SERC BULLETIN

SCIENCE & ENGINEERING RESEARCH COUNCIL

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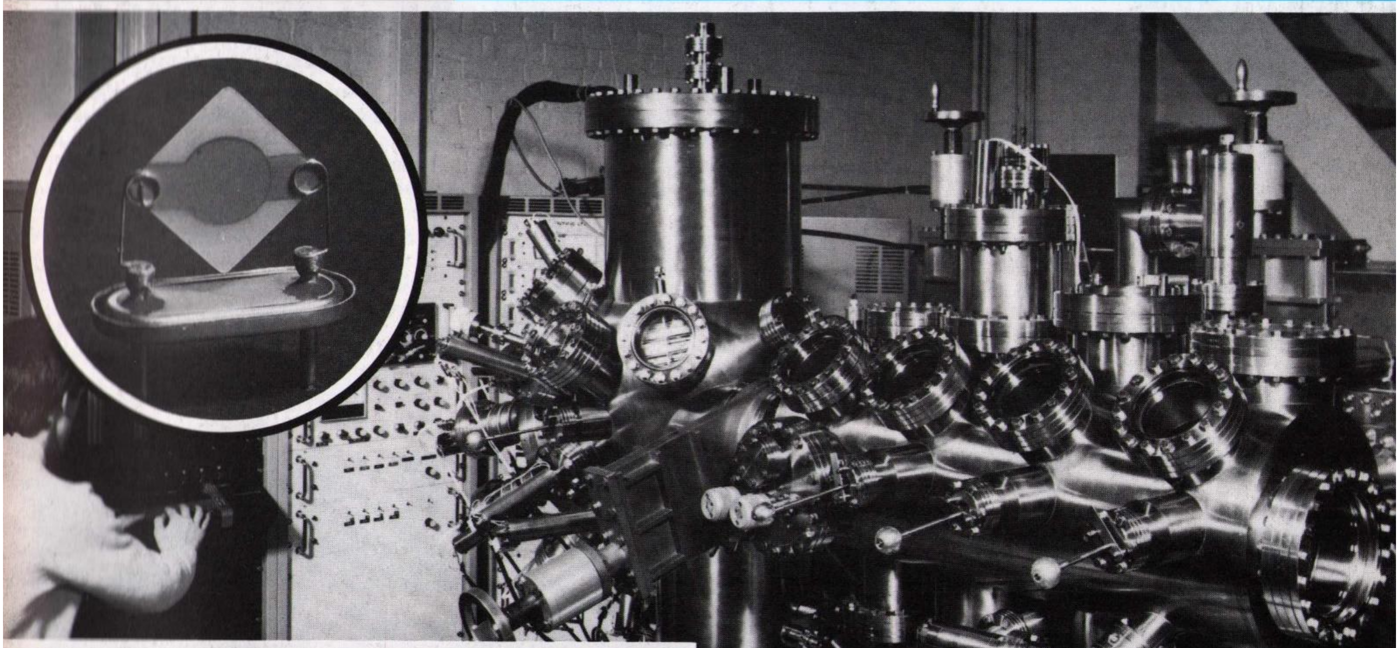

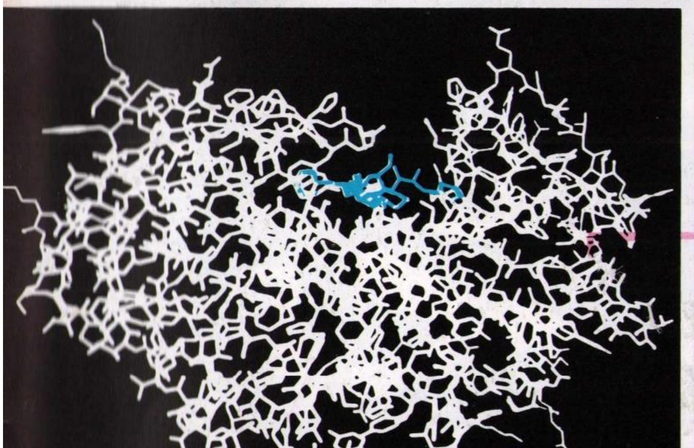

In this issue

Establishments of the Science and Engineering Research Council

SERC Central Office
Polaris House, North Star Avenue
Swindon SN2 1ET
Telephone (0793) 26222

SERC London Office
3-5 Charing Cross Road
London WC2H 0HW
Telephone 01-930 9162

Rutherford Appleton Laboratory (RAL)
Chilton, Didcot, Oxon OX1 0QX
Director Dr G Manning
Telephone Abingdon (0235) 21900

Daresbury Laboratory
Daresbury, Warrington
Cheshire WA4 4AD
Director Professor L L Green
Telephone Warrington (0925) 65000

Royal Greenwich Observatory (RGO)
Herstmonceux Castle
Hailsham, East Sussex BN27 1RP
Director Professor A Boksenberg FRS
Telephone Herstmonceux (0323) 833171

Royal Observatory, Edinburgh (ROE)
Blackford Hill, Edinburgh EH9 3HJ
Astronomer Royal for Scotland and
Director Professor M S Longair
Telephone 031-667 3321

Polymer Engineering Directorate
11 Hobart Place, London SW1W 0HL
Telephone 01-235 7286

The Science and Engineering Research Council is one of five research councils funded through the Department of Education and Science. Its primary purpose is to sustain standards of education and research in the universities and polytechnics through the provision of grants and studentships and by the facilities which its own establishments provide for academic research.

SERC Bulletin **summarises topics concerned with the policy, programmes and reports of SERC. SERC's** *Annual Report* **(available from HMSO bookshops) gives a full statement of current Council policies together with appendices on grants, awards, membership of committees and financial expenditure.**

Enquiries and comments are welcome and should be addressed to the editor, Miss J Russell, at the Science and Engineering Research Council, Polaris House, North Star Avenue, Swindon SN2 1ET; tel Swindon (0793) 26222.

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Holmes-Hines Bequest

As part of 'Women into Science and Engineering' year 1984, two short courses for sixth form girls received small bursaries from SERC's Holmes-Hines Memorial Fund this year. Both held in July, the City University's one-day conference was entitled **Women in information technology**; Bradford University's **Chemical engineering: a career for women** was a three-day residential course.

The 45 girls from Hertfordshire and Bedfordshire who attended the City University's conference in London thoroughly enjoyed their 'hands on' experience, trying out and assessing a range of sample pieces of software. They were also briefed on career opportunities in information technology and shown a film.

In Bradford, 44 first-year sixth formers tried their hands at flowsheeting exercises, heat and mass balances, separation processes and powder technology. Besides tutor group, laboratory and computer project work, they enjoyed an industrial visit, a film and informal discussions. The success of the course can be measured by the high proportion of girls who said at the end of the three days that they were more likely to consider a career in chemical engineering than they had been when they arrived.

The Holmes-Hines Award is the result of a bequest to SERC in 1981 in the Will of the late Miss Frances Hines for the creation of the Holmes-Hines Memorial Fund. Miss Hines, a modern language teacher, developed a life-long interest in scientific research after listening to Lord Rutherford lecture at Cambridge in the 1930s. The bequest stated that the Fund should provide 'annual prizes, scholarships, exhibitions or research grants, the incidental expenses of visiting scientists, the purchase of scientific apparatus and equipment and such other purposes for the advancement of scientific knowledge as the Council shall select'. It can be used to help individuals achieve their scientific aspirations and to sponsor activities related to science for which public funds are not available.

The trustees invite applications for awards from the fund which has an annual income of £6000.

Girls on the Bradford course are given a chance to work on electrostatically enhanced coalescence in the chemical engineering laboratory

Front cover pictures

The Science Board is supporting programmes in three important new areas of multidisciplinary research; the cover shows an example of each:

Low dimensional structures
Mask-making using molecular beam epitaxy equipment at the GEC Hirst Research Centre

Chemical sensors (top left)
A piezoelectric gas analyser developed at Loughborough University

Protein engineering (bottom left)
The structure of a pepsin (an enzyme that decomposes proteins) represented on a computer graphics at Birkbeck College. The blue area shows how this enzyme is bound to the substrate

See page 16

Council commentary

Forward Look 1985/86 - 1989/90

Details of the 1984 Forward Look were submitted to the Advisory Board for the Research Councils in April. This submission described the overall condition of the Science Vote and of the SERC share of it as 'sloping funding', a steady attrition of the real value of the basic allocation. In this situation the Council did not accept the further cut of £11.2 million over the next three years as suggested by the ABRC to help towards the restructuring of AFRC and NERC. Two sets of figures therefore were submitted: the lower met the ABRC guideline while the upper showed the effect of restoring the cut. The funds available under the lower table were, at cash planning levels, £291.9 million (1985/86) £298.9 million (1986/87) £307.9 million (1987/88) £312.4 million (1988/89) and £312.4 million (1989/90). It was noted that even should the cut be restored, the Council would not be able to respond adequately to the demands upon it; research grant applications of the highest quality would be refused, promising programmes of industrial–academic collaboration would be curtailed and central facilities not properly exploited. On the lower table, of course, the situation would be significantly worse.

ISAMS implementation phase

In April Council approved funding for the Improved Stratospheric and Mesospheric Sounder (ISAMS) which will be flown on the NASA Upper Atmosphere Research Satellite, to be launched in 1989. The total cost to the Council is £5.38 million (at 1983 prices) over seven years.

Japanese satellite project ASTRO-C

In June Council approved the participation of the University of Leicester and the Rutherford Appleton Laboratory in the Japanese mission ASTRO-C due for launch in February 1987. The total cost, including 28 man-years of effort, is expected to be about £1.1 million. It was considered that the UK would obtain very good value for money in partnership with a country which does not normally share its work in space in this way.

Computing Committee Report

Council in July considered the report of its Central Computing Committee Review Working Party whose task it was to review the provision of computing facilities and computing support by SERC. The Council decided, *inter alia,* that a full-time Director of SERC Computing should be appointed; that it should continue, for a further year, to pay for vector processing charges at national centres and that a Joint Computer Board/Research Councils Working Party should be set up to give consideration to the future provision of advanced research computing.

Major new grants

March-July 1984

ASTRONOMY, SPACE AND RADIO

Professor J L Culhane (University College London): up to £749,000 over one year for space research at Mullard Space Science Laboratory.

Professor F G Smith (Manchester University): up to £846,000 over four years for the improvement and extension of the Multi-Element Radio-Linked Interferometer Network (MERLIN); and up to £548,000 over one year for radio astronomy research at Jodrell Bank.

Professor K A Pounds (Leicester University): up to £506,500 over one year for x-ray astronomy and astrophysics.

Professor A Hewish (Cambridge University): up to £428,000 over one year for support of the Mullard Radio Astronomy Observatory.

ENGINEERING

Professor W A Gambling and Dr D N Payne (Southampton University): £436,174 over four years for research in optical fibre communication.

Professor S D Smith and Dr B S Wherrett (Heriot-Watt University): £374,715 over four years for research in optoelectronic devices.

Dr F C Lockwood (Imperial College of Science and Technology): £341,666 over four years for measurement in and prediction of pulverised coal fired furnaces.

Grants for university research within the Joint Optoelectronics Research Scheme (JOERS): Professor W A Gambling, Dr D N Payne and Mr M P Gold, Southampton University (£321,589 over three years); Professor D E N Davies, University College London (£95,262 over two years); and Professor C W Turner and Professor P A Lindsay, King's College, London (£155,000 over three years).

NUCLEAR PHYSICS

Rolling programme grants to particle physics experimental groups at Birmingham (up to £661,000), Cambridge (up to £432,000), Glasgow (up to £725,000), Imperial College of Science and Technology (up to £1,050,000), Liverpool (up to £591,000), Manchester (up to £519,000), Oxford (up to £933,000) and University College London (up to £508,000) each over a period of three years.

SCIENCE

Professor R J P Williams and Professor Sir David Phillips (Oxford Enzyme Group, Oxford University): £527,300 over four years for studies of proteins.

Dr H Ahmed, Dr M Pepper and Dr R S Elliot (Cambridge University): special rolling cooperative grant of £1,002,000 over four years for research into three dimensional nanometre microelectronics.

Professor L J Challis and 12 others (Nottingham University): special rolling grant of £1,001,000 over four years for investigation of low dimensional MBE structures grown by NUMBERS.

Dr R J Nicholas, Dr P J Walker and Professor E W J Mitchell (Oxford University): special rolling grant of £519,000 over four years for research into MOCVD growth of III-V narrow and wide gap semiconductor heterojunctions.

Professor E T Hall, Professor K Allen and Dr R E Hedges (Oxford University): special rolling grant of £460,700 involving a new commitment of £318,700 for radiocarbon accelerator laboratory: years 7-10.

PED major review

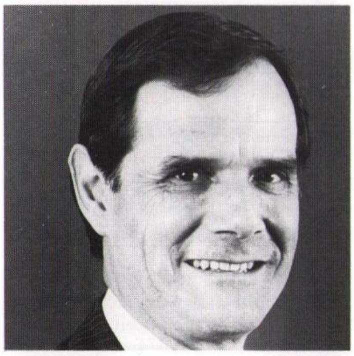
Loughborough University, 15-17 April 1985

The Polymer Engineering Directorate will be holding its final biennial review conference at Loughborough over a 2½ day period. A selection of major programmes funded by PED will be presented by its leading investigators. For further information please telephone PED on 01-235 7286.

Four appointments to Council

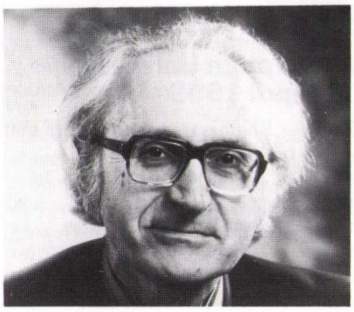
Sir Keith Joseph, Secretary of State for Education and Science, has appointed four new members to the Science and Engineering Research Council. They are Professor Sir Michael Atiyah FRS, Professor B L Clarkson, Professor A H Cook FRS and Professor C H Hilsum F Eng, FRS. They will replace Professor Jack Lewis FRS, Sir Alan Muir Wood FRS, Professor Ken Pounds CBE, FRS and Dr Bill Wilkinson. The appointments took effect from 1 October 1984 and will run until 31 July 1988.

Sir Michael Atiyah, aged 55 has been Royal Society Research Fellow at the Mathematical Institute, Oxford and Professorial Fellow of St Catherine's College, Oxford since 1973. He was educated at Victoria College, Egypt, Manchester Grammar School and Trinity College, Cambridge, becoming a Research Fellow of Trinity in 1954 and an Honorary Fellow in 1976. He was a member of the Cockcroft Committee on the teaching of mathematics, and was formerly a member of SERC's Mathematics Committee.



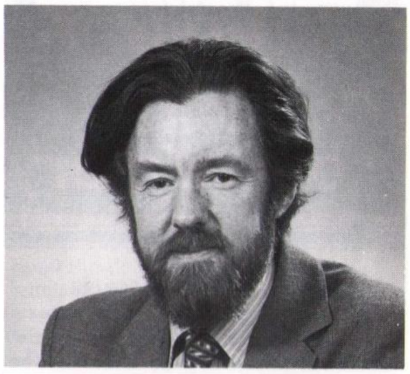
Professor Brian Clarkson, aged 53, has been Principal of the University College of Swansea since 1982. Previously, he held various academic posts at Southampton University, taking one year's leave of absence in 1970-71 to become a Senior Postdoctoral Research Fellow at the National Academy of Sciences, USA. He was for several years a member of SERC's former Aeronautics and Mechanical Engineering Committee and its forerunner the Aeronautical and Civil Engineering Committee and has contributed to books on aeronautics and dynamics.

Professor Alan Cook, aged 61, is Master of Selwyn College, Cambridge. He has been Chairman of SERC's Astronomy, Space and Radio Board since September and was formerly a member of the Board's Solar System Committee. He was elected as a Fellow of the Royal Society in 1969, and is Jackson Professor of Natural Philosophy (since 1972) and Head of Department of Physics at Selwyn College (since 1979). His publications include *Celestial Masters* (1977) and *Interiors of the Planets* (1980).



Professor Cyril Hilsum is 59 and has been Chief Scientist of the General Electric Company Research Laboratories since 1983. He is also Visiting Professor in Applied Physics and Electronics, University of Durham (since 1978). He has spent most of his scientific career in government service, from 1964 to 1983 with the Royal Signals and Radar Establishment, Malvern, where he was involved in the development of new stable liquid crystal materials. He has published more than 100 scientific and technical papers.

SERC man is new ESA head



Dr Harry Atkinson, SERC's Director of Science, was elected Chairman of the European Space Agency (ESA) Council in June. The appointment is for an initial period of two years (from 1 July) during which time Dr Atkinson will continue his duties with SERC.
Dr Atkinson has been a UK delegate to ESA since 1973 and Vice-Chairman since 1981. He succeeds Professor H Curien of France.

The Department of Trade and Industry provides the major share of the UK's subscription to ESA but SERC pays for the science programme which forms a key part of SERC's space science activities.

Professorship for Miss Valerie Bowell

Miss Valerie Bowell, Head of SERC's Nuclear Physics Division, has been appointed Honorary Visiting Professor at the City University, London. This is the University's first step towards the eventual formation of a Technology Policy Research Unit and Professor Bowell will be responsible for Science and Engineering policy matters. She will be continuing her duties with SERC.

Closer still to Absolute Zero

Dr G R Pickett and Dr A M Guénault, Lancaster University, whose achievement of the world record low temperature for a liquid (125μK) featured in the Spring 1984 *SERC Bulletin* (Vol 2 No 10), have recently cooled a solid sample to 13μK (ie only 0.000013 degrees above Absolute Zero). This is the lowest temperature ever achieved.

