AD-A167 501 EUROPEAN SCIENCE NOTES VOLUME 40 NUMBER 6(U) OFFICE OF 1/1
NAVAL RESEARCH LONDON (ENGLAND) C J FOX JUN 86
ESN-40-6

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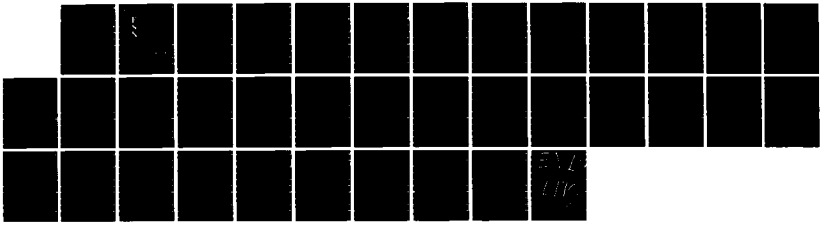

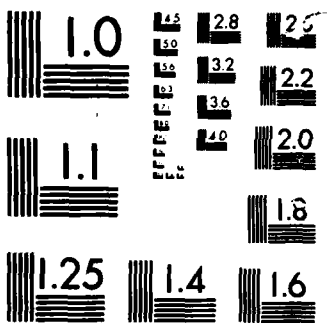

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U.S. Office of Naval Research, London
Vol 40 No. 6/June 1986

(12)

European Science Notes

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD-A167501

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 40-6	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION US Office of Naval Research Branch Office, London 6b. OFFICE SYMBOL (If applicable) ONRL	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Box 39 FPO, NY 09510	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

European Science Notes--(UNCLASSIFIED)

12. PERSONAL AUTHOR(S)
C.J. Fox, Editor

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Monthly	FROM _____ TO _____	June 1986	28

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

European Science Notes (ESN) is a monthly publication with brief articles on recent developments in European scientific research. The publication is not intended to be part of the scientific literature. The value of ESN articles to Americans is to call attention to current developments in European science and technology and to the institutions and people responsible for these efforts. ESN authors are primarily ONRL staff members. Occasionally articles are prepared by or in cooperation with staff members of the USAF European Office of Aerospace Research and Development or the US Army Research, Development and Standardization Group. Qualified US scientists travelling in Europe may also be invited to write an ESN article.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION	
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL C.J. Fox	22b. TELEPHONE (Include Area Code) (44-1) 409-4340	22c. OFFICE SYMBOL 11

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

European Science Notes

US Office of Naval Research, London

Commanding Officer ..... CAPT M.A. Howard, USN
Scientific Director ..... David L. Venezky
Editor ..... C.J. Fox

June 1986
Volume 40
Number 6

Acoustics

The institute conducts a wide range of research projects in acoustics, vibration, and signal processing. Most of the current acoustics research concerns audiology, sound propagation in air, and acoustic interaction with plates and shells. Underwater acoustics is a relatively new medium of investigation, but this line of research is expected to grow.

Biological Sciences

This article surveys the research by TNO institutes in biotechnology, membrane technology, recombinant DNA, immunology, ionizing radiation and cancer, and toxicological food concerns.

The Center of Immunology is working in applied immunology, cellular physiology, immunology and the nervous system, the structure and genetics of immunoglobulins, the functions and membrane structure of T cells, and the structure and expression of genes encoding the antigens of histocompatibility (HLA of Class I) in man. Although this center is relatively new, much of this research is top level.

Material Sciences

This article completes *ESN*'s review of the major composite research programs in French Universities. Surveyed here is the single-fiber and fiber-reinforced plastics work at the Centre des Matériaux and the carbon-fiber-reinforced plastics (CFRP) research at the Université de Technologie de Compiègne. With the capability of preforming 3-dimensional weaving with CFRP fibers and the ability to produce carbon fibers, France has become a formidable competitor in composite materials.

Physics

News and Notes

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European Science Notes is a Class I Periodical prepared and distributed by the Office of Naval Research, London, in accordance with NAVSO P-35.

