she’s writing about such and such, because that’s what is happening to her”. So I was concerned whether I could write about it objectively.

Chris: Would I ever had thought about gender issues if I hadn’t been pushed to think about it? And is it worth making an issue of gender in carbon science, or is it better just to get on with the science and remain “gender neutral”?

Nicole+Chris: What could be gained from writing such an article? And the question sneaks up – are there really any “issues” about women in carbon science at all?

Despite our thoughts and concerns we had no choice but to get on and write the article. We now faced the perennial article writing “blank page” problem, although it’s certainly nothing like writing a science article – no clear subject, results or conclusions, and everything we write has the potential to have impact.

Where to start? We decided to look at the statistics, because numbers is where we feel comfortable (we should point out that we only address the academic carbon science community here, because we feel even less competent to comment on women in the industrial side of carbon science).

The statistics for women in UK science generally make for mixed reading¹. They start well, and are somewhat better than those of many of our European counterparts such as Germany and France. In the UK across the science and technology field in general, 40% of science and research professionals are women². 36.5% of first degree science applicants are women, an increase of nearly 7% since 1996; and notably 41.1% of students starting degrees in the physical sciences are women.

However, these reasonably healthy figures start to drop off as women climb up the academic ladder. Amongst recruitment into full time lectureships in chemistry between 1995 and 2004, the percentage of posts given to women varied between 12 and 22%. For senior lectureships this drops slightly, falling to 0-4% of Professorial posts going to women depending on the year. Physics fares significantly worse, with only a miserable 5-10% of full time

¹ <http://www.setwomenstats.org.uk/sections/>

² Using DTI definitions of SET occupations, science professional and research professional occupations

lectureship posts going to women, dropping to 3-8% of senior lectureships and an impressive 1-4% of Professorial posts. So the statistics certainly point to a problem in recruitment and retention of women in scientific academic posts within the UK.

What about carbon science specifically? The membership list published on the American Carbon Society homepage paints a pretty dismal picture of our carbon brethren across the pond – only 15% of them are women (there is no breakdown by status).

We contacted the other European Carbon Groups and they kindly provided us with statistics on their membership lists. The result is surprising and quite promising: mainland European carbon science seems to have a healthier percentage of women.

The Spanish Carbon Group contains 42 % female scientists, with 30% of its organising council being female, including the president. The Polish carbon group membership is 31% female, with the distribution by “career stage” bucking the pyramidal trend discussed above: 37% of their postdocs are female, 17% of the full time researchers, and 27% of the professors. The French Carbon Group has a different organisational structure and so does not have a members list, however of its steering committee 25% are female.

Rosa Mendez, the Spanish Carbon Group president said “One thing we have observed in Spain is that the rate of women being promoted to higher levels in science is increasing. It’s not the same with management positions. The Ministry of Education and Science and also my own organization (Spanish Council for Research) are making a great effort in this respect. I have been responsible for the Spanish Program for Materials Research in the last three years and I can tell you that in the last two years 26 % of the approved proposals were managed by women; this is not a large number but it seems that it is improving. I am sure it will increase in the next three years.”

Unfortunately in the UK we have more in common with our American colleagues than those in mainland Europe. 13 BCG members from the IOP out of 80 are women (16%). The picture is worse for the RSC: 6 out of 93 (6.5%) and of the 30 SCI members only 2 are women (6%). Including non-institute members, that brings our grand total to 22 women out of 205, i.e. 11% of BCG members are women – certainly not something to write home about.

Nonetheless the mainland Europe statistics seem to agree better with our personal experience. When we both sat down to think

about it, a large fraction of the scientists we collaborate with are female – not a conscious decision on either of our parts, simply the way things have worked out – a quick straw poll of our current active collaborations came out at about 40% female, albeit with the majority of people in senior posts being male.

Nicole: Recently I've noticed that it often seems to naturally work out that I end up collaborating with other female scientists.

Chris: My personal suspicion is that this might be partly due to scientist's natural tendency to communicate, and as a natural consequence, then to collaborate. The chances are that if I sit down with another carbon scientist and have a good chat about research, we can normally find some area of common interest. So then the question is, do you tend to talk more to female carbon scientists?

Nicole: Because they are in the minority, women tend to stand out at international conferences, so naturally they find themselves talking to each other at some point or another. So maybe this tendency for women to collaborate springs out of our minority numbers rather than any fundamental underlying differences in the sexes?