Application of computers to manufacturing engineering

The new ACME Directorate

A new directorate in manufacturing engineering has been established, following approval from the Department of Education and Science. The main aim of the directorate will be the promotion in universities and polytechnics of highly innovative research and training in advanced manufacturing and its management, closely integrated with the needs of industry, with a planned expenditure of at least £22 million over the next five years.

The directed programme will be concerned with all aspects of research into better flexible manufacture. The emphasis will be on flexible automation and effective organisation. The programme will encompass and build on the Council's existing coordinated programmes in Computer-aided Engineering, Industrial Robotics, Application of Numerical Control to Manufacture and Efficiency of Production Systems. The combined programme will be given strong stimulation and positive direction by a joint Department of Trade and Industry/ SERC Management Committee under the chairmanship of Lord Gregson, Executive Director, Fairey Holdings Limited.

Research goal

A production cycle from conception to delivery may be viewed as having three inseparable components. Marketing provides information to engineering on the product required. Engineering designs the product and transfers the product-definition data to manufacturing. The planning function within manufacturing transforms the product-definition data (eg the geometry) into process definition data – the instruction for building the product – and then transfers this information to the factory floor. Computer-based planning and control systems directly schedule and track the manufacturing process as well as controlling the product's quality with regard to its design specifications.

The main goal of the research carried out under the ACME initiative will be to lead to an understanding of the principles necessary to automate completely the creation, analysis, transmission and management of all product-definition, process-definition and related business data. This will ultimately take the form of a Computer Integrated System.

Research framework

The programme will encompass five aspects of research on manufacturing operations:

- methodologies for integration of the manufacturing system (including standards and non-technical issues);
- computer-aided design of the product and the means of its production (eg design, planning and estimating, off-line programming, design for economic manufacture);
- planning and management of the production activity (eg production planning, scheduling, quality control and maintenance);
- the development, control and operation of advanced production systems (eg sensing, distributed systems and flexible work-handling);
- infrastructure; adapting enabling technologies (eg geometric modelling, graphics, applied artificial intelligence) to manufacture;

and will initially concentrate on the following areas:

- performance evaluation of manufacturing systems;
- technological and management background to the introduction of automation in 'islands' within existing factories;
- design of the product simultaneously for function and for economic manufacture by flexible automated machinery;
- ability to program automatic production machinery including accurate models of the production process but without halting production;
- improved sensors, including fast processing to derive control data from them; and better actuators;
- distributed intelligence in manufacture, especially shop floor information networks for flexible manufacturing systems.

Training

The Directorate's role in helping industry meet its needs is not only to support research but also to ensure the training of young engineers of the highest calibre, able to understand the problems of industry and use the latest technology to overcome these. An important part of the new initiative wlll therefore be to support a significant increase in postgraduate training in all aspects of manufacturing.

Further details about the programme of the ACME Directorate may be obtained from Dr P C L Smith at SERC Central Offfice, Swindon, ext 2100.

Fellowships to work at Toshiba in Japan

This year Toshiba will once again offer two fellowships to enable UK scientists and engineers to work in their research laboratories in Japan.

Candidates should be of British nationality aged under 35, have PhDs or equivalent and be engaged in research at a UK academic or Government laboratory.

Fellows may be appointed to work in such areas as: organic thin films; III-V semiconductor devices; surface acoustic wave devices; adaptive antennae; erasable optical memory; natural language processing; expert systems for VLSI CAD; and ultrasonic technology for medical diagnosis. The research would be undertaken at either the Toshiba Research and Development Centre or their Medical Engineering Laboratory.

Each fellowship will initially be for 12 months, but extendable up to two years, and worth £24,000 pa plus allowances for travel. Successful candidates will be encouraged to study Japanese traditions and culture.

Selection will be made annually by Toshiba Corporation in consultation with SERC. The next closing date for applications is 31 November 1984.

Further information is available from: Toshiba Fellowship Programme, Toshiba Corporation, Audrey House, Ely Place, London EC1N 6SN; telephone: 01-242 7295.

Do free quarks exist?

Searching for fractional charge at RAL

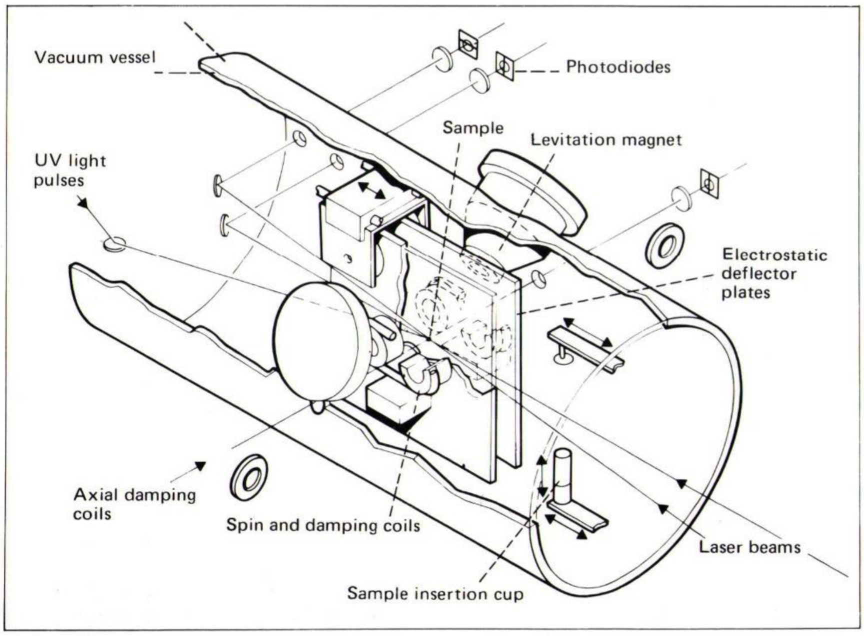
For many years, one of the crucial questions in elementary particle physics has been whether the constituents of the proton and neutron ('quarks') can exist in the free state. The most distinctive feature of these particles is that they would have an electric charge only ⅓ or ⅔ of the electron charge, e. This fractional charge is normally hidden, since in all known particles the quarks combine in threes (or in pairs, with an anti-quark) to produce an exact multiple of e, or zero. However, by probing the nucleon with high energy electrons and neutrinos it has been possible not only to 'see' these elementary constituents but also to confirm that their electric charges do have these fractional values in the bound state.

If the quarks could be separated and observed singly, then at least one type would be stable. No such particles have so far been seen in accelerator experiments, but this could be simply because today's accelerators do not have a high enough energy to produce them. However, there is another way of searching for quarks, based on the possibility that they could be produced by high energy cosmic rays. Even if the production rate in the atmosphere is too small for direct observation, they could nevertheless have accumulated at the Earth's surface, during its 3000 million year lifetime, to form a small concentration (probably less than 1 in 10^{20}) in terrestrial materials. One could look for either a low general concentration in common substances (water, air, rocks) or alternatively a geochemically-enriched abundance in specific materials.
One such search, by physicists at Stanford University, California, has generated considerable controversy in the last seven years, in claiming to have repeatedly measured charges of ⅓e on small (¼mm diameter) spheres of niobium. Their technique was to cool the niobium balls to the superconducting state, levitate them magnetically, and measure their electric charge by their response to an alternating electric field. By adding unit charges – electrons or positrons from radioactive sources – they could neutralise each sample.
In some cases exactly zero charge was obtained, as expected, but in other cases there was an apparent residual charge of +⅓e or - ⅓e. However, the extreme difficulty of eliminating background effects in this experiment has delayed further progress in the past two years, and the earlier results could still turn out to have been caused by some unknown source of error.

A new attack on this problem is now being made, by a team from Rutherford Appleton Laboratory and Imperial College, London, using an improved levitation apparatus capable of accurate and reliable measurements of residual electric charge on samples not only of niobium but also of a variety of other materials. The technique used is to coat the niobium sample with a ferromagnetic alloy so that it can be levitated (in vacuum) by a system of magnetic fields at room temperature. Two laser beam and photodiode systems provide position feedback to stabilise the magnetically-suspended sample, while a third laser beam is used to measure the oscillation of the ball in response to a low frequency electric field. The output is continuously monitored and analysed by an on-line computer, which also controls the firing of pulses of weak ultraviolet light to release single electrons from the sample, changing its charge from about +10e to -10e over a period of several hours.
In contrast to previous experiments of this type, the various background effects and systematic errors have been successfully eliminated, so that each measurement has an absolute accuracy of better than 0.05e, easily sufficient to detect a residual ⅓e value. Possible effects of surface irregularities, arising from the plating process, are eliminated by means of further sets of magnetic coils which spin the sample rapidly about the measurement axis.

At the time of writing, control measurements have been completed on a series of ¼mm steel spheres (giving zero residual charge, consistent with previous quark searches in steel) and running conditions are being readjusted to suit the heavier samples of plated niobium. In addition to the possibility of retesting the original Stanford samples (which are very limited in number) a totally new batch of niobium spheres has been manufactured for this experiment, the plan being to test samples from the same batch both at RAL and at Stanford, in an attempt either to confirm the earlier Stanford results or to trace the reason for the discrepancy.

In addition to providing a definitive answer to a long-standing scientific mystery, the new apparatus will allow high-sensitivity searches to be made in other terrestrial materials by electrically extracting and transferring any fractionally-charged ions from large volumes of, for example, sea water or air, on to the surface of individual steel samples, which can subsequently be examined for fractional charge by the levitation technique. In this way, the apparatus also forms a general facility which could be used by a number of groups investigating the possible existence of free quarks in specific materials.



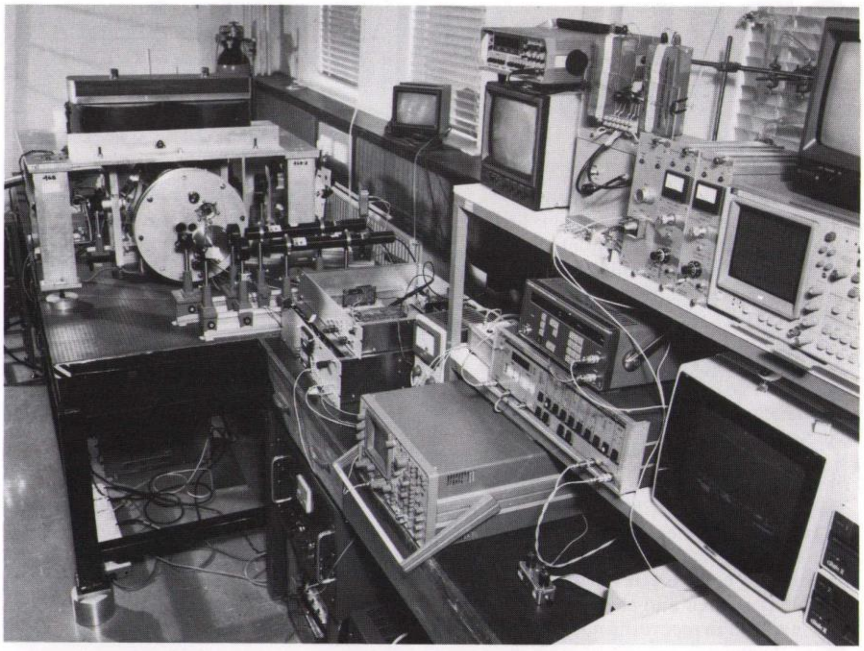
Cut-away drawing of the levitation chamber

Quarks produced in high energy particle collisions could also be trapped and detected in this way.

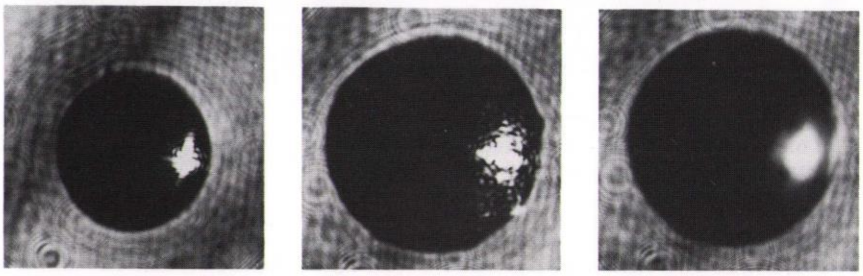
The quark model of particle structure was first proposed in 1964. Now, twenty years later, it is well-established, both theoretically and experimentally, but the nature of the quarks themselves, with their fractional electric charge and unusual binding properties, is still a complete mystery, and it remains an open question whether these objects can exist independently – perhaps attached to nuclei to produce a fractionally-charged atom or molecule.

Many theorists believe that free quarks do not exist, but this is not proven and their observation would provide a fresh challenge to both theorists and experimentalists. Moreover, this is a question which is of far more than purely academic interest; the discovery of free fractional charge, whether in an accelerator experiment, or in cosmic rays, or in terrestrial material, could have remarkable practical applications in many other areas of science and technology. Various quark-enriched materials could be produced either with a high-energy accelerator or by enrichment techniques based on the unusual physical or chemical properties of the fractionally-charged atoms. Perhaps one of the most immediate and exciting applications would be as a catalyst in nuclear fusion reactions – giving rise to an entirely new route to controlled fusion power generation.

Dr P F Smith
Rutherford Appleton Laboratory



General view of the levitation experiment



Magnified photographs of levitated samples. (a) 0.25mm steel ball (b) 0.34mm plated niobium ball, showing surface irregularities (c) as (b), but spinning, to smooth out irregularities

ABRC and SERC review particle physics

A joint review by the Advisory Board for the Research Councils and SERC of the UK's participation in high energy particle physics research was announced in March 1984. The Review Committee is chaired by Sir John Kendrew CBE, FRS President of St John's College, Oxford, and formerly Director of the European Molecular Biology Laboratory. The Committee's members are Professor Eric Ash CBE, F Eng, FRS (UCL), Professor Sir Douglas Hague CBE (Chairman, Economic and Social Research Council), Sir Jack Lewis FRS (Cambridge University), Sir John Mason CB, FRS (Treasurer of the Royal Society), Professor Ken Pounds CBE, FRS (Leicester University) and Sir Francis Tombs F Eng (Chairman, Turner & Newall and the Weir Group).

The review was announced at the same time as the publication of advice submitted to the Secretary of State by the ABRC on science and its funding. This publication, entitled *Scientific opportunities and the science budget, 1983,* is available on request from the Publications Despatch Centre, DES, Canons Park, Stanmore, Middlesex.

The Review Committee is meeting at about monthly intervals. As part of its gathering of evidence, it will visit both the Rutherford Appleton Laboratory and the European Organisation for Nuclear Research (CERN) in Geneva, and possibly other centres of particle physics activity overseas. In May, it invited evidence in the form of views on five topics:

- ☐ the standing of the UK's contribution to experimental high energy particle physics research;
- ☐ the relevance of experimental high energy particle physics to the totality of British science and the education and training of young scientists and engineers;
- ☐ the intellectual, technical and industrial 'spin-off' from high energy physics;
- ☐ the standing of CERN and the advantages and disadvantages of such centralised international facilities; and
- ☐ new areas, or grossly underfunded existing areas, of science and engineering research that would benefit from a significant increase in funding.

A copy of the DES press notice inviting evidence, which also gives the full terms of reference of the review, is available from Miss Angela Smith at SERC Central Office, Swindon, ext 2325.

OPAL : another giant detector for LEP

The OPAL detector is a large, multi-purpose apparatus for use on the LEP accelerator, due to be completed in 1988. OPAL is being built by physicists and engineers from 20 institutes in eight countries including, from Britain, Queen Mary College and University College/Birkbeck College, London, the Universities of Birmingham, Cambridge and Manchester, and Rutherford Appleton Laboratory (RAL).

When assembled, OPAL will weigh nearly 3000 tonnes and it will have over 86,000 separately-instrumented data channels. It is designed to record 'events' when, as a result of a collision of particles, a Z° particle is created and then decays. The data involved in recording just one of these Z° events amount to 140 kbytes, and OPAL aims to record them at the rate of 3½ million a year.

OPAL is similar to ALEPH (see *SERC Bulletin* Vol 2 No 11, Summer 1984) in that it consists of separate specialised detectors arranged in concentric cylinders (the barrel detectors), complemented by a set of planar detectors at each end (the end caps), as shown in the figure. However the distinguishing feature of OPAL is that wherever possible the design chosen for a given detector is based on a technique which has already been proven in a present-generation experiment. This approach has been adopted to ensure that OPAL will be ready to produce physics results as soon as LEP starts up.

The volume of OPAL is about ten times greater than that of similar detectors at lower energy accelerators and, despite the decision to make the design as conservative as possible, considerable problems are encountered in extrapolating even proven techniques to this scale. Furthermore, readout electronics are being designed to obtain the best possible performance from the drift chamber detectors, and completely new photodetection devices are being developed. For these reasons the R & D programme for OPAL is as intensive as for the other LEP experiments.

These are the parts of the experiment for which British groups are responsible:

The vertex detector

This is a cylindrical drift chamber with very high spatial resolution, whose purpose is to detect the decays of short-lived particles. Cambridge and QMC, together with the Electronics Group at RAL are responsible for providing the readout for this device, which is designed to sample particle tracks with a spatial accuracy of $50\mu m$, enabling particle lifetimes to be measured down to 10^{-13} seconds.

The muon detector

Among the physics objectives of this part of the experiment are studies of the properties of heavy quarks by measurement of events in which muons are emitted.

The muon detector consists of a cylinder with four layers of drift chambers being built at Manchester University. Construction of drift chambers has already started at Manchester and, in parallel, a test programme is under way using cosmic rays. The Birmingham team is evaluating prototype detectors on a cosmic ray test set up at RAL.