Acoustics

ACOUSTICS RESEARCH AT THE INSTITUTE FOR SOUND AND VIBRATION RESEARCH, UNIVERSITY OF SOUTHAMPTON, UK

by J. Thomas Warfield. Dr. Warfield is the Liaison Scientist for Underwater Acoustics in Europe and the Middle East for the London Branch of the Office of Naval Research. He is on assignment here from the Office of Naval Research, Arlington Virginia, where he is Deputy Program Manager for the Undersea Technology Project.

Background

The Institute for Sound and Vibration Research (ISVR) was founded in 1963 by Professor E.J. Richards, who at that time was Head of the Aeronautics Department at Southampton University. At its founding, ISVR was mainly a postgraduate institute set up for advanced research into the many new problems of acoustic noise and vibration analysis that were cropping up in connection with other research in aeronautics and vibration control. Gradually, regular graduate and undergraduate courses began to be given, then whole curricula; finally, degrees came to be granted.

Today, ISVR has full departmental status within the Faculty of Engineering. At present there are over 60 undergraduate students, with a yearly intake quota of 18. They work towards a B.S. in Engineering Acoustics and Vibration in a three-year program, or a B.S. with Diploma of Engineering in a four-year program. There are three M.S. and Diploma programs: sound and vibration studies, automotive engine and vehicle design technology, and audiology. These programs produce between 35 and 40 graduates per year. Thirteen Ph.D. degrees were awarded in 1983-84 academic year.

The academic staff is headed by Professor Robert G. White, who is Director of ISVR and Professor of Vibration Studies. There are five other professors, three readers, four senior lecturers, eleven lecturers, and three research professors.

There are now four research groups in ISVR: Fluid Dynamics and Acoustics, Audiology and Human Effects, Structures and Machinery, and Signal Processing and Control. For those already acquainted with ISVR, the former Automotive Engineering Group has recently been merged into the Structures and Machinery Group. The Signal Processing and Control Group derives from the old Data Analysis Group, which in turn was upgraded to research group status in 1983 from its previous designation as the Data Analysis Centre. In addition, ISVR operates a Wolfson Unit for Noise and Vibration Control.

I recently spent a day at ISVR, where I talked with some of the researchers about their projects in acoustics and signal processing. My hosts during this visit were Dr. Michael Fisher, Head, Fluid Dynamics and Acoustics Group and Dr. Joseph Hammond, Head, Signal Processing and Control Group.

The Fluid Dynamics and Acoustics Group

Underwater Acoustics is a relatively new area of acoustics for ISVR. The interest stems largely from recent contractual support by the Admiralty. There are four projects to describe.

Research is currently underway concerning underwater propeller noise. This is sponsored by Admiralty Research Establishment (ARE), Teddington. The work consists of some theoretical noise models and source level prediction, with emphasis on experimental work done by ISVR researchers in the 12-inch water tunnel at ARE Teddington. ISVR helped ARE to solve the problem of high tunnel background noise obscuring the propeller noise signal. (The background noise was traced to the propeller drive housing, and was reduced to acceptable levels by designing and installing a new housing.) The tunnel has now been calibrated acoustically, and a test conducted to assess the effects of blade tip clearance and blade skew on broadband propeller noise (Glegg, 1984). Admiralty support for this work has recently been extended and increased.

Another underwater acoustics effort was the development of a shallow-water acoustics propagation model based on finite element methods. A major achievement of this effort was the inclusion of shear waves in a solid bottom (in contrast to liquid) underlying the water channel. The code is, however, limited at present to two-dimensional problems. Plans by the sponsor, Royal Aircraft Establishment (RAE), Farnborough, to extend the code to three-dimensional problems are in limbo at the moment, as the developer of the code, P.M.W. Pack, has left ISVR for a position with Rolls-Royce. Thus, the future of this thrust is not clear; it may well remain dormant until another qualified and interested student appears or is trained at ISVR. Meanwhile, the two-dimensional code has been implemented on the Cray computer at RAE, and tested successfully against

other propagation programs already in place there.