Chris: If this is the reason then gender need not be the only "minority" issue to bind scientists together... I remember a few years ago being locked away in a Russian conference for a week with hundreds of participants but only about six other non-Russian speakers; we were naturally thrown together, and out of this has sprung some good friendships and productive research collaborations.

N+C: So there seems to be a mixed message from the figures. Mainland Europe seems to have a reasonably healthy male/female balance of carbon scientists, and in these countries women in carbon science are not under-represented in comparison with subjects such as engineering, nuclear physics, and maths. However the UK is in the same camp as the US, lagging far behind our mainland European counterparts. The development of carbon science shows some spectacular examples of trail blazing women – Rosalind Franklin with her pioneering work on the structure of amorphous carbons *, Millie Dresselhaus with her work on Raman spectroscopy of graphite and carbon nanotubes, and Oberlin in the field of carbon fibres are three that immediately spring to mind.

we hope to publish an article on Rosalind Franklin in a subsequent newsletter
Ed

We've deliberately skipped here some of the broader issues of women in science such as the difficulty of achieving a career / family balance, managing career breaks for children, lack of role models, and glass ceilings, as these are not issues specific to carbon science and have been covered in detail elsewhere. And certainly it doesn't seem right to "make light" of these hugely important issues. The women in carbon science we discuss here are the ones who have made it, despite all the difficulties along the way, but there are many others (some our friends) who have fallen foul of the competing pressures of family life, enforced career mobility and are no longer active in research.

But in general, the future looks "sparkly" for women in European carbon science, as many of the next generation of academic carbon scientists are women – even if we in the UK need to make more of an effort to achieve the balance seen on the continent. This is reflected at this summer's NanoteC which will include a "women in nano" session, supported by the European "WomenInNano" project (end of August 2007, book your ticket now! www.hpc.susx.ac.uk/nanotec)

Just as the various allotropes of carbon are all important in making carbon science such a rich and varied field, so the two allotropes of people – male and female – are what makes our research field what it is!

Books of interest to BCG members

A limited number of copies of the RSC publication "Managing of Ageing Processes in Graphite Reactor Cores", edited by Gareth Neighbour, proceedings of a BCG conference held at Cardiff University in November 2005, are available from the Treasurer (Tony Wickham) at the price of £ 60.00 inclusive of UK postage. This represents a large saving on the RSC price and an additional saving on the RSC members' automatic 35% discount price.

Hardback, 300pp, ISBN 978-0-85404-345-3. Check it out at Amazon.com.

Strictly cheques with order (payable to The British Carbon Group) and sent to Tony Wickham at P.O. Box 50, Built Wells, Powys LD2 3PW. First come, first served.

Recently published and Forthcoming RSC Books on the Nanosciences

Fullerenes: Principles and Applications

The second title in the new series from the RSC on areas of Nanoscience and Nanotechnology, this book discusses all aspects of this exciting field from basic principles of fullerene chemistry to the most remarkable advances that have occurred in recent years. For more information:

<http://www.rsc.org/Publishing/Books/0854045511.asp>

Carbon Research in Portugal

All researchers have published in CARBON and/or FUEL and/or have attended International CARBON Conferences. All are permanent staff members. PhD students and Post-docs are not included. Full professors (“catedráticos”) are indicated by *. There are also a number of people not included here carrying out mainly theoretical research on fullerenes. There are also many other people in fields such as separation or purification technology who use carbon materials, amongst others, and are also not included. All are members of the Portuguese Chemical Society but very few are members of the Portuguese Materials Society. In most cases, more information can be found at <http://www.dcmp.uevora.pt> following the “contacts” link.

University of Évora

Prof. Peter Carrott
Prof. Manuela Ribeiro Carrott
Prof. João Nabais
Dr. Isabel Cansado
Dr. Paulo Mourão
Prof. João Paulo Ramalho

University of Minho

Prof. Carlos A. Bernardo*

New University of Lisbon

Prof. Luís Sousa Lobo*
Prof. Isabel Fonseca
Prof. Joaquim Vital
Prof. Ana Ramos
Prof. João Paulo Mota

University of Oporto (Faculty of Science)

Prof. Baltazar de Castro*
Prof. Cristina Freire
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Prof. J. L. Figueiredo*
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Prof. João Pires
Prof. Manuela Brotas

National Industrial Engineering and Technology Institute

Dr. Ibrahim Gulyurtlu
Dr. Isabel Cabrita
Dr. Dulce Boavida

Review of WONTON'07 Conference

The 2nd Workshop On Nanotube Optics and Nanospectroscopy was held at the Lord Elgin Hotel in Ottawa, from the 4th to 7th of June 2007. With over 70 leading international scientists from the USA, Japan, Germany, France, Canada and the UK in attendance, the conference was a truly international event of the highest quality.