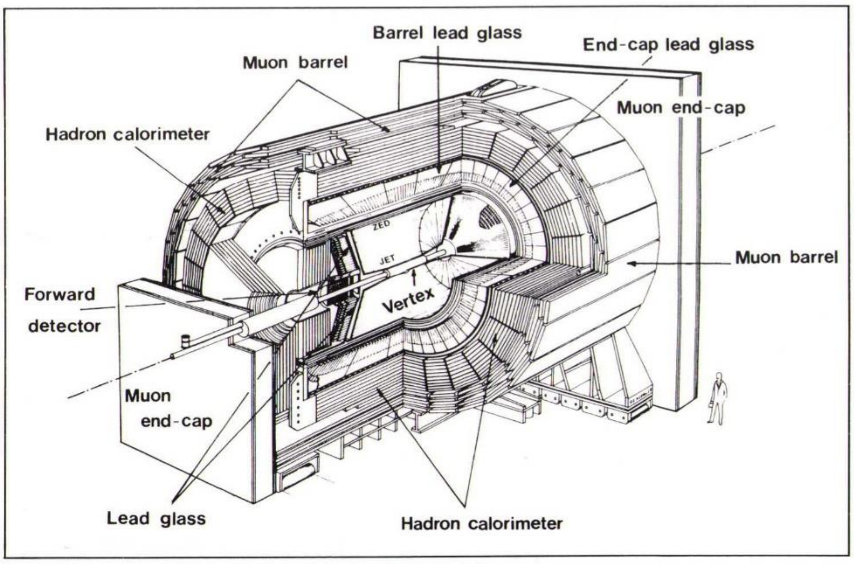
The forward detector

The forward detector consists of tracking chambers followed by an electromagnetic calorimeter. Its purpose is to identify a particular class of events in which two photons are exchanged and to measure the luminosity of the LEP machine.

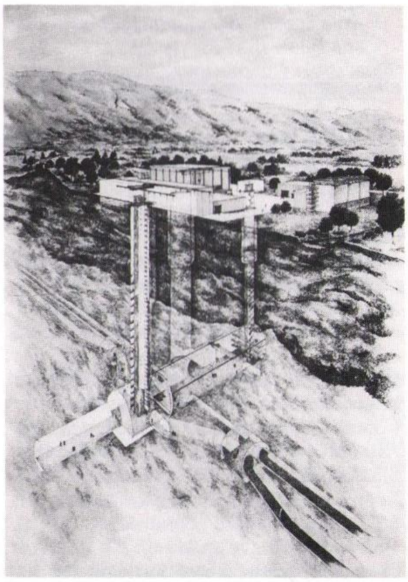
The detector is the joint responsibility of groups from Bologna, Maryland and UCL/Birkbeck. Development work is under way at UCL/Birkbeck where a CASE student is working on gas-filled photodetectors.

End-cap calorimeter

One of the principal features of the OPAL experiment is its excellent electron/photon detection, provided by a system of lead glass counters covering 99% of the solid angle. This system will be capable of identifying electrons and photons and measuring their energy with high precision, allowing rare processes



A cut-away view of the OPAL detector



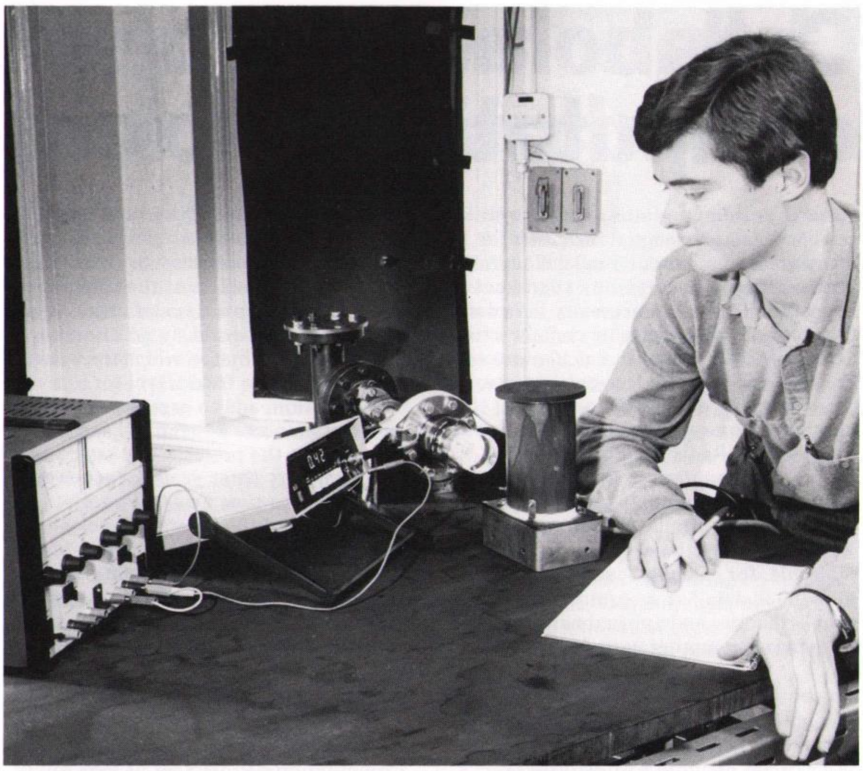
An artist's impression of one of the LEP underground experimental caverns, some 70 metres long by 20 metres in diameter, that will each house one of the large detectors involving the elusive Higgs and other possible new particles to be studied.

A group from Tokyo is responsible for the barrel part of the lead glass system and Cambridge, QMC and RAL are building the end caps. Since these are inside the solenoid magnet, conventional phototubes cannot be used to detect the light from the glass. Single-stage phototubes (vacuum phototriodes) are therefore being developed, which have gains of between 10 and 20 in a magnetic field of 1 Tesla. These devices are used in conjunction with a high-gain, low-noise amplifier designed at RAL.

Data acquisition and computing

Data will be collected from OPAL by a microprocessor system and will then be passed for final processing to large computers which are the responsibility of Canada and RAL. Work is under way to determine which items of hardware and software may be developed jointly by OPAL and other LEP teams. Within the UK, a strong software group has been set up, with representatives from several institutes working on on-line and off-line software.

Physicists from Cambridge and QMC are also collaborating with the electronics group at RAL on the design of a microprocessor system which will provide part of the trigger for OPAL.



John Edmends holds a CASE studentship in the Department of Physics and Astronomy at University College London, in association with Instrument Technology Ltd, St Leonards-on-Sea, East Sussex. He is working on the development of a new type of photo-detector that will be used in OPAL

Design and installation

In addition to their direct involvement in the design of the items listed above, engineering and technical staff at RAL are playing a leading role on the overall planning of OPAL. One of the major problems that is being tackled is to schedule the entire installation of this complex detector in the short period of 15 months, between the time when the underground cavern becomes available and the LEP accelerator starts operation at the end of 1988.

R M Brown
High Energy Physics Division, RAL

Sir John Adams CMG, FRS

Sir John Adams CMG, FRS, who died in March, played a leading role in building up the European Organisation for Nuclear Research (CERN), the world's first international research establishment, and was a central figure in engineering physics in Europe for 30 years.

In 1949 he commissioned the Harwell cyclotron, Europe's first major accelerator, and joined CERN on its foundation in 1953 to build the 25 GeV proton synchrotron (PS). After a spell as Director-General at CERN he was brought back to Britain to establish the Culham Laboratory and to start off its research into controlled fusion. From 1966 to 1969 he was Member for Research in the UKAEA, initiating many of the industrial applications of the Authority's work.

Returning to CERN in 1969, he led the SPS project (a 'super' proton synchrotron) to its successful commissioning in 1976, and then served a second spell as Director-General until 1980.

Adams's machines were always delivered on time and within budget. In operation, they have exceeded all reasonable expectations of performance and reliability. The PS is still serving not only as a research facility but also as a pre-accelerator to the SPS. The design of the SPS has proved good enough for the original design energy to be exceeded by 50% in everyday operation, and for it to be used, latterly, as a proton-antiproton collider.

These achievements needed more than engineering skill: Sir John also excelled as financial manager, as leader of personnel and as diplomat. Remarkably, he made no enemies.

Sir John Adams CMG, FRS

Collaborative projects in UK computational science

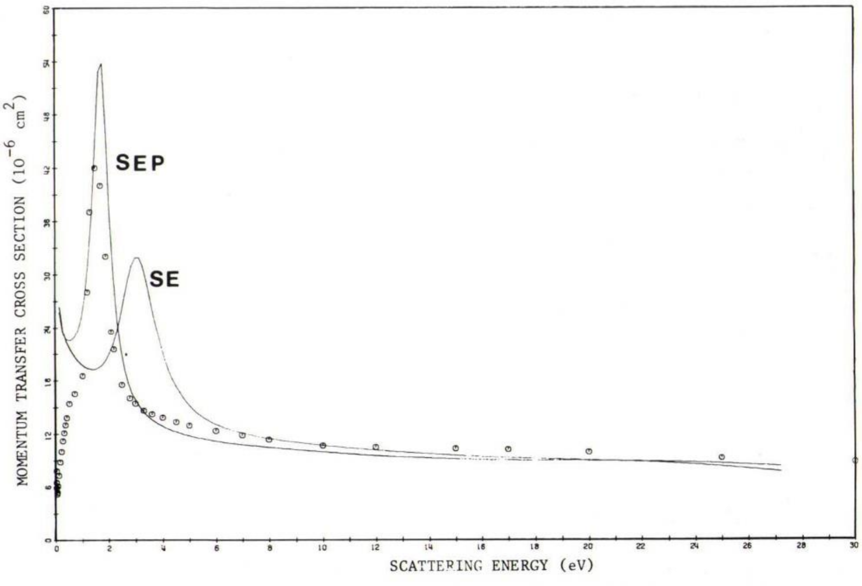
Large scale computations are now well established as an essential ingredient in many areas of science, complementary to both traditional theory and experiment. In fact they are often necessary in order for theory to make realistic contact with experiment; for example, calculations of the bulk and surface electronic structure of a material are essential to interpret the photoemission spectrum coming from the Synchrotron Radiation Source (SRS) properly. Computations also reach those parts which experiments cannot reach: given plenty of computing time the wavefunction of the electrons in a molecule, for example, can be calculated in as much detail as is required, enabling simple theories and approximations to be tested via a computer experiment.

To coordinate the development of computer programs, the first Collaborative Computational Project (CCP) was set up in 1974, on Electron Correlations in Atoms and Molecules. This CCP, initially called a Meeting House Project, led to the development of the ATMOL suite of computer programs which are now used throughout the UK and abroad to calculate the electronic structure of atoms and molecules. Following the success of this project, new CCPs were set up and they now total nine, covering a whole range of scientific activity (see table) and constituting a unique facility for exchanging information on algorithms and computer programs.

The CCPs are each run by a working group consisting of a dozen or so scientists from the universities and SERC laboratories, who decide the requirements and priorities for software development. The working groups are generally made up of a healthy mixture of experimentalists, theorists and computational scientists so that the CCPs meet the computational needs of at least a representative part of the academic community. Each CCP has one (in some cases two) postdoctoral research associates, based at a university or in the Computational Science Group at Daresbury, who undertake program development and will usually be involved in collaborative research with other members of the CCP. In addition several permanent staff in the Computational Science Group are associated with the CCPs, helping to ensure the continuity of particular projects and bringing great expertise in computing to the whole CCP programme. The software developed by CCPs is freely available to the UK academic community, and there is also program exchange with computational scientists abroad. In no sense are they intended to be an exclusive club, and each working group encourages contact with interested scientists; to ensure widespread awareness of these activities, the CCPs distribute newsletters throughout the world. In addition, each CCP has a small budget which the working group can use to fund travel for collaboration, and to organise meetings and conferences. A Steering Panel coordinates the projects, and reviews each of them every three years for renewal. From time to time new CCPs are proposed, and the Steering Panel is always keen to hear of any bright ideas for collaborations in computational science, and suggestions for ways in which CCP might develop – for example in the future there might be industrial involvement.

Continuum states of atoms and molecules

As an example of a Collaborative Computational Project let us look at CCP2, which is mainly concerned with the scattering of electrons and photons by atoms, ions and molecules. This is an area in which there are many phenomena interesting in their own right, involving many-body effects due to all the electrons in the system interacting with one another and with the electron or photon probe. Studies of the photoionization of atoms and ions and the interaction of electrons with ions are also very important for interpreting astronomical spectra, for studies of the upper atmosphere and for understanding the properties of plasmas in fusion research. At the moment a major interest of CCP2 is the study of molecules, and scientists at Daresbury and Belfast have developed world-leading computer programs for studying the scattering of electrons by molecules (see figure). Many of the techniques they are using are related to those of the computational chemists and there is strong collaboration between the scientists associated with CCP2 and those of CCP1. As many cross-sections for photoionization of atoms and ions can be calculated more accurately than they can be measured (if indeed they can be measured at all), results obtained by members of CCP2 are extensively used by CCP7 (Analysis of astronomical spectra). For the future, a potentially exciting collaboration is with CCP3 (Computational studies of surfaces), as there are many surface processes such as the breaking of bonds of adsorbates which have an analogy in free molecules. The work of CCP2 also bears directly on the Theory Group activities at



Elastic scattering of electrons by the CO molecule. The figure shows the (momentum transfer) cross section as a function of the incident electron energy. The curves labelled SE and SEP show the results calculated using R-Matrix theory excluding and including polarization effects, respectively. The circles are the experimental measurements of Land (J E Land, J Appl Phys 49, *5716-5721). The crucial role of polarization in shifting the position of the resonance into agreement with experiment is apparent from this figure.*

Daresbury in supporting the experimental programme on the SRS.

The increasing use of vector processors throughout the world makes it even more important to have efficient, vectorisable algorithms. Following the arrival of the Cray-1 computer at Daresbury in 1979, the CCPs played a large part in demonstrating that the greatly increased power of the first super-computer could lead to new science. At Daresbury a configuration interaction program, used by CCP1 computational chemists to include the electron-electron interactions in their calculations, was vectorised so efficiently that the Cray runs this program at its maximum rate. This enabled a record number of configurations (the assignment of electrons to different orbitals) to be considered, so that more approximate treatments could be properly tested. In the field of condensed matter the use of the Cray-1 enabled members of CCP9 to calculate the electronic structure of the rare-earth metal gadolinium, the properties of which were previously considered to be beyond the reach of conventional band structure techniques. This calculation was sufficiently accurate to determine not only the lattice spacing of the hexagonal-close-packed structure, but also the axial ratio. Further details of the work done on the Cray at Daresbury appeared in the *SERC Bulletin* Vol 2 No 11, Summer 1984, but it is fair to say that a considerable part of its success was due to the activities of the CCPs.

Dr John Inglesfield
Head, Theory and Computational Science Division, Daresbury Laboratory

Collaborative Computational Projects

	Chairman	Secretary
CCP1 Correlated wavefunctions	Prof I H Hillier	Dr R Amos, University Chemical Laboratories, Lensfield Road, Cambridge CB2 1EP
CCP2 Continuum states of atoms and molecules	Prof P G Burke	Dr W Eissner, SERC Daresbury Laboratory
CCP3 Computational studies of surfaces	Prof A North	Mr R J Blake, SERC Daresbury Laboratory
CCP4 Protein crystallography	Prof T Blundell	Ms P A Machin, SERC Daresbury Laboratory
CCP5 Computer simulation of condensed phases	Dr J Clarke	Dr W Smith, SERC Daresbury Laboratory
CCP6 Heavy particle dynamics (Interactions of atoms and molecules; chemical reactions)	Dr M S Child	Dr M Novak, Dept of Chemistry, Bristol University, Cantock's Close, Bristol BS8 1TS
CCP7 Astronomical spectra	Prof M J Seaton	Dr A E Lynas-Grey, Dept of Physics and Astrophysics, University College, Gower Street, London WC1E 6BT
CCP8 Nuclear structure physics	Prof J M Irvine	Dr I J Thompson, SERC Daresbury Laboratory
CCP9 Electronic structure of solids	Dr B L Györffy	Dr P Strange, H H Wills Physics Laboratory, Bristol University, Royal Fort, Tyndall Avenue, Bristol BS8 1TL

Plasma physics and fusion research

Progress towards the achievement of controlled thermonuclear fusion in the laboratory has been rapid and sustained over the last decade. The thrust of the main research programme is correspondingly directed increasingly towards the more technical aspects of devising an exploitable power source, leaving aside many of the more basic problems of plasma physics in general. The (then) Chairmen of the UKAEA and SERC, Professor Sir Peter Hirsch FRS and Professor John Kingman FRS, met recently to discuss ways and means of ensuring that the limited funds available to both sides could continue to enable both academic research and practical applications to be pursued with maximum effectiveness.

The AEA programme at Culham, which is part of the European Community's coordinated effort, has enabled apparatus to be constructed that can produce hydrogen plasmas at temperatures between 10^5 and 10^8 degrees Kelvin sustained for fractions of a second. Such plasmas, confined by magnetic fields, form invaluable targets for academic study, as well as being stepping stones towards fusion power.

Since its formation in 1960 the Culham Laboratory has organised an annual Plasma Physics Summer School (this year from 2 - 13 July) and has used extra mural contracts with university collaborators to extend the scope of its studies and to help in the training of young physicists and technologists. At present there are 56 contracts. The SERC has recognised the value of highly oriented fusion research in bridging the gap between university studies and industry, and has accordingly made a considerable number of Cooperative Awards in Science and Engineering (CASE) to students working on specific points of the Culham programme. An increasing number of these lie in the areas of technology of specific interest to fusion reactor development.