A third underwater acoustics effort, also supported by ARE Teddington, concerns the development at ISVR of a facility and methodology for measuring the acoustic reflection and transmission characteristics of flat panels in water. A water tank has been constructed for these studies. It has a hydrophone mounted on a computer-controlled positioning arm, with a broadband spark source independently positioned by a separate arm. Measurements can be made for any three-dimensional source-receiver geometry relative to the plate, including receiver locations on the same side or opposite side of the panel as the source. Work on this project began about a year ago, and efforts to date have concentrated on making the water tank facility, including data processing, operational. This is largely complete now, and real data are beginning to be collected and analyzed. Steel plates are being used at this time in order to validate tank data with theory. I would anticipate that future work will investigate more complicated panels; e.g., coated plates, ribbed plates, composite plates, etc. This work is being done by Mr. Jeremy Nedwell under the direction of Dr. F. Fahy.

Also part of this thrust is work being done by Dr. Roger Pinnington to predict the vibration power transferred into a ship's hull by machinery located in the interior of the vessel. His approach is to obtain the averaged frequency response of simple structures (e.g., beams, plates) to various forcing functions, and then to approximate the ship structure with a large number of such shapes. This work has begun just recently.

ISVR also acts as a consultant to Dr. David Blackstock, Applied Research Laboratories, University of Texas at Austin, on his ONR contract, Nonlinear Effects in Long Range Propagation (Morfey, 1984). Dr. Morfey of ISVR has been a consultant to Dr. Blackstock on this work since 1983. Unfortunately, Dr. Morfey was not available the day I visited ISVR.

There are many activities within the Fluid Dynamics and Acoustics Group other than underwater acoustics; in fact, underwater acoustics is only a small part of the total group effort. One of these efforts that may become transferable to underwater acoustics concerns active control of aircraft propeller noise within the crew cabin. Theoretical work to date has produced a practical technique for evaluating the acoustic performance of active control systems, and this has led to results on the optimal locations of sources and sensors. Related work in signal processing has made progress in developing fast multivariable adaptive algorithms for active control of quasi-periodic sound fields. Research is also being done on active control of random noise in ducts, and a control system capable of producing substantial downstream reduction has been developed (Elliott and Nelson, 1984). Robust high-intensity sound sources are under development at ISVR for this application.

ISVR has long had strong interests in aircraft noise, and this continues today. Dr. Fisher, head of the group, is the present Rolls-Royce Reader at ISVR, and much of the research in aircraft noise is sponsored by Rolls-Royce or RAE. These efforts include development of a computer program for prediction of jet noise in flight; acoustic transmission through jet flows; transient excitation of a jet at high acoustic intensities; excitation and fatigue of aircraft structures by the high pressure, high-exit-velocity jet engines envisioned for future military aircraft; and a revival of interest in propeller noise in anticipation of a return to this type of propulsion for future short-haul aircraft.

The Department of Energy funds the Wind Energy Group (WEG), located elsewhere within the Faculty of Engineering at Southampton University, for research on extraction of energy by wind turbines. ISVR collaborates with WEG on the noise of these turbines. ISVR has recently completed development of a technique for prediction of the near-field noise of wind turbines, including the effects of atmospheric turbulence and acoustic scattering by the turbine support tower. This model was successfully compared with data taken on the 20-m-diameter wind turbine on the Orkney Islands.

A recently completed three-year study on the design of quiet laminar flow fans led to a design approach for these fans which eliminates the remaining dominant tonal in the noise spectrum without degrading fan performance. These fans operate by generating laminar flow between closely spaced discs. They are from 5 to 10 dB(A) quieter than centrifugal fans of the same performance, but suffer from a noise tonal at the "bolt-passing" frequency. This tonal was found to be generated by the interaction of the bolts supporting the discs with the cutoff in the volute. A theoretically based method for the performance of these fans was developed (Merry and Glegg, 1984), which, together with

extensive testing, led to the simple design approach of tapering the discs towards their outer edge.

Other acoustics projects include studies on the interaction between the acoustics of the speech generation process in humans and the digital signal processing used to analyze and synthesize speech pressure waveforms (done for IBM), the use of the cross-spectral method of sound intensity measurements to evaluate sound power distribution in branched ducts, and the technique of spatial wave field transformation to evaluate flexural mode dispersion characteristics of oil-filled steel pipes.

In vibration analysis, the lightweight helmet design project aims to develop models of the human head as a fluid-filled structure. The goal is to prevent head injury under impact loading.