The scope of the WONTON series of meetings is entirely focused on carbon nanotubes, with brief references to graphene where similar properties might be relevant. Optical spectroscopy has for many years been the most informative technique for investigating nanotube properties and characterising their bulk samples. Also, in recent years, some applications have even been proposed which utilise these optical properties. This is a very fast moving, exciting field to work in and a meeting such as WONTON is really the best means of keeping abreast of the latest developments.

The programme consisted of 18 invited speakers, with around the same number of contributing talks and two poster sessions. Talks with similar themes such as Raman spectroscopy or time resolved photo-luminescence work were grouped together and gave an informative overview of current research in these areas. Unlike in the first of these meetings in 2005 many of the results nicely complemented each other, so giving the feeling that progress has been made towards a thorough and more accepted understanding of the physical nature of carbon nanotubes. Certain issues, such as the excitonic behaviour of the photo-generated carriers, have moved on from the being the work of theorists and are now being investigated with novel experimental methods showing interesting results.

Some of the papers at WONTON'07 which got my attention concerned the recent theoretical and experimental work done on so called dark excitons. These are excitonic energy states from which emissive recombination of the electron and hole are symmetry forbidden. It has been shown that, at low temperatures, when a magnetic field is applied parallel to the SWNT axis a phase shift in the electronic wavevectors occurs due to the Ahronov-Bohm effect. This shift then lifts the degeneracy of the energy levels and breaks the symmetry, causing a large field dependent increase in the photoluminescence yield. Measurements of the 'dark-bright exciton splitting' using this method were then used to explain the low observed PL quantum yield of SWNTs at room temperature. It is a remarkable result and should lead to some even more interesting work in the future.

The title of my own contributed talk was 'Interactions between Single-Walled Carbon Nanotubes and Conjugated Polymers: Purification and Charge Transfer'. It was very well received by people working along similar lines of interest and I have already heard from a number of notable researchers seeking

collaborations.

The workshop has given me a much clearer view of where my work stands with regards to the field I'm in and should help enormously over the coming year as I begin to write-up my thesis. I am greatly indebted to the British Carbon Group for their support in getting me to this conference.

Adrian Nish

Has carbon-based energy a future?

It now seems to be generally accepted that the emissions of CO₂ that Man has caused over the past 200 years are at least partly responsible for the global warming phenomenon that many believe to have detected already. There are some pockets of resistance to this view but they are increasingly fewer as time goes on. It would seem therefore, only prudent to look to future sources of energy that do not cause such emissions. One of these is of course nuclear and the BCG has been involved in meetings relating to fissile fuels, although it has to be said, more from a point of view of the problems involved in decommissioning elderly reactors than in the problems of building new ones. These are in truth, societal rather than technical, given the almost fanatical opposition to the idea of nuclear energy from some "green" organisations. The other source is of course renewable energy but I remain unconvinced that the wind-powered generators springing up everywhere are going to do much more than contribute marginal amounts of power to the economy. I notice that the boss of Shell, Joroen van der Veer, in a recent article in the Times shares this belief. Reducing demand, in the sense of better insulation for heating homes and offices, has perhaps more potential for saving CO₂ emissions but that's not what I wanted to go into to here.

In a sense, we have been here before, in that in the mid- to late-1970s, when it was believed that there was going to be a shortfall of oil due to the formation of OPEC and also the expected decline in supplies, there was a considerable effort into developing alternatives. Production of both gas and liquid products from coal were extensively investigated, in some cases right up to a commercial scale. The Carter administration in the United States put its faith in the unlovely term "coconuke"—coal, conservation and nuclear. Of course, 30 years on, we can see with hindsight that this prognosis was too gloomy as far as oil production was concerned and we have gone on our merry way using up oil reserves with perhaps less thought for the future than would have been prudent

but alas, when has Man ever been prudent? None the less, oil will start to run out within the lifetime of our children at the latest and the question must arise, what do we do instead? I believe that much of the work done in the 70s and 80s still has application today, with the additional and fairly major complication of CO₂ removal and sequestration added.