Facing increasing restriction on finance for research, both organisations feel that a correspondingly structured approach to the collaboration on the physics side might well be more effective. This year therefore there will be two specific new events:

- ☐ a presentation of the UKAEA/Euratom forward programme at Culham, to which it is hoped that most interested university supervisors and students will come;
- ☐ a presentation by university groups interested in plasma physics of their current work and results, to which it is hoped a number of Culham staff will come.

These meetings should give ample opportunity for all parties to improve their joint forward planning, and help to ensure that construction of new equipment, closure of existing machines, or formation or closure of research groups can be better taken into account. It is not intended that these meetings will be exclusive either in terms of people attending or of subjects covered. Many active topics concern only a few people and might not command general interest or benefit from closer coordination; others may be of interest to groups not already participating.

Interested scientists should contact either Dr D V Thomas, SERC Central Office, Swindon (ext 2114), or Dr W M Lomer, Director, Astrophysics Research, Culham Laboratory, Culham, Abingdon, Oxon OX14 3DB; telephone Abingdon (0235) 21840.

Recent work at SERC's Central Laser Facility

The Central Laser Facility (CLF) at the Rutherford Appleton Laboratory has for the last eight years provided a uniquely versatile high-power laser facility for the UK university community, currently numbering about 130 users. The neodymium-glass laser (VULCAN) is the most powerful laser in western Europe and supports two separate target areas where world class research is carried out in plasma physics, x-ray lasers and applications of the intense x-ray and thermonuclear particle emission from laser-produced plasmas. The recently introduced Ultra Violet Radiation Facility (UVRF) provides a variety of synchronised lasers operating throughout the ultraviolet and visible spectrum. The UVRF has an interdisciplinary programme involving photochemistry, photobiology, non-linear optics, plasma physics and novel lithographic processes for microelectronic circuit manufacture. A research programme into the highly efficient rare gas halide lasers has developed the unique 200 Joule SPRITE laser which is a world leader in its field (*SERC Bulletin* Vol 2 No 9, Autumn 1983).

High densities obtained by laser compression

The recently upgraded VULCAN laser, providing over 1 kJoule of energy, was used by a consortium of university groups including Imperial College, Essex, Queen's University of Belfast and Bristol to produce the highest densities yet achieved in directly-driven laser compression. The frequency-doubled output of the laser provided a drive pressure of over 20 million atmospheres to implode small hollow spheres of plastic polymer (150μm in diameter and 10μm thickness) with a degree of spherical symmetry never before achieved. The unique, synchronised long and short pulses of the VULCAN laser enabled two dimensional x-radiographs of the imploded core to be obtained, and one of these is shown in figure 1. The small shadow in the centre is less than one tenth of the original target diameter and has a density in excess of 10gcm^{-3}. The implosions were sufficiently hot to produce large numbers of thermonuclear reactions in the deuterium tritium fill gas and the emerging protons and alpha particles were detected in CR39 plastic track detectors. The energy distribution of the protons was unexpectedly uniform for different angles of emission and shows a high degree of sphericity in the implosion.

Laser plasmas provide high brightness x-ray sources

Laser-produced plasmas provide a source of x-rays in the 0.5 - 5 keV range with a brightness exceeding that of synchrotron sources by many orders of magnitude, and offer the possibility of observing transient phenomena with a time resolution down to 10psec. For example the high brightness continuum emission from a laser-produced plasma has been used to obtain EXAFS (extended x-ray absorption fine structure) spectra of aluminium with a 100psec time resolution. The aluminium was rapidly heated to a few thousand degrees by a laser pulse and the EXAFS spectrum showed the rapid transition from the crystalline state to a more disordered state.

In another experiment the technically important process of annealing a semiconductor surface was followed through the melting and recrystallisation by observing the Bragg diffraction of x-rays from the surface. The silicon crystal was heated and annealed by one laser pulse with an energy density of 1 Jcm^{-2} in a pulse of 1 nsec while a second laser-produced plasma provided intense, narrow line x-ray emission to probe the surface layer. As the surface melted, the reflected x-rays became more diffuse and the Bragg angle changed slightly. During recrystallisation, over a time of about 100 nsec, the reversal of this process is observed. Figure 2 shows some of these data; the narrow spectral lines correspond to the unheated part of the silicon and the shifted and broadened lines reflect the change in lattice parameters immediately following the annealing pulse.

New insights into plasma waves

One of the many non-linear phenomena occurring in laser produced plasmas is

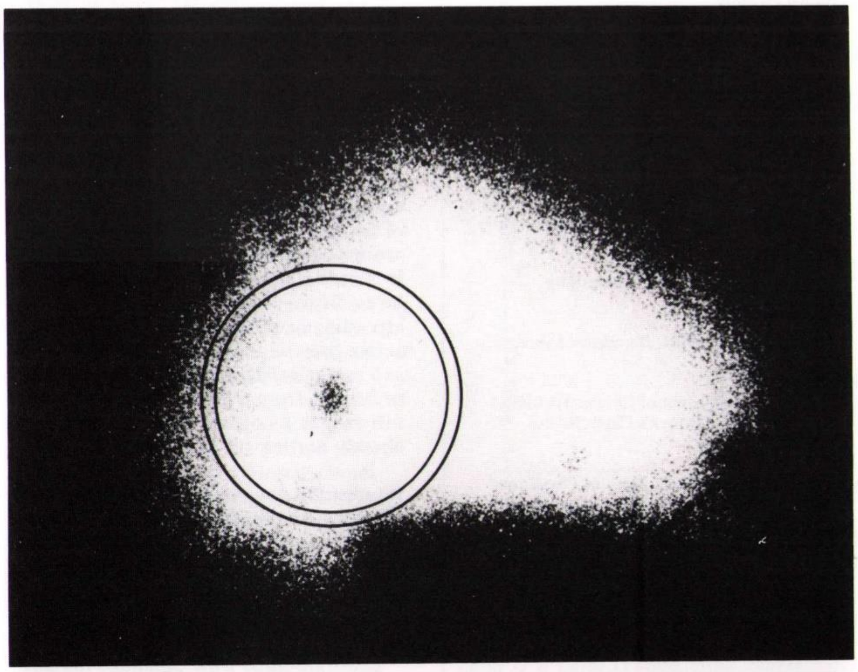
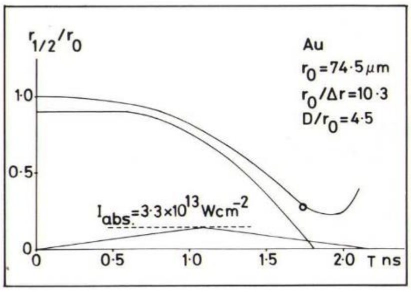


Figure 1: An x-radiograph of a laser-imploded plastic shell showing in outline the original shell size and position. The graph below shows a computer prediction of the observable shell radius as a function of time together with the measured value.



the generation of light at 3/2 times the incident laser frequency. This process has been qualitatively understood for a number of years as being due to the 'decay' of the laser photons into two plasma waves each with roughly one half of the laser frequency. One of these decay waves then couples to a laser photon to produce the $3/2\omega_0$ emission. The standard theory of this process does not agree with the experimental observation that the $3/2\omega_0$ spectrum is roughly symmetrical about the centre frequency. Recent work at the CLF in collaboration with the University of Helsinki has looked at the effects to be expected in a non-uniform plasma, when the plasma waves are allowed to propagate. As the plasma density changes by even a small amount the plasma waves refract in exactly the same way as light refracts in a changing refractive index. The different wave numbers that are produced, due to plasmon propagation and even reflection, change the predicted form of the $3/2\omega_0$ spectrum and make it in much better agreement with the experiment.

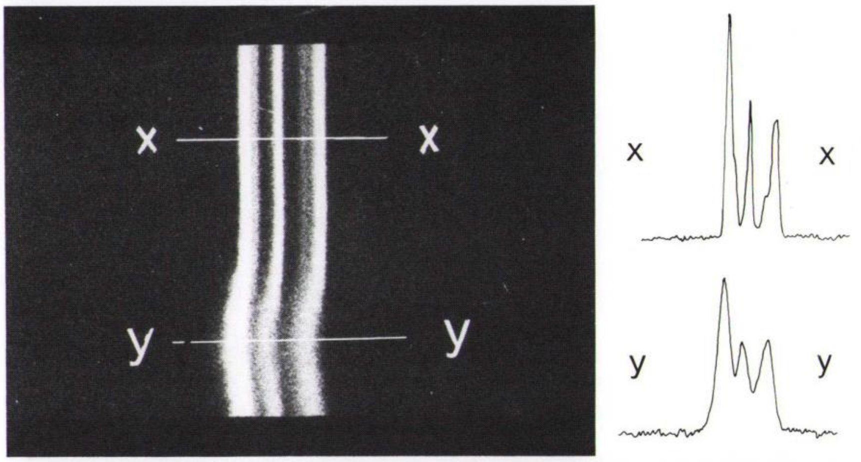


Figure 2: Reflected x-rays from a laser-annealed silicon wafer showing a shift and broadening from the heated part of the wafer.

Ultraviolet lasers provide new lithographic technique

In recent research at the CLF by a group from the Clarendon Laboratory at Oxford, the short wavelength radiation from Argon Fluoride lasers has been shown to etch the photo-resist materials used in microcircuit fabrication without any wet processing. The radiation at 193 nm wavelength breaks the polymer bonds in materials such as poly methyl methacryllate (PMMA) and causes thin layers, about 0.1 to 1μm deep, to be controllably removed by each laser pulse. Since the laser wavelength is so short, submicron resolution is easily achieved and these lasers also have the capability to operate at the high repetition rates needed for commercial purposes. An example of this high resolution laser 'dry etching' in PMMA is shown in figure 3.

Dr R G Evans
Laser Division, RAL

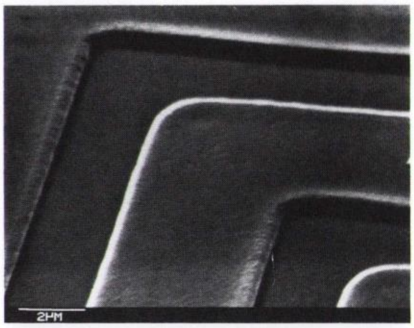


Figure 3: An example of ultraviolet laser 'dry etching' of PMMA photo resist.

European discussions at Daresbury

Professor Paulo Fasella (centre), European Commission Director General, Science, Research and Development, discussing the use of angle-dispersed electron spectroscopy in surface science research with Dr David Norman during a visit to the Synchrotron Radiation Source (SRS) at Daresbury Laboratory on 7 March 1984. Professor Fasella visited the laboratory to discuss the scientific and industrial perspective of synchrotron radiation in Europe and possibilities of broadening the accessibility to the SRS on a European scale, thus improving the overall utilisation of this unique facility. On the previous day he saw the Spallation Neutron Source and the Central Laser Facility at the Rutherford Appleton Laboratory.

Left to right are: Dr David Norman, Professor Fasella, Professor Leslie Green (Director, Daresbury), Dr Leo Hobbis (Head, Science Division) and (behind) Dr D J Thompson (Deputy Director, Daresbury)

The UK free electron laser

The free electron laser (FEL) represents a radical alternative to conventional lasers, being potentially the most flexible, high-power and efficient generator of tunable, coherent radiation from the ultraviolet to the infrared.

The UK free electron laser project, a major collaborative programme involving Glasgow and Heriot-Watt Universities and Daresbury Laboratory, has completed the design and construction phases, and successful observation of spontaneous emission in commissioning trials bodes well for successful oscillation by the end of the second year of the three-year SERC funding period.

In a conventional laser, the gain mechanism involves electrons making radiative transition between bound states of atoms or molecules. A free electron laser does not have these restrictions on operating wavelengths, and is constrained only by the phase-matching condition for strong interaction between the electrons and laser field: ie for a given periodic magnetic (wiggler) structure, the wavelength is determined only by the energy of the electron beam. However, despite the vast literature on the subject, FEL oscillation has only been achieved in four laboratories and its potential as a broadly tunable source of radiation in picosecond pulses has not yet been utilised. We believe this is principally because of the lack of availability of suitable dedicated electron beam sources.

A key feature of the UK FEL, a collaborative project between, principally, Heriot-Watt University, Glasgow University and Daresbury Laboratory, is that it is a dedicated facility based upon the electron linear accelerator (LINAC) at Glasgow's Kelvin Laboratory. Daresbury have led the design and construction of the wiggler magnet, while Heriot-Watt have been responsible for laser physics and diagnostics. The project committee comprises S D Smith FRS (Chairman), C R Pidgeon and W J Firth (Heriot-Watt), J M Reid, M Kelliher, A Gillespie and J Gunn (Glasgow), M W Poole and G Saxon (Daresbury), J Lawson (Rutherford Appleton Laboratory – the SERC nominee). In addition, a number of outside individuals and groups have made and are making useful contributions to the collaboration.

The objective of the UK project is in the first instance to mount a comprehensive series of experiments to characterise the performance of the FEL in both the amplifier and oscillator configurations. A uniform wiggler of flexible design enables a relatively high gain performance to be achieved over a wide range of output wavelengths, with a target range of 1 - 20μm for a variety of LINAC energy and wiggler field combinations. Harmonic generation provides the exciting possibility of extension to even shorter wavelengths in the visible and ultraviolet. At a later stage, the combination of broad tunability and very short pulses with high peak powers will be applied to experiments providing a deeper understanding of energy transfer processes in gaseous and condensed-state materials.

By June 1984, the LINAC and electron beam line was essentially complete in its first stage, all four sections of the wiggler were assembled, two were in place, the cavity and alignment optics and signal processing systems were ready. Extensive measurements had already been made of spontaneous emission characteristics: strong narrowband visible harmonic radiation had been detected even with a test electron beam interacting with the two wiggler sections. Spontaneous emission and small signal gain in the 10μm region would then be measured under full beam current conditions, leading on to first oscillation in Autumn 1984.

Physics of the FEL

The basic layout of the free-electron laser is illustrated in figure 1. Electrons traversing the wiggler magnet array undergo forced transverse oscillations due to the spatially alternating magnetic field. For relativistic electrons, the resulting synchrotron radiation is strongly peaked in the forward direction, and spectrally peaked at λ, where

$$\lambda = \lambda_w/2\gamma_z^2 \equiv \lambda_w(1+K^2/2)/2\gamma^2$$

Here λ_w is the wiggler period (65mm for UKFEL) and the input electron energy is γmc^2 ($\gamma \approx 100$ for 50 MeV electrons, ≈ 200 at 100 MeV). K is proportional to the wiggler magnetic field (1 for UKFEL).

Stimulated emission and free electron laser action arises because a strong optical field of wavelength close to $\lambda_w/2\gamma_z^2$ acts with the wiggler field so as to 'bunch' the electrons on an optical wavelength scale. So bunched, there is coherent transfer of energy between the electrons and the optical field. This transfer can have either sign: there is optical gain, and FEL operation, at a wavelength red-shifted from $\lambda_w/2\gamma_z^2$, as shown in figure 2.

As the light is amplified, the electrons lose energy, and the gain disappears or even changes sign. This limits the conversion efficiency to 1% of the electron energy. One approach to overcome this problem is to reduce λ_w or K along the wiggler to compensate for the reduction in γ_z due to FEL action.