The Wolfson Unit for Noise and Vibration Control

Wolfson Units are to be found throughout the British university system, covering a wide variety of technical subjects. They are fostered by the Wolfson Foundation, which was established in the 1950's with a trust fund left by the late Sir Isaac Wolfson. The foundation gives start-up grants to fledgling consultancy units in universities for a period of 3 to 5 years. Within that time, a new Wolfson Unit is expected to become commercially self-sufficient, or else lose its affiliation with the foundation. (The failure rate, I am told, is very low.)

The Wolfson Unit for Noise and Vibration Control (WUNVC) at ISVR operates, in effect, as a commercial consulting firm in noise and vibration, with a business volume of nearly £300,000 (~$450,000) per year. The staff is academically related, in that they receive comparable salary and benefits, and enjoy the same rights and privileges as university faculty, except for tenure. WUNVC was established in 1968.

The bulk of the work done by WUNVC is state-of-the-art applications; e.g., industrial noise surveys, machinery noise evaluations, and environmental noise control. Very little of their work, less than 10 percent, is in the marine world. Their strong points are that they offer a full-time qualified staff of seven consulting engineers with close ties to ISVR and other departments or Wolfson Units (there are 14 other Wolfson Units in Southampton University alone), that they are completely independent and objective (no profit-making motive), and that they are highly flexible and available for quick-response tasking.

In addition, they can and do prepare and present evidence for public enquiries or cases brought in courts of law. They prepare and conduct specialized short courses on noise and vibration control for industry or government. WUNVC has an international register of clients, including US firms such as Dow Chemical, IBM, Bechtel International, and several major oil firms.

The Signal Processing and Control Group

This group has evolved rapidly over the past eight years. In 1978, its forerunner, the Data Analysis Centre, was solely a computer service group to ISVR, with neither academic staff nor research students. Beginning in 1978, academic staff were added, undergraduate and postgraduate courses begun, an annual short course initiated, and research effort developed for time series signal processing. Also, a Shock Analysis Laboratory was created in the early 1980's, with Ministry of Defence funding, to study pyrotechnically induced shock. The growth of the Data Analysis Centre, and recognition of the role of signal processing in sound and vibration research, led to its upgrading to research group status in May 1982.

In May 1985, the group was expanded by the inward transfer of two lecturers together with their research teams, and the group was renamed the Signal Processing and Control Group to indicate its expanded scope. A further lecturer was appointed to the group in October 1985, with funding support by ARE. Dr. Joseph Hammond took over as group chairman in September 1985, having joined as the first lecturer in time series analysis in 1978. Today the group has five full-time professionals and 32 students.

The group continues to operate a large computer facility as a significant part of its overall activities. In addition to providing computing services to ISVR and the University, personnel at this facility are also involved in software and hardware development. Three VAX 11/750 computers are now operating as an integrated facility. Two of these are used primarily for teaching computer-aided design to all engineering students, and for research training for design calculations. There are approximately 50 terminals connected, with comprehensive software support available both in-house and on license from software houses. During 1985 the scale of the computer service tripled.

The research interests of the group are diverse, including signal modeling, signal enhancement and deconvolution,

nonlinear systems and simulation, speech studies, shock phenomena, and, of course, the now nearly obligatory subject of expert systems. In signal modeling, nonstationary stochastic processes are currently being investigated. One example of this effort that is relevant to underwater acoustics is the prediction of time-frequency spectra of acoustic signals emitted by a moving source and received on a fixed sensor (Hammond and Harrison, 1984; Hammond and Harrison, 1984; Hammond, 1985). I would hope that this work will be expanded to include an independently moving receiver as well. Another example is the propagation of acoustic transients.

In the area of signal enhancement and deconvolution, work has been done on dereverberation techniques for improved speech intelligibility in reverberant enclosures (Mourjopoulos, 1985; Mourjopoulis, Clarkson, and Hammond, 1984; Clarkson and Hammond, 1985). This work to date has been formulated as a deconvolution problem, in which the reverberant field is a sum of time-delayed replicas of the emitted signal. I mentioned to Dr. Hammond that the ocean reverberation problem, in which the reverberant field also contains frequency shifted or smeared components resulting from time-compressed or time-expanded echoes from moving reflectors, is one of interest at present. This problem could tie in nicely with their work on moving sources.