The World's reserves of coal are vast, enough to last for some 200 years or more, even at the present rate of consumption. The problem is, as BGC members will immediately recognise, that coal consists of from 60-90% carbon and that as presently used, all this appears in the atmosphere as CO₂, hence the question posed at the head of this article. There is much breast-beating in Europe and in the UK about our present contribution to atmospheric emissions in this way and Drax power station, for instance, has regular visitations from well-meaning but perhaps ill-informed groups, objecting to its continuing operation. The media don't help by their general level of ignorance on scientific matters. Whenever there is an item on television on CO₂ emissions from power stations, the camera pans in unerringly on the cooling towers, which as we all know, emit nothing more harmful than water vapour, admittedly itself a powerful greenhouse gas. However, anything we may do in Europe in reducing emissions like this is like spitting against the wind, when you consider that China has the firm intention of burning 2000 million tonnes of coal by 2020, utterly dwarfing the total likely consumption in the whole of Europe.

At a recent meeting on the topic under discussion, held by the Coal Research Forum and the Energy Sector of the RSC, it was however pointed out that all the coal-burning plants being built in China and India are being constructed by firms from the West, so any developments in clean coal technology could be very quickly transferred to the newly-developing industrial countries. Most speakers at the meeting were more concerned with the "energy gap" that was developing in the UK in the near future, with old coal-burning plants being taken out of commission and gas-fired plants running out of indigenous gas, which increasingly will have to be imported, either as LNG (Liquefied Natural Gas) or by pipeline from Russia and Norway, with a consequent question over cost and reliability of supply. Nuclear plants were indeed needed but the lead in planning and construction time was much too long for them to fill the gap. The recent government White Paper does at least recognise this but apart from a cautious green (well, amber) light for nuclear construction, all the emphasis was on renewables and conservation. The newspaper reports, when they mentioned coal-derived power, invariably prefaced it with the word "dirty". However, at the CRF

meeting, which took place several months before the White Paper appeared, nobody had much faith in the ability of renewable energy to make a really useful contribution, so the call was for more coal-burning plants. The big proviso though, is that they have to take the current demand for CO₂ reduction into account and the meeting was concerned with the best way to do this.

The phrase of the meeting seemed to be “CO₂ removal-ready”, that is, building plants that had the capability of having CO₂ taken out, but no-one was prepared to do it without considerable inducements, in order to offset the much increased costs of operating such a power station. The main theme seemed to be removing the CO₂ by absorption in an amine solution, like for example triethanolamine or triethylamine. Now, I have to say that this made me very uneasy. 25 years ago the former British Gas Corporation (and later British Gas plc) was deeply involved in Substitute Natural Gas. We were exploiting our own technology for converting petroleum distillates into methane by our proprietary Catalytic Rich Gas process. We had considerable success in exporting this technology to the United States and to Japan but the whole process did require considerable amounts of CO₂ to be removed. We opted for a solution of activated potassium carbonate to do this and did quite a lot of work on this part of the process. When you consider the problems we had with a clean gas mixture (just methane and CO₂), at up to 30 bar pressure, which makes the process engineering much more compact, you can see why I wonder what the practicality is of treating vast volumes of relatively dirty gas at atmospheric pressure. Mind you, I am no expert in acid gas removal. I tended to go into a light trance when this subject came up in technical meetings. On one notable occasion I was abruptly woken from my slumbers by hearing a colleague, a chemical engineer to who held acid gas removal close to his heart, saying to his neighbour “What you mean is that co-current flashing does more for you than counter-current stripping” at which point I had hurriedly to pick up a pencil that had apparently fallen under the table just at that moment. To be serious though, removal of CO₂ from the volumes of combustion gas that could be necessary is a major undertaking and one where I feel that new thinking is needed. It could be that adsorption on active carbon could be a solution but I’ll return to this point later.

The main emphasis at the CRF meeting was on improvements that are in the pipeline to improve efficiency and hence reduce the amount of CO₂ emitted per kWh generated. Supercritical steam generation is now a reality, the critical temperature for water being 374°C and the critical pressure 220 bar. New materials are now available capable of working under more extreme conditions and use

of this technology seems capable of raising the efficiency of electricity production to as much as 45%, compared with figures in the mid- to low-thirties a generation ago. Centrica, a by-blow of the former British Gas plc, has announced such a plant for the North-East of England. However, even with such an advanced plant, emissions of CO₂ are still considerable and would require clean-up by amine absorption at the stack.