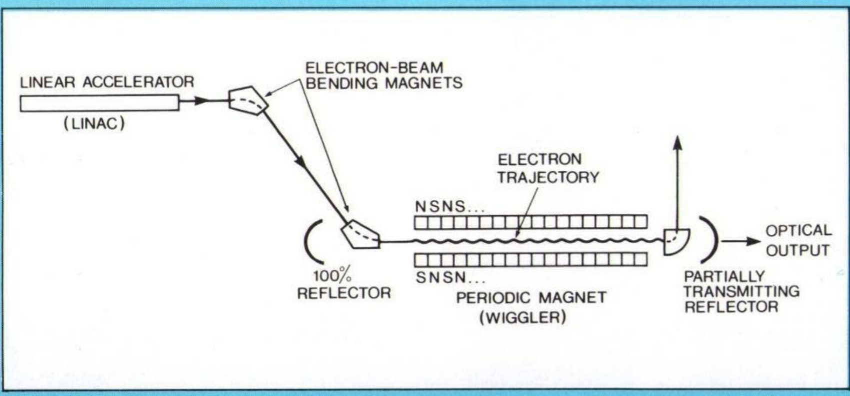


Figure 1: Schematic layout of a free electron laser

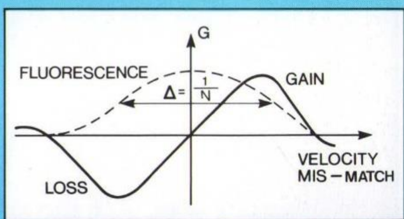
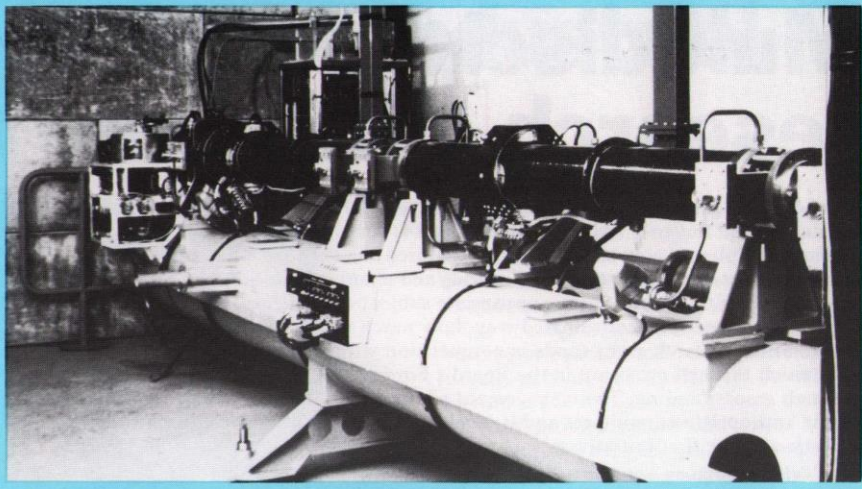


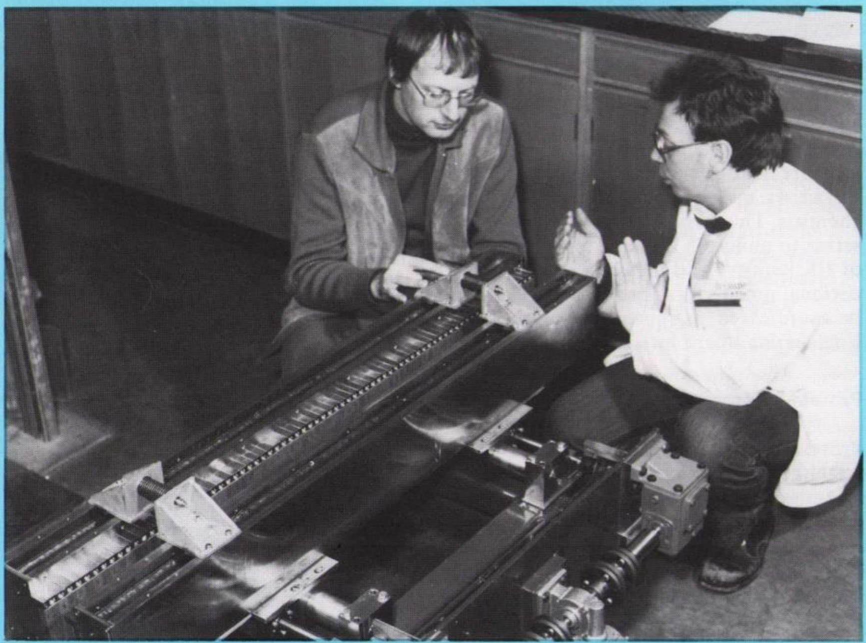
Figure 2: FEL gain and spontaneous emission spectra vs. electron energy

The electron beam

The electron accelerator is the key component in any FEL system, and has caused delays and failures in other FEL projects. The UK project is fortunate in having sole use of Glasgow's high-performance LINAC. This 170 MeV machine is being modified to produce 8.5 μs electron pulses with a current of up to 300 mA and a maximum repetition rate of 100 pps. At the operating frequency of 2.856 GHz the peak current of ~ 10A occurs in bunches of width 6 ps. An optional energy compression system reduces the natural spectral width to 0.1%, but lengthens the bunch width to ~ 50 ps. Operation at the central laser wavelength of 10.6 μm requires an electron energy of 53 MeV.



Kelvin linac: gun and first two acceleration stages



Mr M W Poole and Mr M Thirsk, Daresbury Laboratory, examine the first wiggler section

The wiggler magnet

The UK project employs a 5 m long permanent magnet wiggler, constructed in four identical, independently controllable sections. This design confers great operational flexibility and allows a wide range of experiments to characterise FEL performance. Each section comprises two parallel arrays of permanently magnetised rare-earth cobalt blocks. The 65 mm period was chosen after extensive computation of the effects of the various broadening mechanisms (finite number of periods, electron energy spread and beam divergence). As assembled, the on-axis field is 0.46T when fully closed on the FEL vacuum pipe. The field drops off exponentially as the gap is opened, by 0.64% per 0.1 mm of gap. This allows a very substantial degree of magnetic tuning of the FEL output wavelength.

Optical system

The optical layout comprises: the FEL cavity, the alignment system, and the diagnotics system. Accurate alignment of electron and radiation beams through the wiggler is achieved with a system of retractable screens viewed remotely by TV cameras. The overall system facilitates measurement of spontaneous emission, small signal gain and FEL oscillation.

Both from the point of view of studying the laser physics and establishing that the system is correctly aligned it is essential to measure the spontaneous emission. For a plane wiggler, harmonics in the spontaneous emission result from an oscillation at twice the fundamental frequency in the longitudinal component of the electron's velocity as it proceeds down the wiggler.

In preliminary experiments it has been possible to observe harmonic output in the visible region of the spectrum using the e-beam set at 100 MeV, and varying the wiggler field from K=1 to K=2.5. This has been highly convenient because it has facilitated our initial spatial and spectral analysis by the use of a colour television camera. Reasonable agreement with theoretically predicted profiles has been obtained giving optimism as to the electron beam quality and preliminary alignment.

W J Firth, C R Pidgeon and S D Smith
Department of Physics, Heriot-Watt University, Edinburgh

Figure 3: UKFEL spontaneous emission on third harmonic at 100 MeV, June 1984. Upper trace: no aperture. Lower trace: 0.5 mrad half-angle aperture.

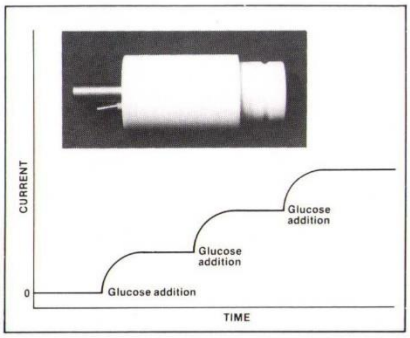
Multidisciplinary research initiatives

The Science Board reported in its recent strategy statement for the support of core science (*SERC Bulletin* Vol 2 No 11, Spring 84) that it was convinced of the importance of multidisciplinary activities and had recognised the need for programmes in low dimensional structures, protein engineering and chemical sensors. The Board is now considering, with the aid of the appropriate subject committees, how best it can support these programmes in a coordinated way, how much of their funding will need to come from normal research grant funds in competition with standard research grants and how much through provision in the Board's Forward Look for an enhancement of its research grants funding. The management of the new initiatives will be the responsibility of the appropriate committees and it is felt that it would be helpful to outline the scope of each of these first initiatives.

Low dimensional structures

Low Dimensional Structures (LDS) are formed by precise deposition of thin, well-defined layers (typically only a few atoms thick), principally on crystalline semiconductors, and by the formation of narrow channels using lithographic techniques. In LDS nearly all physical properties are changed from those of bulk solids. Electronic transport, optical absorption and emission, phonon interactions and structural stability all take on new, often astonishing forms. The best known examples are the quantum Hall effect and the fractional quantum Hall effect, which are only partly explored and are as yet unexplained. These and other electronic properties are related to very fundamental problems of disordered and interacting many-body systems.

LDS have enormous technological relevance. A feature of LDS is that they can be designed to emphasise and isolate the property of interest, allowing direct observation and measurement. The semiconductor industry already invests heavily in short and medium-term LDS research but the whole potential range of devices can be realised only when the fundamental physics has been more fully explored and understood so that desired properties can be designed in detail into the structure.



Enzyme electrode: a solution of the enzyme is in contact with the electrode; the current produced by the reaction is proportional to the amount of target molecule (glucose)

The programme aims to provide the latest growth and sample preparation facilities in selected universities; to fund associated manpower resources; to train research students in skills needed by industry; and to coordinate teams of physicists, materials scientists and chemists. This basic physics research serves to underpin the long term future of UK industry and is essential for future national prosperity. The programme will be coordinated, as appropriate, with Engineering Board interests in this area.

Protein engineering

Proteins, such as enzymes and hormones, are large biological molecules composed of amino acids joined together to form long chains which are variously twisted and folded. It is the precise nature of this highly complex tertiary structure which determines the specificity of the macromolecule or, in the case of enzymes, the chemical reactions which they catalyse.

X-ray crystallography has been used to elucidate the structural features of proteins although other spectroscopic techniques, such as NMR, have found increasing application. Once the three dimensional structure has been obtained, interactive computer graphics may be used to model and manipulate the structure so that particular features may be identified. This type of analysis opens up the possibility of postulating structural changes which may lead to modifications in protein function. The DNA message coding for a given protein may be altered in a precise manner by the technique of site directed mutagenesis such that, on expression, the amino acid sequence of the protein is modified in a predetermined way. The 'altered' gene may then be cloned and quantities of the modified protein produced.

The potential for designing and manufacturing 'new' enzymes, hormones and other protein materials, and the development of new drugs, is exciting both academically and industrially. To exploit this potential, the Biological Sciences Committee and the Biotechnology Directorate are currently drawing up a major programme in collaboration with industry whereby a small number of academic groups possessing expertise in the diverse contributing disciplines will tackle problems of both fundamental and applied importance. UK companies are actively involved in the development of the programme, which it is envisaged will receive support from both public and industrial sources.

Chemical sensors

A sensor system consists of three basic parts. At the front end is a system which will recognise a specific chemical species; this could be, for example, a membrane, a surface-bound enzyme or a chemical compound. On recognising the chemical species, a signal is produced from a transducer and transmitted to a data handling system. The transducer and the instrumentation cannot be divorced from the sensor at the front end; in order to produce a reliable device it must be developed as an integral system.

There is considerable demand for specific sensor systems to recognise chemical species and reactions in the research laboratory, in industry, in agriculture and in clinical medicine, and there is a need to develop a comprehensive library of sensors and to consolidate knowledge of the basic processes occurring at chemical sensors.

The chemical sensors intiative is conceived as a major programme to increase our understanding of sensors and to develop new sensors for the recognition and management of specific chemical species. A working party of the Chemistry Committee has been established to manage the programme, in consultation with the relevant Engineering Board committees.

In order to produce reliable devices, systems must be developed as a whole and a wide range of disciplines are expected to contribute to the programmes, ranging from electrical engineering and solid state physics, through physical, polymer and organic chemistry to enzyme chemistry and biotechnology.

To make a significant input in the area, it is planned to establish six or seven multidisciplinary teams to complement those already supported by the Engineering Board. A facility for surface analysis, specifically for the programme, is also envisaged. The progamme will be stimulated by a series of workshops.

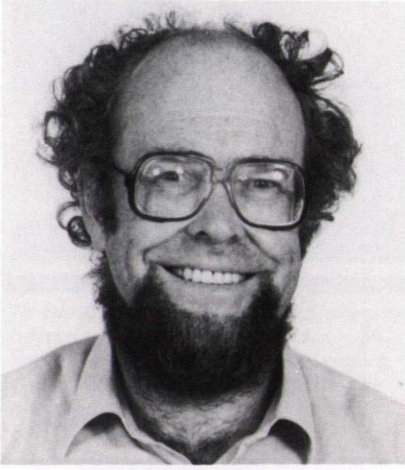
Royal Society/SERC industrial fellowships scheme

SERC's efforts to promote closer relationships between the academic community and industry are well illustrated by the Industrial Fellowships Scheme operated by SERC in conjunction with the Royal Society. This flexible scheme was established in 1980 and is proving highly successful. Fellowships are awarded so that scientists, engineers and mathematicians can move from academic life into industry or vice versa for a period of between six months and two years, engaging during that time in a project of importance to both the industrial and the academic partner, and subsequently taking back with them what they have learnt of the other side and its needs.

The Scheme's conditions require that Fellows should ordinarily be resident in the UK, the Channel Islands or the Isle of Man. They must also be of PhD status or equivalent, and hold a tenured post in a university or polytechnic, or in industry. They will normally retain their existing employment during the fellowship period, so that superannuation and National Insurance contribution arrangements etc remain the responsibility of their employer. The Fellow's stipend is paid directly to his employer and will normally be his current salary for an academic or the appropriate step on an academic scale for an industrialist.

Dr R F Bilton of Liverpool Polytechnic: 'It has been a most refreshing experience, after 12 years in teaching and administration, to return to the bench in a stimulating industrial environment'.

Dr Bilton held his fellowship at ICI Runcorn, where he made a study of catabolic plasmids with new degradative functions.



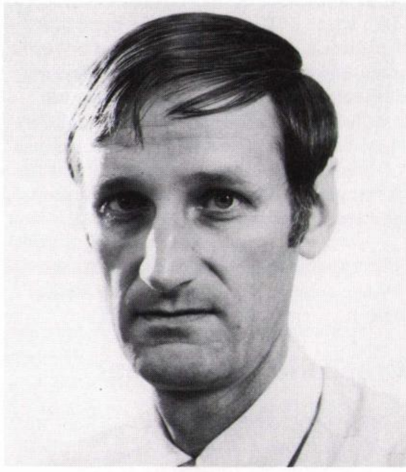
Dr A D C Grassie of Sussex University: 'I would hope that each university department of physics could see its way clear to letting at least one of its members spend time in industry on a fellowship scheme such as this in order to project more effectively to their undergraduates the real excitement and challenge of industrial applied science'.

Dr Grassie spent his fellowship with Phillips Research Laboratories at Redhill, working on the properties and possible applications of III-V semiconducting compounds produced by molecular beam epitaxy.

The project undertaken by the Fellow might be a piece of research and development which is of significance to the company's engineering programme and, at the same time, has important implications for research and teaching in the university or polytechnic. Or it might consist of course development in a topic where the company has strong interests. Projects must be in a field supported by SERC, ie in any part of science or engineering other than agriculture, the natural environment sciences, medicine or social science. Many of these projects will be research-centred, but the Royal Society and SERC are concerned also to encourage design-oriented projects.

To date, a total of 26 awards have been made, split almost equally between academics moving into industry and industrialists moving into the academic world. A wide range of companies has been involved with, on the academic side, 18 different universities and polytechnics with departmental interests spanning physics, chemistry, biology and a number of engineering disciplines. In several cases, fellowships have followed an extended period of contact between the company and the academic department, and it is clear that, where such prior contact exits, the fellowship usually gets off to a flying start. Another circumstance that inevitably eases the practical problems associated with a fellowship is where the academic and industrial partners are geographically close. Nevertheless, it is pleasing to note that there are several fellowships which amply demonstrate that neither of these circumstances is necessary for success.

The Royal Society and SERC wish to encourage further high-quality applications for Industrial Fellowships. In particular, they would welcome applications involving smaller companies. Applications are considered twice a year, the closing dates being 31 March and 31 October. Full details and application forms are available from Miss Carol Armstrong, Fellowships Section, SERC Central Office, Swindon, ext 2352, or contact Dr Peter Wakely at The Mount, Cosby, Leicestershire LE9 5SH, telephone Leicester (0533) 863255.



Dr A J Rogers of CEGB: 'The fellowship has been very successful ... the ground work has been laid for what is potentially an important new area of measurement technology. A notable consequence has been the establishment at King's College of an interest in optical fibre measurement'.

Dr Rogers held his fellowship at King's College, London; his project concerned polarisation phenomena in optical fibres.

Research through collaboration

The Council's Cooperative Research Grants Scheme is aimed at fostering partnerships between manufacturers who wish to develop new products or processes requiring research which has an academic content beyond the resources of their own research and development facilities; and UK universities and polytechnics which can provide such necesssary expertise and specialised facilities.

Under the scheme, joint programmes of research are developed by academic departments and industrial companies. SERC finances the academic side of the collaboration through the provision of research staff and specialised equipment, while the company is required to make a substantial contribution in materials and capital. The application for a grant is made by the academic partner in association with the company, and any UK company is eligible that is directly engaged in the manufacturing or extraction industries or in supplying commercial services, provided that it intends to exploit the results of the research. SERC's contribution may be up to three times that of the industrial partner in terms of direct costs. In return for its contribution the company is assigned any patent or intellectual property rights subject only to a small royalty to the British Technology Group on successful exploitation.

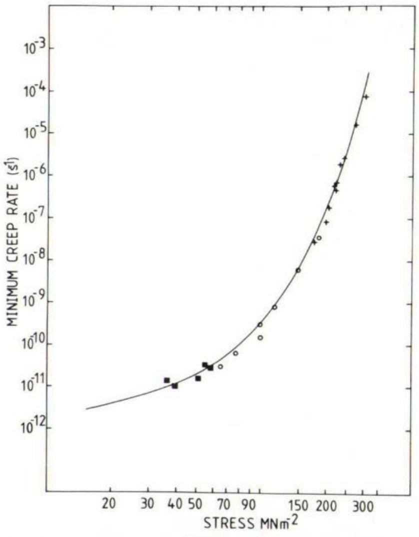
The scheme has generated much interest since it was set up in March 1979 and to date some 270 projects have been started. Applications have been received covering a wide range of science and engineering subjects and involving both large and medium sized companies. The Science Board in particular wishes to see the use of the scheme in its area expand and to attract as industrial partners medium-sized and small companies.

The type and range of research sponsored by the scheme are illustrated by some case histories of current projects.

Creep life assessment

Components and structures for high merit power stations and petrochemical plant may be required to operate for periods up to 25 years or more. As a result of the national importance of extending the life of existing generating plant, there is an urgent need for accurate methods whereby the remaining life of components can be assessed. For these reasons, the Swansea/CEGB collaborative programme on creep life assessment was initiated under the terms of a Cooperative Research Grant.