A newly developing interest is in adaptive processing for signal shaping to compensate for system interaction effects or poor transducer characteristics (Hammond and Davies, 1985; Clarkson and Hammond, 1985). This topic is of considerable interest to the underwater acoustics community, and Dr. Hammond and his colleague within the Group, Dr. Peter Clarkson, have been sponsored to visit several research groups in the US under the ONR London Visiting Scientist Program.

In addition to research and regular academic teaching, the group is active in running various short courses. "Applied Digital Signal Processing" is given annually by Dr. Hammond, as is "Data Analysis and Dynamic System Modeling." Of particular interest to the underwater acoustics community is "Adaptive Signal Processing, with Applications to Underwater Systems," to be given in July at Southampton University by Drs. Clarkson and Hammond (see ONR London *Science Newsbrief* 4-5 for details).

Funding

ISVR draws its financial support from five basic categories, as do all higher academic institutions in the UK. The ISVR annual report for the fiscal year ending March 1985 provides the funding support data shown below. The value of the pound on 1 March 1984 was $1.47.

	(in £000)
University Grants Council	597
Research Council Grants	336
Government Departments	889
Industry	164
Consulting Clients	802
TOTAL	2788

The nationwide University Grants Council provides funds for plant expenses and other regular costs. Annual proposals for research are submitted, reviewed, and approved (or not) by a group of nationwide research councils. For ISVR, the most important is the Science and Engineering Research Council. These grants pay salary for researchers plus equipment and experiment costs. Contract research is conducted for various government departments, including Ministry of Defense, and six others. ISVR also conducts contract research for an international clientele of some 20 or more firms, plus another dozen or so nonprofit organizations or foreign agencies. Consultancy Units are a significant source of income for ISVR, and there are three others in addition to the WUNVC described herein. The level of support for ISVR has been growing at about 9 percent over the past five years, a figure at or perhaps a little above the inflation rate for this period.

Concluding Remarks

On the whole, ISVR seems well diversified both technically and fiscally. Although there are some senior staff retirements now that the organization is well into its third decade, newer appointees appear to be taking up the responsibilities of technical leadership quite well. ISVR remains a major academic center for sound and vibration analysis.

Computer-aided data reduction and signal processing research have become firmly established as main stream efforts over the past few years, supplementing the traditional approaches of analysis and experimentation. To my mind, an excellent example of the interplay now possible between these three approaches is the ISVR research on active noise control. Such problems would have been unmanageable a decade ago.

Most of the acoustics research at ISVR is concerned with propagation in

air or in plates and shells (pipes). Underwater acoustics is still very much a new medium for them, especially ocean acoustics. However, this line of investigation can be expected to grow because of increased sponsorship by the Admiralty, and ISVR could in time become a center of excellence in this field. Should major growth in this field take place at ISVR, I would anticipate its being centered on the signal processing mathematicians rather than the classical acoustical physicists. I say this because there is already a reservoir of signal processing talent at ISVR, just waiting to be tapped by the Admiralty, whereas there are not many senior researchers specializing or even keenly interested in ocean acoustics, as far as I can determine. However, there is a strong capability in underwater structural acoustics--i.e., the interaction between waterborne sound and plate and shell vibrations.

It will be interesting to watch the evolution of ISVR in underwater acoustics over the next several years. I would encourage US researchers in this field to get to know ISVR better, as ISVR has potential to contribute to advancement of the science.

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3/25/86

Biological Sciences

BIOLOGICAL SCIENCE UNDER TNO--THE NETHERLANDS ORGANIZATION FOR APPLIED SCIENTIFIC RESEARCH

by Claire F. Tomely-Neurath. Dr. Tomely-Neurath is the Liaison Scientist for Biochemistry, Neurosciences, and Molecular Biology in Europe and the Middle East for the Office of Naval Research's London Branch Office. She is on leave until July 1986 from her position as Director of Research, the Queen's Medical Center, Honolulu, Hawaii, and Professor of Biochemistry, University of Hawaii School of Medicine.