For this reason, a more radical approach is under intensive investigation. This is the so-called "oxy-coal" process in which the coal is combusted in pure oxygen, the resulting very high temperatures being modified by recycling combustion gas. There is now no nitrogen in the system at all and this means that the combustion products at the end of the process are carbon dioxide and steam. If the combustion is done at pressure, all that is needed is modest cooling of the exhaust gas for the sole product to be liquid CO₂, for which the critical temperature is only 31°C. In principle, this can then be piped to spent gas wells in places like the North Sea. I say in principle, because BP who were proposing to do this using one of their disused gas wells, have pulled out of the project, on the grounds that no government was coming up with a subsidy price that would make this economic. There is in place in Europe a system of carbon emission trading but this is of such Byzantine complexity that I cannot begin either to understand or explain it: I suspect that BP's announcement may be in the nature of a warning shot fired across the bows of the politicians in Brussels to come up with a more workable system.

The other main technology for low CO₂ emissions is Integrated Combined Cycle Gasification (IGCC) and is more favoured in the United States, where the process has been operating on a commercial scale for around 20 years, so there is little radically new development needed. The complete gasification of coal has been around for many years now. It simply means that coal is reacted in a mixture of steam and oxygen to produce a combustible gas, the ash is the coal being removed either as fly ash or as a slag, depending on the temperature of operation. The oldest extant representative is the Lurgi process, developed well before the Second World War in Germany to provide a H₂/CO gas feed to the Fischer-Tropsch plants that made liquid hydrocarbon products essential to the Nazi war effort. The technology was taken up in South Africa by Sasol, where for strategic reasons in the apartheid era, it was felt essential to have a source of liquid fuels that could not be the subject of an external boycott. The process still runs on a huge scale in Sekunda and with petroleum prices at 60\$/barrel and likely to rise, it may even be profitable.

However, the Lurgi process, tried and tested though it is, does have major drawbacks. The mineral matter in the coal, which remains after gasification of the carbon content, is removed as ash, so it is essential that this does not melt or sinter. The temperature of the reactor is thus controlled by adding excess amounts of steam beyond that required to gasify the coal and this leads not only to inefficiency but also the production of large amounts of aqueous liquor that has to be treated. Not only that, but the low temperature imposed by the need to avoid ash fusion means that only reactive coals can be used. That was no problem for the brown coals of Germany and South Africa but it means that bituminous coals that form the majority of coals available today in the World, are far less suitable for this sort of reactor, although I have to say that the process ran in Scotland for 10-15 years on local bituminous coal. The modern generation of gasifiers overcomes this restriction by limiting the steam/oxygen ratio to that required by to gasify the coal as CO and H₂: the resultant reaction temperature is around 2000°C, which allows unreactive coal or carbons (like petroleum coke) to be used, the mineral matter melting and being tapped off as slag.

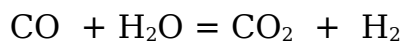
Two of the processes that have operated on a commercial scale, the Texaco and the Prenflo, are entrained flow gasifiers where pulverised fuel (PF) is entrained in the steam/oxygen mixture and injected into the reactor. Of these two, the Texaco is by far the most commonly used and has a record of commercial use, especially in the United States, going back some 25 years. Bankers tend only to lend money for big projects where the technology is totally reliable, so the Texaco has a big lead over its rivals in this respect and must come at once into the frame for future projects for clean coal use. Shell chose the Prenflo process for operation at their refinery at Pernis in Holland; not surprisingly, since they developed the process in the first place.

There is however, one development about which there has been less commercial application but one that retains the advantages of the Lurgi gasifier but without its drawbacks. This is the modification by the former British Gas jointly with the Lurgi company to demonstrate a slagging gasifier, now called the BGL gasifier. Prof. Mark Thomas and I were part of the team that worked intensively on this project in the 70s and 80s. Basically, it consisted, quite literally of cutting off the bottom of the Lurgi gasifier that has been operating at Westfield in Scotland, and grafting on the slagging bottom, where the steam/oxygen mixture was injected through tuyères. If you like, it was a sort of high pressure blast furnace but where the feed was coal and limestone (flux for the slag) through a

pressurised lock hopper, rather than coke and iron ore. The aim was to demonstrate a complete utilisation of run-of-mine coal, where lump coal was fed in at the top and fines (< 6mm) through the tuyères.