The dual problems of long-term creep life prediction and remaining life

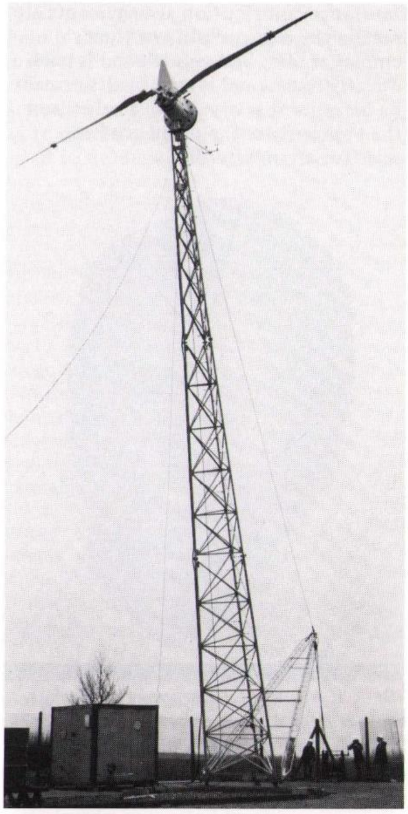


Using the θ Projection Concept, information derived from tests having creep lives of less than three months (denoted +) can be used to predict the creep properties expected under conditions giving lives of 10 years or more. The solid line shows the predicted variation of the minimum creep rate as a function of stress. Long-term data made available by the CEGB (shown as ○ and ■) indicate the accuracy of the predictions even at service stress levels.

assessment are obviously related since a knowledge of the expected total life of a component is an essential prerequisite for determining the remaining life under normal operating conditions. An entirely new method of long-term creep life prediction, termed the 'θ projection concept', has been devised on the basis of analysis of the known changes in creep curve shape with increasing test duration. Using test data lasting only up to a few months, this new procedure has forecast accurately all of the long-term data so far made available on ½Cr½Mo¼V ferritic steel, a material widely used in UK generating plant. Furthermore, the 'θ projection concept', if fully validated, offers the major advantage of providing not just long-term stress rupture properties but also full strain/time predictions which would enable modern numerical procedures to be used for high temperature design.

Wind and diesel power system

The high cost of diesel generation of electricity in remote areas isolated from the grid supply has prompted an examination of integrated wind/diesel systems where the wind turbine is viewed primarily as a fuel saver. The variability of the wind does, however, lead to a number of problems and it is the aim of a joint project by the Electrical Engineering Department at Imperial College of Science and Technology, London, the Rutherford Appleton Laboratory (RAL) and Hawker Siddeley Power Plant Ltd to examine the transient behaviour of such systems and to develop an integrated wind/diesel system which could serve as a prototype power plant for isolated communities. The study will employ both computer simulation techniques and data from tests on an experimental system at RAL; the latter will comprise a test diesel set and an aerogenerator with a 9m diameter rotor on an 18m tower. The research will take note of the types of application envisaged for such systems; these are expected to be mainly in the developing countries where a considerable market for diesel sets exists and Hawker Siddeley Power Plant Ltd are confident that the results of this project will enable them to gain an early entry into this market by being able to offer a reliable integrated wind/diesel package.



The 16 kw Hawker Siddeley 'Mistral' aerogenerator being erected on the RAL experimental site.

Tribology of polyetheretherketones

Poly(etheretherketone)s (PEEKs) are one of a relatively new generation of polyaromatic organic polymers. These materials have been found to have exceptionally good engineering properties. In particular they possess a combination of high corrosion resistance with high toughness and strength and also considerable fatigue resistance over a wide temperature range. These properties, along with the fact that the materials may be formed by relatively simple and cheap fabrication techniques, make them very attractive alternatives to metals and conventional polymers in an increasing number of engineering applications.

It has therefore been natural to evaluate these materials as bearing surfaces either as parts of fabricated components or as bearings in their own right. In principle these polymers should produce outstanding lubricated bearing surfaces. Under certain circumstances they do but in many cases they do not. The research funded jointly by SERC and the Glacier Metal Company (part of the A E group) during the last year has sought to elucidate the peculiar features of these polymers which currently limit their use as commercial bearings. Several factors have now emerged which explain the origin of these limitations in performance. In brief, high surface temperatures are generated because of the high friction dissipated in these contacts. Under these conditions the subsurface of the polymer is mildly plasticised by certain lubricating media which leads to a type of contact failure commonly observed in metallic contacts. The programme at Imperial College of Science and Technology continues and researchers are now concentrating on optimising the performance of these polymers under less extreme contact conditions where the interfacial temperatures generated during sliding do not produce irreversible lubricant-induced changes in the polymer matrix.

Optimisation of plastic scintillator performance

Plastic scintillators are widely used as radiation detectors in the nuclear and medical industries as well as in research. A collaboration between Thorn EMI Nuclear Enterprises and the Heriot-Watt and Strathclyde Universities has led to a significant advance in the understanding of the photophysical processes observed in scintillator operation, and in particular the identification of the extent to which scintillation yield and time response is a function of the extent of polymerisation in the fluorophore-doped matrix. The ability to define the characterisation of the polymer in a precise way means that it is now possible to predict the optimum duration of a polymerisation cycle necessary to obtain a specified scintillator performance with consequent benefits in manufacturing costs.

Dr David Birch of Strathclyde University operating the γ-ray spectrometer developed with a Cooperative Research Grant for studying how scintillation in plastics depends on the extent of polymerisation.

Synthesis and characterisation of novel zeolites

Rarely does the discovery of a new class of materials have such wide fundamental and technological implications as that of zeolites. Zeolites are crystalline hydrated aluminosilicates in which the basic structure is a tetrahedron made up of either a silicon or aluminium atom surrounded by four oxygen atoms. The tetrahedra combine to give an ordered framework which contains holes or cavities of a very well defined size of molecular dimensions: the zeolite can act as a 'molecular sieve' permitting the separation of molecules according to their size. In addition, because zeolites possess chemical properties related to the fact that an aluminum atom linked to four oxygen atoms must have a negative charge, they are capable of performing as highly active and specific catalysts. Although naturally occurring zeolites have been known for many years, synthesised novel materials have been shown to display interesting properties of economic significance. A collaboration between ICI and Edinburgh and Aberdeen Universities has led to the synthesis and investigation of the structure, adsorbtive and catalytic properties of 13 new zeolites. To complement the successful synthesis programme, novel characterisation techniques have been developed which rely on intrinsic catalytic properties: in effect, letting the new materials characterise themselves. A detailed study has also been made of silicate and aluminate solution chemistry, from which a new method for the controlled synthesis of zeolite catalysts is being developed.

Kinetics of drug degradation

A prime requisite of any pharmaceutical dosage form is that the drug should have adequate stability during the envisaged storage life of the product. A better understanding of the solvent effects on the kinetics of drug degradation is important since in the case of liquid products the formulation is rarely a simple solution of the drug in water. In many cases cosolvents or solutes are employed to increase the solubility of the drug, or to alter the viscosity or sometimes to improve the chemical stability of the formulation. For example it may be necessary to increase the pH value of a liquid preparation in order to improve the solubility of the drug but with consequent reduction in stability. A collaboration between Upjohn Limited and King's College, London has identified the importance of the acidity of non-aqueous systems, as defined by pH scales, to the stability of drugs in such solvents.

The investigation also clarified some of the general factors involved, especially the effect of solvent changes on the concentration and reactivity of various catalytic species of molecule present in the preparation. The research allowed expertise to be developed within the company on the effects of solvents on drug stability with implications for the formulation of drugs in liquid systems.

Contract for Technical Change Centre

The Technical Change Centre, with its function to develop a major programme of research on the choice, management and acceptability of technical change relevant to the advancement of the national economy (see *SERC Bulletin* Vol 2 No 6, Autumn 1982), has received a contract from the Council to investigate the programmes supported under the Cooperative Research Grant Scheme since its inception in 1978-79.

The study, over a twelve month period from July 1984, will assess the effectiveness of the collaboration achieved in practice between the academic and industrial partners in each programme; for example it will look at the quality and progress of the research and development work and at the situation regarding the exploitation of the work.

Further details on the Cooperative Research Grants Scheme are given in the booklet *SERC Research Grants* or may be obtained from the relevant subject committee secretariat at SERC Central Office, Swindon.

Grinding away at the academic-industrial interface

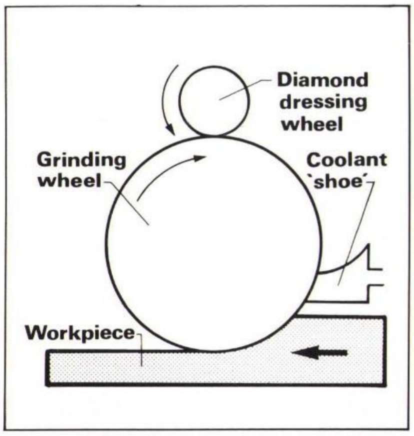
Since 1971, the Grinding Research Group in Bristol University's Mechanical Engineering Department has sent some 16 postgraduates into UK manufacturing industry, some of whom have already reached very senior positions. The group has a high international reputation and has received substantial support from SERC for many years; it participated in the former Specially Promoted Programme on Grinding Technology.

Grinding is the process whereby material (usually metal) is removed from a workpiece through contact with a moving abrasive surface (usually a rotating grinding wheel). It has been used traditionally as a finishing process on engineering components where high dimensional accuracy and/or good finish has been called for, but is now increasingly used for the complete metal shaping operation in industries such as aerospace and automobile manufacture. The research at Bristol has made a real contribution to grinding both in its traditional and newer role.

The research activities at Bristol fall into two categories: fundamental research and more applied investigations carried out in partnership with firms. The fundamental work is largely supported by SERC while the applied investigations are mainly funded by industry. The two elements are interdependent and support from industry and from SERC is now about equal.

Creep feed grinding

One major study in the fundamental research programme has centred on creep feed grinding – the process whereby the grinding wheel removes most or all of the metal to be cut in a single slow pass, rather than in many shallower but faster cuts. The initial concentration was on difficult-to-grind nickel-based alloys, typical of those used for aerospace turbine rotor blades. The rate at which metal could be removed was limited by surface burning of the workpiece. The Bristol research showed, through some elegant experiments, that the limit corresponded to the point when heat was generated in the grinding zone at a rate sufficient to cause the grinding fluid to boil off. This inhibited the dissipation of heat from the grinding zone, causing the workpiece temperature to rise, leading to burning which often means scrapping the workpiece.



Schematic of continuous-dress creep-feed.

Two approaches were adopted to overcome the problem. The first was to investigate more efficient means of heat removal from the grinding zone. Research showed that this could be done by improving the method of applying the coolant. The normal method is to use a coolant jet injected into the wheel/workpiece interface. Experiments showed that a much more dependable performance could be obtained by applying the coolant under pressure through a 'shoe' in contact with the grinding wheel. The coolant is forced into the pores of the wheel and then expelled centrifugally into the grinding zone. The depth of penetration of coolant into the wheel and the length of arc through which the coolant was expelled were both shown to be predictable using fluid mechanical analysis. Thus, the shoe was shown to provide a means of control in coolant application not previously considered.

The second approach was to ensure that the grinding wheel was kept as sharp as possible, minimising the rate of heat generation in the grinding zone. This was done by 'dressing' (sharpening) the wheel continuously by contact with a diamond dressing wheel. This led to an increase in maximum metal removal rate of up to 20 times.

Both of the above improvements have been adopted in UK industry. Rolls-Royce, Derby, has used continuous dressing for creep feed grinding of turbine rotor blades. Extension of its application to the grinding of profiles (rather than plane surfaces) has led to a reported annual saving of £1 million achieved simply by modifying manually-operated machines to use continuous dressing and by improving coolant application.

Since then, the much improved control of the process, which the adoption of continuous dressing and better coolant application permits, has enabled Rolls-Royce to assemble grinding machines into flexible manufacturing configurations. The savings are now even greater but are, as yet, unpublished.

Chatter

Another aspect of grinding studied at Bristol has been the self-excited vibration, known as chatter, a common limitation to grinding in its traditional role. Chatter manifests itself as periodic marks left on the workpiece surface rendering the component unacceptable. The Group analysed the problem and deduced that the flexibility of the outermost part of a grinding wheel is crucial in avoiding chatter since the flexibility absorbs the force feed-backs that cause the excitation. In a two year project undertaken with De Beers (Pty) Ltd the Group applied their analysis to cubic boron nitride (CBN) grinding wheels (a type of wheel made with a special abrasive highly suited to hardened steels) which had been found to be particularly prone to chatter. As a result, world-wide patents have been sought by De Beers for a means of introducing flexibility into CBN wheels. A publication by the research group gained them the first prize of the James Clayton Awards of the Institute of Mechanical Engineers this year.

Reinforced plastic pipes

Typical of the Group's more applied projects is a recently completed study in conjunction with a major UK manufacturer of glass-reinforced plastic pipes. The flanges at the ends of the pipes are normally finished by turning. This is time-consuming because of the extreme abrasiveness of the pipe material and the low allowable rotation rate imposed by the pipes' tendency to 'whip'. Experiments at Bristol determined how the pipe ends could be finished by grinding much more economically than by turning.

Cam grinding

Another example is that of cam grinding employing CBN grit wheels. A useful characteristic of this type of wheel is its resistance to wear. However, experience had shown that it produced a poor surface finish. A project undertaken for a UK company involved in cam grinding resulted in much better finishes being obtained. And, because of the wheel's wear resistance, substantial savings were made in production since many fewer wheel dressings and changes were needed.

Future plans

Future research plans include further refinement of the continuous dressing creep feed grinding process, the main aim being to reduce wheel wear rates and thus yield further savings. Variables to be evaluated are the size of the grits in the grinding wheel, intermittent (rather than continuous) dressing, the choice of grinding lubricant, and the ratio of dressing wheel to grinding wheel speed.

Other projects will include an investigation of whether the grinding fluid boiling limitation applies to traditional shallow cut (as well as the creep feed) grinding. It seems possible that the metallurgical properties of some shallow-ground surfaces are modified by heating as a result of being ground 'dry' – the fluid having evaporated from the grinding zone. It is intended that this project will be carried out in conjunction with a leading bearing manufacturer. It is suspected that the fatigue life of the bearings is affected by thermal damage caused by grinding of the working surfaces. The research programme will include checking whether this is so with a view to finding ways of avoiding it.

These examples illustrate the benefits which can accrue from a thorough analysis of a manufacturing process and the introduction of improvements based on the understanding derived. They also show how SERC support of fundamental research can spawn more applied investigations which attract direct industrial sponsorship.

But the success of the Bristol group stems equally from the excellent cooperative relations it has built up with industry. As SERC's policy is to strengthen academic–industrial links and to encourage technolgy transfer, it is appropriate to analyse the Bristol formula.

The Bristol formula

A lot of the credit must go to the founder of the Group, Professor Colin Andrew, former Head of the Mechanical Engineering Department, and his then deputy, now leader of the Group, Dr Trevor Howes. Professor Andrew identified grinding as a technology which, although widely used, could benefit from a concerted effort to develop and build on a fundamental understanding of the mechanisms involved since, hitherto, much industrial grinding practice was something of a 'black art'.

Howes was recruited from a senior technical position in a related industry and, in his view, his industrial experience has been a key element in developing the successful academic–industrial relationship the Group enjoys. He considers there are five main prerequisites for successful academic/industrial liaison:

- A working knowledge of industrial needs and constraints. This requires a frank dialogue with industry. Howes acknowledges that this is difficult to achieve, especially for the majority of academics who have not worked in industry. He regards this as so important that he recently spent six months with a UK grinding machine manufacturer through the SERC/Royal Society Industrial Fellowship Scheme in order to up-date himself on industrial needs (see page 17).

- A very selective approach to the collaborative projects taken on by the Group. Howes says that such projects must be carried out with high academic rigour to ensure that the Group's research findings are reliable and, as a precaution against slipping in this respect, he recommends that, wherever possible, the work be PhD-examinable. The projects must also be of high potential value to industry. Project targets should be agreed at the outset and progress reviewed by regular, formal meetings beween the two sides, but the university group leader should retain management control and reponsibility.

- Secondment of engineers from industry. Howes maintains that this increases the knowledge available to the Group since it provides a direct link with the expertise of the firms from which the engineers come. Perhaps more importantly, it greatly increases the chances of successful technology transfer when the researcher returns to his employer.

- Interdisciplinary group. The Group has expertise in mechanical engineering, metallurgy, chemistry and micro-electronic control. The training of post-graduates benefits by their exposure to a wide variety of disciplines and the research benefits from an interdisciplinary approach.

- Engineering design within post-graduate training. Howes believes strongly that the post-graduate experience should contain a significant design element to ensure an awareness of the rigours of design. This, too, is a facet of the research at Bristol which is welcomed by industry.

The success of grinding research at Bristol seems set to continue. The Group's future research will increasingly aim to facilitate the integration of grinding machines into the automated factories of the future. To this end, the Group already collaborates with the recently appointed Professor of Micro-electronics at Bristol and hopes to participate in SERC's new directed programme on the Application of Computers to Manufacturing Engineering (see page 5).

J Monniot
ACME Directorate

Members of the Grinding Group at Bristol University, standing in front of one of their creep feed grinding rigs. Dr Trevor Howes is on the right.

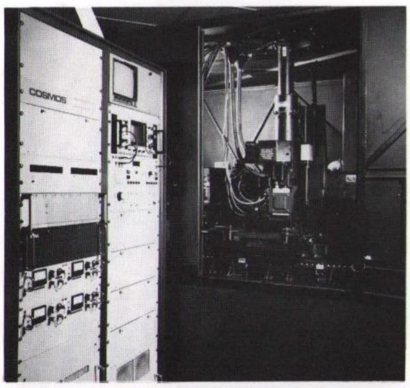
COSMOS — astronomy and technology

COSMOS is a high-speed, fully automatic, photographic-plate scanning machine. It is operated as a national facility for SERC by staff at the Royal Observatory, Edinburgh (ROE) where the machine is housed. Its purpose is to scan astronomical photographs in a short period of time producing meaningful information on the very large numbers of images recorded thereon. Since first introduced as a national facility in 1977, COSMOS has scanned over one thousand plates. Recently, several modifications have been made both to the hardware and to the software of the machine. These modifications have considerably enhanced the machine's performance, increased the flexibility of the system and improved the quality of the data. At present the machine is scanning plates at the rate of three per day and leads the world in the field of high-speed extraction of data from astronomical photographs. COSMOS is a powerful research tool and has contributed directly to several important discoveries in astronomy.