This worked extremely well and culminated in a long run at 250 tonnes a day in the early 1990s. In origin, this work was done initially to ensure that we had an alternative route to Substitute Natural Gas (SNG) because, incredible though it may seem now, there was the thought that natural gas, and certainly petroleum, would be in short supply by the end of the 20th century. It just goes to show how impossible forecasting the future is. On the other hand, to have more than one option available must always be desirable and this was the thought that drove the coal-based work both in Europe and in the United States at that time (1975). However, well into the SNG project, it was clear that a more immediate application was likely to be provide a clean combustion gas for electricity generation. The concept was for coal gas combusted in a gas turbine, the hot gases being using to generate steam for a steam turbine, Integrated Combined Cycle Gasification (ICCG). Ironically, many combined cycle plants have been built in the UK, only their feed is natural gas, the elimination of the gasifying step making the capital cost much lower. Even then, in the early 1990s, we reckoned that an ICCG plant using coal in the BGL gasifier built on a greenfield site would be cheaper, both in capital and running costs, than a comparable conventional coal-fired power station. The latter had efficiencies then of only 33-35% because of the need to remove acid gases from the stack whereas we reckoned we could easily get 55% with ICCG and gas clean-up was very cheap. Of course, it will be interesting to see if any of the gas-fired CC power stations will be economically retrofitted with coal gasification, as natural gas becomes more expensive. Only the front end of the process needs to be changed.

So, we are currently in a situation where commercially proven gasifiers are available. You may well ask though, how does this get us nearer lower CO₂ emissions. IGCC has inherently lower emissions because of the higher efficiency, although this advantage is being eroded, as we have seen, by the gains in efficiency in the most modern supercritical boilers. CO₂ still needs to be removed from the stack gases from the steam turbine. However, the product from a gasifier is clean, sulphur-free synthesis gas. In other words, this can be used to make for example, methanol, by conventional catalytic processes as is being proposed for the BGL gasifier in China at the moment. It can also be converted to hydrogen using the water gas shift reaction;



Taking out the CO₂ leaves pure hydrogen that can be used a fuel gas, either in a conventional process or in a fuel cell to generate electricity. The main snag from a process point of view, is that the shift reaction is exothermic and gives good yields of hydrogen at only at low temperatures, say 200-300^o, which this means that you generate a lot of low grade heat that you have to try to integrate in what is essentially a high temperature process in order to maintain thermal efficiency. Thermodynamics always get you in the end! None the less, gasifying coal, and this does include the oxy-coal process, which is simply an extreme version of steam/oxygen gasification with no added steam, does give some flexibility in the down-stream side of power generation that is not available by simple combustion.

This now brings us to the final step, that of removing and sequestering the CO₂. I use the term sequestering, because storage implies that the gas can be recovered and re-used. Current thinking does suggest that some at least, could be used as a chemical feedstock but the demand for this would be very small in comparison to the amounts produced for energy needs and it simply needs to be sent somewhere out of the way from which it will not easily escape. Two ideas are in the air. The first is to store it in disused gas wells but as we have seen, the pilot work by BP on these lines is in stasis until someone comes up with some money to fund the scheme. There seems no insuperable obstacle in principle however. The other is to get rid of the gas in geological deposits and this is much more speculative. The important point however, as the Chairman of Shell points out in his article, is to get going, to test out the validity of either approach. As he says, time is running out.

Returning to the other untested part of the low-carbon-emissions programme, that of taking out the CO₂ from stack gases, I suspect that active carbon technology has much to offer. In some work on adsorption of CO₂ on active carbon that I was involved in a few years back, we measured uptakes of about 100% w/w at quite modest pressures, say around 15 bar for highly activated wide pore nanocarbons. If the combustion process can be carried out at pressure, removal of CO₂ by adsorption at ambient temperatures is quite feasible and one could envisage a simple Pressure Swing Adsorption (PSA) process where the two vessels are alternately adsorbing and releasing the gas. Of course, it then has to be recompressed to deliver to a pipeline for final disposal. For conventional combustion at atmospheric pressure, the use of adsorptive carbons is still possible and current research is

concentrating on this aspect, only now one needs narrow nanopores to get a reasonable uptake, and regeneration has to take place under vacuum with subsequent compression to disposal.

About the final step, that of disposing of the gas, I can say very little as this lies outside my experience, or for that matter, most other people's. It is clearly the area that needs attention and probably can only reasonably be tested on a semi-industrial scale from the beginning.

So we come back to the implied question in the title of this article and of course, the answer is yes, coal can have a future for energy production even in a world that seeks to reduce CO₂ emissions and I hope I have shown how that could be done. Of course, it must be more expensive than just releasing the gas into the atmosphere as we do now but the extra cost is not crippling. I have seen figures of 25% above current costs quoted and although these may be no more than an educated guess on someone's part, they do mean that a CO₂-free coal process can play its part in future supplies of energy. What is needed is work to establish the feasibility of the unknown steps I have outlined above, and this can only be done by governmental support.

Norman Parkyns