Why do we need COSMOS?

Anyone who has had even a cursory look at the excellent photographic material produced by modern telescopes will appreciate the scale of the problem. On any single photographic plate taken with a wide-angle telescope (eg the UK 1.2 m Schmidt Telescope in Australia – UKST) there are recorded the images of several hundreds of thousands of stars and galaxies. To cover the whole of the southern sky in one waveband with the UKST would require some 900 plates, and astronomers like to work in several different wavebands.

These plates represent, therefore, a vast storehouse of information, presenting an enormous problem of data-extraction for the astronomer. For example, it would take one astronomer several years to measure manually all the objects on a single plate, and even then the data would suffer seriously from errors, omissions and subjective selection effects. *COSMOS extracts the same information in a few hours!* What is more, with COSMOS the measuring is done effortlessly, accurately and completely objectively.



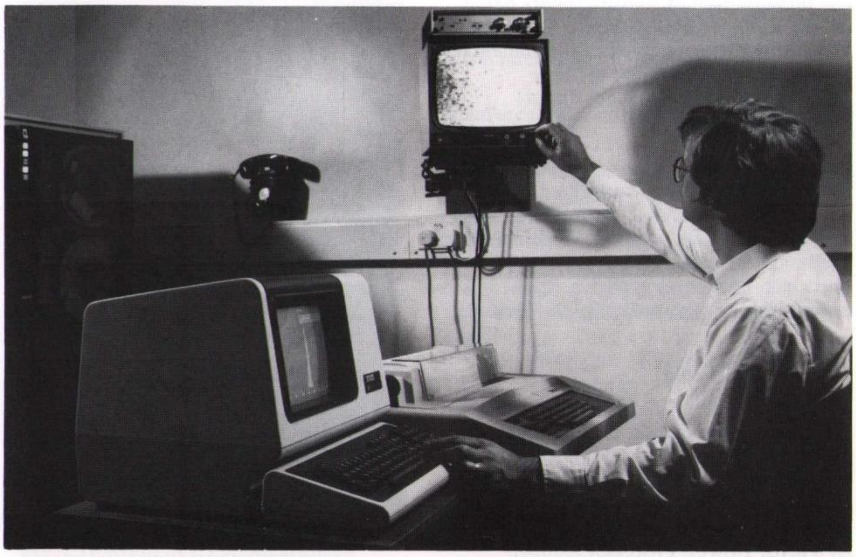
The COSMOS machine, showing the electronics racks (left), the plate carriage (centre-right) and the scanning system.

How COSMOS works

The scanning system on COSMOS consists of a purpose-built cathode ray tube (CRT) which produces a very small scanning spot. This spot is deflected by means of electro-magnetic coils, thereby generating a raster scan. As the spot is deflected in one direction, the plate is drifted underneath the CRT by means of hydraulic rams. Thus a scan of the whole plate is built up by a combination of the raster scan of the CRT in one direction and the motion of the plate carriage in the orthogonal direction. The light from the CRT which is transmitted through the photographic plate is recorded at every 8 or 16 micron interval by means of a photomultiplier. A second photomultiplier looks directly at the face of the CRT and is used in a divider loop to normalise any effects of non-uniformity of the scan due to blemishes or sensitivity variations on the face of the CRT. The transmitted light is converted into an 8-bit transmission value producing a 'grey scale' with 256 different levels. The speed of the machine is such that a 290 mm x 290 mm area on a UKST plate can be scanned in a timescale of four hours or less, producing over 300 million 'pixels' (picture elements) of data.

The data processing

COSMOS is basically a very fast microdensitometer, outputting pixel data which is subsequently analysed off-line by sophisticated software techniques on powerful computers. There are two main modes of operation of the machine. In the first, mapping mode (MM), every pixel is output. This mode is, however, rather expensive on data storage. In the second, thresholded mapping mode (TM), a threshold (at a fixed fraction above the night sky intensity level) is set for image detection and only those pixels above the threshold level are output. This mode is rather more economical in terms of data storage, a compression in the amount of data by a factor of 10 being achieved, and is the most frequently used mode on the machine. The TM pixel data are put through a software pattern analyser for joining together pixels belonging to the same image and for calculating various parameters including image centroid, brightness, size, orientation and shape (image analysis mode data – IAM). Computer routines are available for processing MM data off-line into IAM parameters in a similar



Dr H T MacGillivray operating COSMOS at the computer control terminal. A TV camera helps with plate-positioning.

manner. IAM data satisfy the requirements of most astronomers. However software also exists for extracting the spectra of objects from objective-prism plates (thereby enabling searches for quasars to be carried out and redshifts for galaxies to be obtained); for smoothing raw MM data enabling thresholds closer to the sky background to be set (for the detection and photometry of very faint objects against the sky background); and for the removal of the images of bright objects. This last facility is useful for the detection of globular clusters or variable stars superimposed on the images of bright nearby galaxies.

Astronomical investigations with COSMOS

The machine is currently being used by many astronomers, both in the UK and overseas. A large number of projects is being supported, perhaps the most important of these being investigations of the structure of our own Galaxy by analysis of counts of stars as a function of position, brightness and colour; and of the large-scale structure of the Universe by analysis of the properties and distribution of galaxies and quasars. Another major application of COSMOS is in the detection of objects which are unusual or otherwise interesting on the basis of variability in brightness or extremes of colour. Usually, such objects are prime candidates for more detailed study on other telescopes (eg the Anglo-Australian Telescope or the UK Infrared Telescope).

Some of the discoveries

The discoveries made with COSMOS can be grouped into two classes – the 'gee whiz' kind and the more mundane, slower but fundamentally important kind. Of the former category, COSMOS has several firsts to its credit: the detection of the intrinsically faintest star; the faintest RR Lyrae variable; and the quasar with the second-highest known redshift (and the highest known redshift for an object detected by means of objective and systematic search procedures). Of the second category, several important observations have been made such as direct evidence for a massive halo to the Galaxy, an upper limit to the space density of M dwarf stars in the solar neighbourhood, a better understanding of the structure of our Galaxy from comparison of observed star counts with theoretical models, confirmation of the isotropy of the Universe on scales of several hundreds of megaparsecs, and evidence for evolution in the luminosities, colours and clustering of distant galaxies with time.

The future

The COSMOS team continues to explore ways in which the quality of the data and service to astronomers can be improved. Plans are in progress to incorporate a new generation of CRTs in which the halo associated with the scanning spot will be considerably reduced. This will allow regions of plate which are very black (eg the centres of globular clusters and bright galaxies) to be more accessible. It will also be possible to increase the speed of the machine slightly in order to scan a UKST plate in about three hours. A dedicated processing computer is soon to be linked up to COSMOS. This computer (a VAX 11/750) will have a floating point accelerator, 5 Mbytes of memory, nearly 2000 Mbytes of disk storage space, VDUs and a monitor for the display of colour-coded pictures. Once fully linked up, the computer will considerably increase the processing power, flexibility and efficiency of the COSMOS system. With these enhancements, COSMOS will continue to be well ahead of its main rivals throughout the world, in terms of performance and data quality, for years to come.

On the astronomical front, there is no doubt that COSMOS has an important role to play in the future, not only as a powerful survey instrument in its own right but also as a valuable support instrument underpinning observations made with both ground-based telescopes and the Space Telescope. With COSMOS we have as yet barely begun to dig beneath the surface, only a few fields of the sky having been examined in detail. One thing is certain – if past history is anything to go by, then we are in for exciting times ahead.

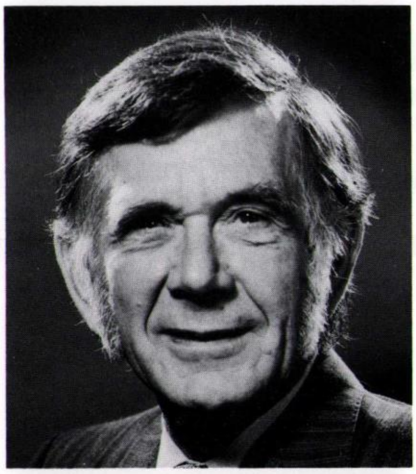
Dr Harvey T MacGillivray
Royal Observatory, Edinburgh

Senior Fellowship for astrophysicist

A Senior Fellowship has been awarded to Professor M J Seaton FRS for research in the field of stellar opacities.

Professor Seaton's career has been associated over many years with University College London, where he has been Professor of Physics since 1963; he was President of the Royal Astronomical Society (1979-81) and was awarded its Gold Medal in 1983.

He has made major breakthroughs in the quantum–mechanical calculation of atomic collision and photoionisation cross-sections, essential to the physics of gaseous nebulae and stellar atmospheres. He has also taken a leading part in the application of these results, notably to the study of planetary nebulae and novae of which he is now also an active observer using the International Ultraviolet Explorer. Resonance effects discovered in the course of this work have a bearing on the opacity in stellar interiors and are therefore important in the theory of stellar structure, evolution and variability. Professor Seaton will now devote most of his time to the problem of computing more accurate stellar opacities (and their effects) in collaboration with colleagues at the Queen's University of Belfast and the University of Colorado.



Professor M J Seaton FRS

Fellowships 1984

This table shows the allocation, the number of applications and distribution of awards in 1984 between the various fellowships schemes and the Special Replacement Scheme.

Type	Allocations	Applications	Awards
Senior	1	19	1
Advanced	18	100	21
Postdoctoral	54	231	54*
RS/SERC industrial	7	13	6
Special replacement	7	48	7

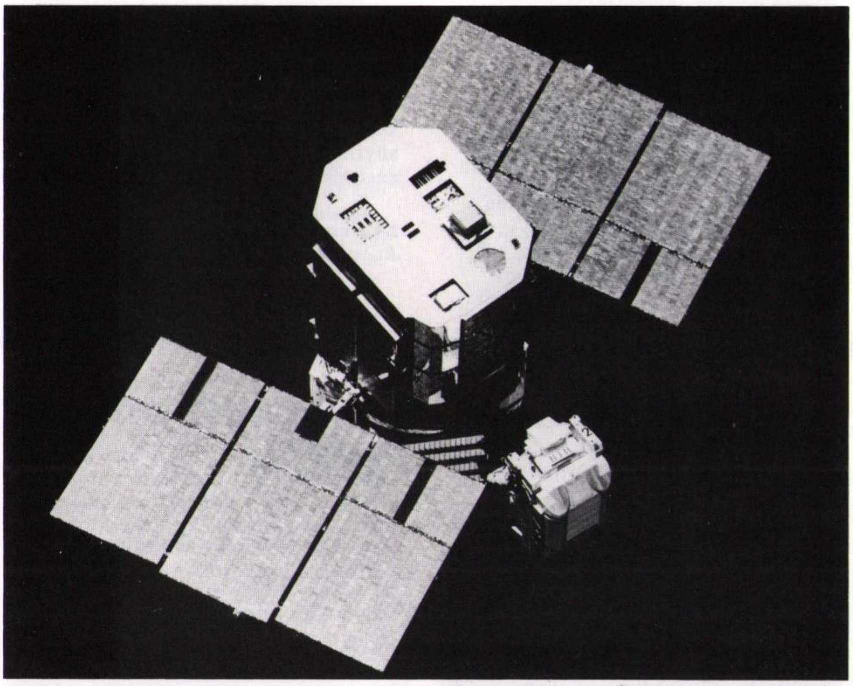
*In addition, nine awards tenable in Europe were taken over from the Royal Society for support under the NATO programme and two awards allocated to the Natural Environment Research Council.

Successful repair of Solar Maximum Mission

Between 6 and 12 April the NASA Space Shuttle carried out the first in-orbit satellite repair. The solar flare observatory Solar Maximum Mission, or SMM, had operated successfully for nine months after launch in February 1980 but then developed a series of faults in its attitude control system which seriously degraded its pointing accuracy. This lack of fine pointing prevented observation by several of the payload instruments, among them the X-ray Polychromator or XRP. The major objective of the repair mission was to replace the entire attitude control system with a spare taken into orbit by the Shuttle. A secondary objective was to repair electronic faults which had developed in another instrument, the Coronagraph/Polarimeter, and a minor objective was to place a baffle over an XRP vent pipe to prevent ingress of ambient plasma. After repair it was intended to boost SMM to a higher orbit before release.

XRP was designed and built by a consortium consisting of the UCL Mullard Space Science Laboratory, Rutherford Appleton Laboratory and Lockheed Palo Alto Research Laboratory. The instrument examines soft x-ray spectra in the range 0.15 – 2.2 mm which is a critical region for non-thermal to thermal energy transfer within flares.

The repair mission achieved all its objectives but one – the Shuttle had insufficient fuel to allow SMM to be boosted to a higher orbit. However, at the start of the repair, the chances of success looked small. The problem was that astronaut George Nelson, using a jet-powered backpack and a special docking attachment, could not dock with SMM (see picture). His docking attachment could not be made to grip the docking pin on the satellite. In a desperate effort to stop SMM spinning, he grabbed a solar panel and used his backpack thrusters but this only made matters worse – SMM was still spinning but now with a precession which meant that soon its solar panels would no longer face the Sun and consequently would no longer generate power.



Astronaut George Nelson approaching Solar Max during the docking attempt.

The astronaut's attempts to capture SMM were abandoned and the spacecraft heaters were switched off to conserve battery power. The satellite's magneto-torquers were then used to point Solar Max at the Sun once more and to put it in an attitude which would allow capture by the Shuttle's remote manipulator arm. Fortunately, this was achieved before the batteries ran flat – but only just.

On Wednesday 11 April, three days behind schedule, SMM was captured using the arm and berthed in the Shuttle's cargo bay. From then on the repairs went according to plan and exceeded expectations – even the very difficult repair to the Coronagraph/Polarimeter's electronics was accomplished with no problems.

Following the repair SMM's new attitude control system was calibrated and the instruments restarted observations in May. This now gives the opportunity to run the more complex and demanding observing sequences which were being developed when the attitude control system failed. First indications are that the new observing period is proving as successful as the first in unravelling the mechanisms of solar flares, with an X12 event (the strongest flare that SMM has yet detected) observed soon after its repair.

Dr J C Sherman
RAL

MT enclosure awaits its antenna

The rotating enclosure for the UK/NL Millimetre-wave Telescope is nearing completion at the astronomical observatory crowning 4200 m Mauna Kea on the island of Hawaii. The telescope will cover the waveband 5 mm to 0.5 mm (adjacent to the IR band). The cylindrical enclosure is 25 m high and 28 m in diameter with huge doors and roof shutter opening to expose a 16 m wide aperture covered by a wind and sun blind of woven PTFE, protecting the 15 m antenna.

Having arrived in May 1984, the steelwork was completed in July and the cladding in September, remarkable progress for such a large building on a remote high-altitude site. Now, it is being put through its paces. After fitting out it will be ready for the antenna by July 1985.

Meanwhile, the antenna is under construction, the surface panels at RAL and the steelwork in Holland. It will soon be trial-erected near Amsterdam, then shipped and erected in the enclosure during 1985. Commissioning will be in 1986 and UK/NL astronomers should soon have a new world-beater.

Progress on La Palma

Since the Isaac Newton and Kapteyn Telescopes at the new Roque de los Muchachos Observatory on La Palma received their 'first light' in February, commissioning work has progessed well and scheduled observing by British, Dutch and Spanish University astronomers began in mid-Summer.

'First light' images from the 2.5 metre Isaac Newton Telescope (INT) were recorded by an intensified low light-level television camera at the prime focus while the commissioning team from the Royal Greenwich Observatory (RGO) brought the telescope under computer control. It is believed that this is the first time that an optical telescope has seen 'first light' in this way, and enabled the general public to share with the commissioning astronomers the excitement when it was broadcast on Channel 4 news.

The first image caught on video tape was of the Crab Nebula, the expanding remains of an exploding star 6000 light years away. The raw video images revealed the Crab's pulsar which is magnitude 16. Since these 'first light' observations were made, full commissioning of computer integration and enhancement means that the television system reaches magnitude 21.

'First light' observations were also made of the Orion Nebula, the Whirlpool Nebula, and the Seyfert Galaxy NGC 4151, of which a team of astronomers with strong RGO involvement had recently weighed the central black hole at 500 million solar masses (*SERC Bulletin* Vol 2 No 11, Summer 1984).

During the commissioning period, the RGO astronomers and engineers have adjusted the alignment of the axis of the 100 tonne telescope and used the television system to test its tracking accuracy and optical performance. The images obtained have shown that the atmospheric stability on La Palma lives up to expectations: astronomers were delighted to see star images less than one arcsecond in diameter on many nights during the commissioning period.

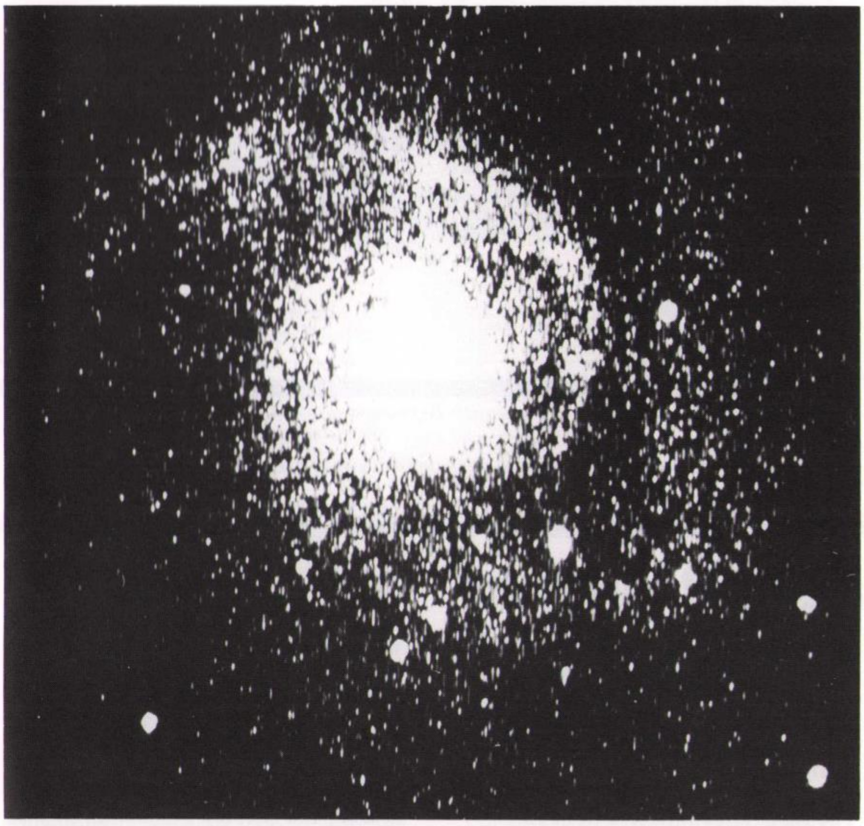
Testing has also commenced of the main spectrograph, located at the telescope's Cassegrain focus. A diffraction grating in the spectrograph splits the light from a star or galaxy into a spectrum, which is then detected by an image photon counting system (IPCS). This is a combination of image intensifier, TV camera and computer that rejects noise to give a very accurate 'clean' spectrum, and was originally developed 10 years ago by Professor Alec Boksenberg FRS, then at University College, London, and now Director of RGO. Already the telescope/spectrograph combination is as sensitive as and has higher resolution than that of the larger, 3.9 metre, Anglo-Australian Telescope.

The one metre Kapteyn Telescope has also shown encouraging results. Its unique Harmer-Wynne optical system (parabolic primary, with spherical secondary and correcting lenses) gives it a wide field of view of 1½° (three Moon breadths). Although it can be used for spectroscopy, the telescope's main purpose is the photographic astrometry of faint objects, to establish a fixed reference frame based on galaxies and quasars, and so reveal the absolute proper motions of stars – a field pioneered by the Dutch astronomer after whom the telescope is named, Jacobus Cornelius Kapteyn (1851-1922).

Like the INT, the Kapteyn Telescope has had its alignment checked and computer control programs for pointing and tracking tested. A number of plates have been taken including a 60 minute exposure of the globular cluster M3 and a 45 minute exposure of M13. Taken in excellent seeing conditions, this showed stars as faint as magnitude 21.5.

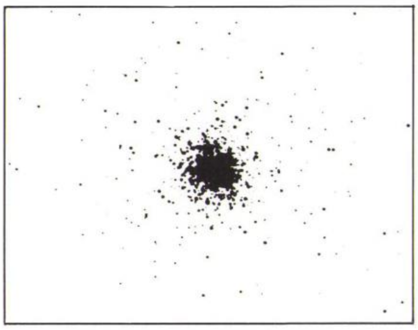
Certainly the sharpness of the images obtained by both telescopes has encouraged RGO astronomers in their belief that this really is a superb site for the world's newest observatory.

C Parker
Royal Greenwich Observatory



Left: Whirlpool Nebula, M51: picture obtained during 'first light' with the 2.5 metre Isaac Newton Telescope and computer-enhanced with the telescope's picture display system designed to help astronomers to see faint stars

Below: 'First light' image from the 1 metre Kapteyn Telescope of Globular Cluster, M3



MARINE TECHNOLOGY DIRECTORATE

Seabed surveying

High density bathymetric information on seabed surveying can be obtained using a sonar and sensor package deployed in a towed 'fish'. The feasibility and advantages of this technique have been studied over the last four years by the Schools of Physics and Engineering at Bath University in two different but complementary strands of research.

The first took the development of a one-way interferometric side-scan, and its associated software for data processing, to the stage of sea trials. The resulting depth matrix was compared with a painstakingly produced echo sounder survey, and found to measure depth to within 20 cm. A major advantage of the swathe sounding technique is that the area was covered in 20 minutes as compared with 5 hours using the conventional method, while much more data were obtained.

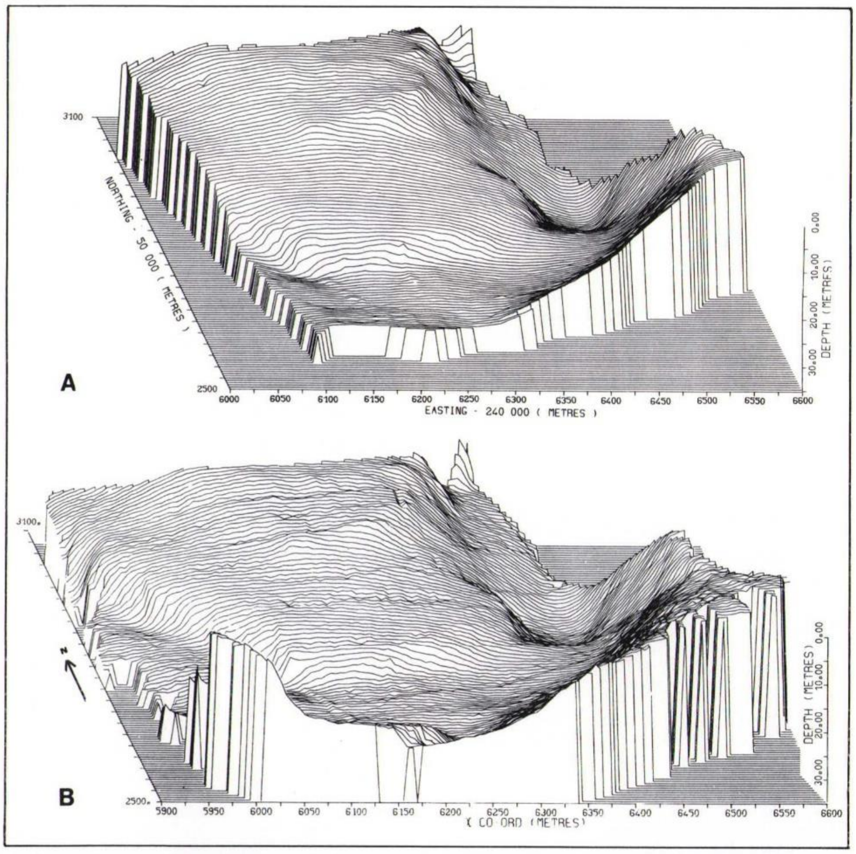
The second investigation related to the hydrodynamics of the towed system itself and the static and dynamic properties of single-body towed systems. It involved development of computer programs and validation of the software for determining the fish and cable responses to ship motion in three dimensions in both towing tank experiments and sea trials. This also led to the development, manufacture and test of a new low-drag clip-on cable fairing. Good agreement was obtained between the predicted and measured time-varying fish position in both two and three dimensions. From this work a good knowledge of the relationships between the fish and ship position was achieved.

Despite recent developments in free-ranging self-propelled survey vehicles, it is now contended that towed survey vehicles are far from obsolete. Indeed, there is a real need for fish to operate at depths up to 5000m and to be completely decoupled from the motion of the towing vessel, perhaps by utilising autopilots to control their attitude, lateral position and depth to within close limits.

Support for both parts of the research programme has been provided by the Marine Technology Directorate (MTD), the Department of Trade and Industry (DTI) and Plessey Marine. Present indications are that the second part of the programme will be succeeded by a further project which will be supported by equal contributions from the MTD and the Ministry of Defence. The first part of the programme which has led to the development of a swathe sounder, is now being examined actively for commercial exploitation by a number of companies.

For further information contact:

Professor H O Berktay
School of Physics
University of Bath
Claverton Down
Bath BA2 7AY
Tel: Bath (0225) 61244



A: 'Benchmark' sea bed area in Plymouth Harbour surveyed by a high line density echo sounder

B: The same area surveyed by the interferometric swathe sounder, 15 times faster

1984 Lord Brabazon Premium

The Institution of Electronic and Radio Engineers has awarded Dr J Dunlop and Mr C Stirling, Department of Electronic and Electrical Engineering, University of Strathclyde, the 1984 Lord Brabazon Premium for their paper on *Conduction current signalling in the vicinity of a subsea offshore structure.* The work leading to the paper, supported by SERC's Marine Technology Directorate within its 1981/83 overall programme, was in determination of the viability of using conduction current techniques for data transmission in the offshore platform environment.

The paper was considered to be the outstanding paper on a subject associated with aerospace, maritime or military systems published in the Institution's Journal in 1983.

Dr Dunlop is a lecturer at Strathclyde. Mr Stirling subsequently moved to Glasgow University to work on a SERC Small Business Teaching Company Scheme and is now a production engineer within the electronics industry.

Molecular electronics

The establishment of the Molecular Electronics Discussion Group (MEDG) in 1980 represented the first coordinated initiative by SERC to stimulate discussion and interest in basic research in molecular electronics – defined as the systematic exploitation of molecular materials in the field of electronics. Under the chairmanship of Professor Gareth Roberts FRS, Department of Applied Physics and Electronics, Durham University, the Group set up Working Parties on Langmuir-Blodgett (LB) Films, Metal Organic Chemical Vapour Deposition (MOCVD) and Self Organisation in Molecular Systems. Reports on the opportunities for fundamental and mission-oriented research in LB Films and MOCVD have been published (see below), and a report on Self Organisation in Molecular Systems will be published in the latter half of 1985. The MEDG also organised a series of workshops as a forum for discussion of all the various interests of SERC Committees and Directorates in the field of molecular electronics. These include *biosensors* (Biotechnology Directorate), *electroactive polymers* (Materials Committee: Engineering Board), and *chemical sensors* (Chemistry Committee: Science Board). Other related initiatives with potential impact, either currently active or under development, include *low dimensional structures* (Physics Committee: Science Board), *low dimensional devices* (Solid State Devices Sub-Committee: Engineering Board) and *optoelectronics* (Joint DTI/ Engineering Board Optoelectronics Research Scheme – JOERS).

Professor Gareth Roberts FRS

In its recent report to the Science and Engineering Boards, the MEDG recommended that it now be succeeded by an advisory group on molecular electronics which should monitor and aid the development of a strategy for molecular electronics research. The MEDG proposed that the multidisciplinary nature and the potential technological relevance of the subject underlined the value of coordinating the research effort required to maintain the current strong position of the UK. This proposal was welcomed by both the Boards, which have jointly appointed the new Molecular Electronics Advisory Group.

For further information contact Mr D M Schildt at SERC Central Office ext 2212. Further details on the molecular electronics initiative will appear in the next issue of the *SERC Bulletin*.

Some new publications from SERC

All publications described are available from the appropriate section of the SERC, free except where otherwise stated.

Biotechnology

The Biotechnology Directorate has recently issued a number of publications:

Biotechnology and British industry. This report, prepared by Dr Peter Dunnill and Dr Martin Rudd of the Department of Chemical and Biochemical Engineering, UCL, discusses the potential application of biotechnology across the entire range of British industry. Price £10.

The biotechnology brain drain and *Enabling manpower for biotechnology in the UK* These two reports have been prepared for the Directorate by the Institute of Manpower Studies, Sussex University. The former investigates the extent of, and reasons for, the movement of biotechnologists from the UK, and the second report assesses the future needs for trained biotechnologists in the UK.

Directory of research in biotechnology sets out the strategy of the Directorate and includes one-page descriptions of each of the 93 programmes supported.

Cell adhesion, prepared by Sir James Baddiley FRS, Cambridge University, discusses the importance of studies of cell adhesion to biotechnology and highlights areas where further research is required.

Biobulletin: the first issue of the Directorate's newsletter was produced in May 1984.

Copies of all these publications are available from Ms Jan Orme, Biotechnology Directorate, Central Office, Swindon, ext 2310.

Molecular electronics

Langmuir-Blodgett films: current status and prospects for further development: report of the Langmuir-Blodgett Working Party. Volume I: The report – describes the initiative and presents scientific overviews of the subject as well as conclusions and recommendations for future action. *Volume II: Annexes to the report* – provides a review of national and international research on LB films and summarises the workshops held.

Metal organic chemical vapour deposition: current UK status summarises the current research status and the future potential for the development and application of MOCVD.

Copies of both reports are available upon written request to the MEDG Secretariat, Room 0094 at SERC Central Office, Swindon.

Astronomy

Copies of the annual reports for the Astronomy I and Astronomy II Committees, both for the period 1 October 1982 - 30 September 1983, are available from the Committee Secretariat at SERC Central Office, Swindon, ext 2266.

Copies of the *Solar System Committee annual report 1 October 1982 to 30 September 1983* are available from the Committee Secretariat, SERC Central Office, Swindon, ext 2366.

Machines and power

Copies of the *Machines and Power Committee Annual report 1982-83* are available from the Committee Secretariat at SERC Central Office, Swindon, ext 2200.

Environment

Copies of the *Environment Committee report 1981-83* are available from the Committee Secretariat at SERC Central Office, Swindon, ext 2123.

Materials

Copies of the *Materials Committee Annual report 1982-83* are available from the Committee Secretariat at SERC Central Office, Swindon, ext 2277.

Precision forming

Casting Processes: Report of an industrial workshop on priorities for research and development. Copies are available from the Production Committee Secretariat, at SERC Central Office, Swindon, ext 2250.

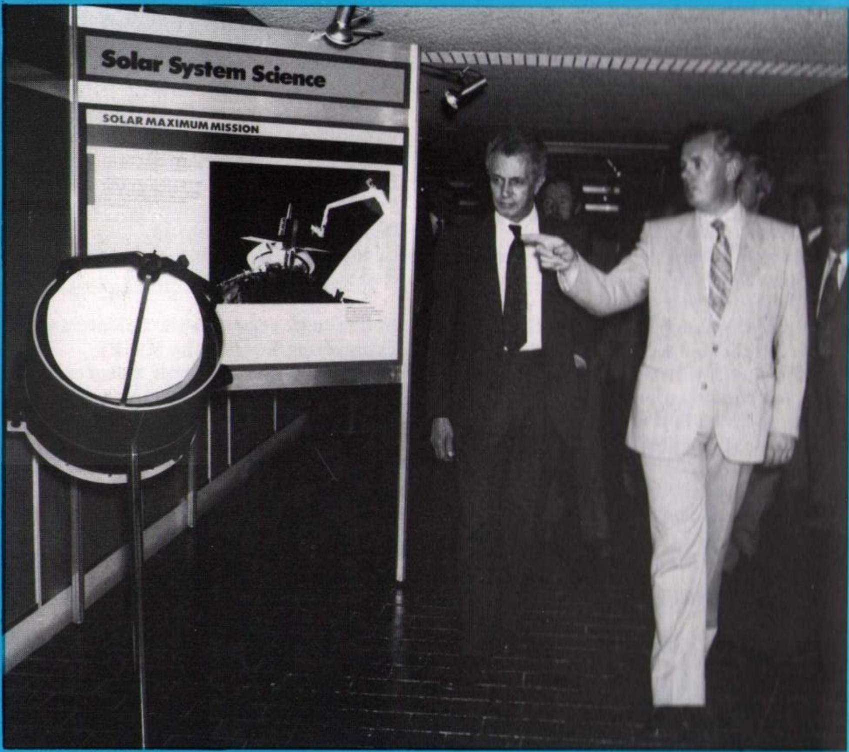
Engineering design

Report of the Engineering Design Working Party. Copies are available from Mr A Spurway at SERC Central Office, Swindon, ext 2102.

SERC on display

Above: the Rt Hon Sir Keith Joseph, MP, Secretary of State for Education and Science, visited the Council's exhibition on 17 July. Here he is seen discussing the nuclear physics exhibit with Professor Peter Kalmus (left) of Queen Mary College, London

Right: Sir Keith and Professor Kingman examine part of the astronomy display (a model of GIOTTO is in the foreground)



A major exhibition covering the broad range of activities in science and engineering supported by SERC was mounted at the Council's Swindon office in July. The display is designed for use as a touring exhibition and will be on show at various locations around the UK during 1985. It is divided into four main areas of research.

Astronomy, space and radio

Displays and models cover spaceborne activities (such as last year's highly successful Infrared Astronomical Satellite and the current x-ray astronomy satellite, EXOSAT); radio research (MERLIN, the network of radio telescopes centred at Jodrell Bank); studies of the Earth's environment (including AMPTE, launched in August); and Solar System science (such as the GIOTTO spacecraft due to intercept Halley's Comet in 1986).

Dr Geoff Manning (centre), Director of the Rutherford Appleton Laboratory (RAL), describes the Spallation Neutron Source to Sir Keith and SERC Chairman Professor John Kingman FRS

Engineering

Projects from all the Directorates are featured – application of computers to manufacturing engineering, biotechnology, information technology, marine technology, polymer engineering and the Teaching Company Scheme – as well as recent work on grinding technology and the Continuing Education project with the Open University.

Science

The wide range of research disciplines in this category is illustrated by exhibits on lasers, synchrotron radiation, neutron beam research (including the Spallation Neutron Source nearing completion at Rutherford Appleton Laboratory) and the special programmes in low dimensional structures, protein engineering and chemical sensors.

Nuclear physics

Nuclear structure research is illustrated by an account of the tandem Van de Graaff accelerator at Daresbury Laboratory. The particle physics display highlights the discovery of the new fundamental particles, the W and Z bosons, at the CERN laboratory in Geneva.