TNO was established by law in 1930 with the aim of ensuring that applied scientific research is put at the service of the community in the most efficient manner possible. TNO is a fully

independent, nonprofit research organization with a staff of about 5000 and an annual research volume of approximately F1560 million (~$220 million). In the past year, TNO executed some 20,000 contract research and development projects, commissioned by about 6,000 Dutch and foreign clients. TNO's major target group is trade and industry, the small and medium-sized firms in particular. Other important target groups are: central and local authorities, private organizations, and individuals. In some cases, collective research is carried out for specific branches of industry. (For detailed information on TNO's organization, policy, and funding see *ESN* 38-8:438-440 [1984].)

TNO's main fields of interest are industrial technology, energy, the environment, food and nutrition, health, and defense. In this connection, TNO's activities can be subdivided into three major categories: explorative research, applied research, and the transfer of know-how. The TNO consists of eight divisions (each with its own special field of research) comprising about 35 institutes.

The quality of research carried out at the various TNO institutes is excellent. In many instances, the research is at the basic level although areas of investigation which are emphasized are based on potential practical application. It is beyond the scope of this report to describe all the research at TNO. Thus, only selected areas of investigation are presented in the following section.

Biotechnology

In its research into the possibilities of extending the active life of enzymes, the Division of Technology for Society has achieved some interesting results from the application of amylase derivatives as stabilizing carriers for the immobilization of enzymes. The specific surface area of metastable amylase proved to be quite large, and the preparations obtained by means of complexing were 100 percent soluble in cold water. By encapsulating glucose isomerase in amulose-ether gels with an amylase-ether concentration of more than 35 to 40 percent, a half-life extension with a factor of 2.5 was obtained, compared with concentrations lower than 35 percent. A problem which remains is the presence of amylase in the solution of the glucoseisomerase preparation which decreases the mechanical stability of the catalyst particles. Work on the solution to this problem is continuing. By making succinate and, subsequently, cross-linking alpha-chymotrypsin using a specific method, an increase in thermal stability was achieved which, compared with the natural enzyme, is better by a factor of 20 than reported in the literature.

A number of models have been developed for describing the mass transfer processes in immobilized enzymes. These are now being tested experimentally with invertase immobilized on alginate spheres.

In order to obtain greater efficiency of the Penicillin/Acylase/Urease systems, experiments were carried out to optimize the quantities of enzymes and substances. It was found that the method of internal pH control leads to a quicker and higher conversion of penicillin than does the method which makes use of an external buffer.

Another development, and one which has equally interesting industrial potential, is the catalysis of chemically difficult esterification reactions. It proved possible to demonstrate that with the right choice of immobilization of the enzyme carboxylesterase and the other reaction conditions, methanol could be esterified to methyl acetate. This technique is used to prepare interesting flavor and odor compounds in a natural way. Initial experiments with so-called "reverse micelles" indicated that this system can also be useful for two-phase reactions. Cholesterol oxidase, for example, was found to have a much higher activity than claimed by the manufacturer. These results would appear to be of importance for industrial application. For research into a better preparation method for technical alcohol, a modified upflow fermenter was constructed in which, among other things, there was improved sedimentation of the floculated micro-organism. An analysis and control program was developed for research with this fermenter whereby sucrose, glucose, fructose, and ethanol concentrations can be followed simultaneously as a function of time. Experiments with a special strain of *Zymomonas mobilis* gave a conversion of 99 percent at 100 g/l glucose and a 7 percent higher yield than with the usual strain *Z. mobilis*.

Membrane Technology

In support of a project for the enzymatic hydrolysis of paper, studies were carried out to concentrate the dilute glucose solutions thus obtained. The method was one developed and patented by TNO, in which hyperfiltration membranes with both high and low retention are used. After experimental research on model solutions, a computer simulation program was developed to determine the optimum configuration at

minimum energy consumption. Compared with multieffect evaporation, energy consumption which is lower by a factor of 8 appeared to be possible. The experimental results were in accordance with the theoretical basis. However, a number of practical problems had to be solved, since in processing paper hydrolysate a number of other substances are present which have a greater retention than glucose. Work is continuing on a solution to these problems. In the continuous production of ethanol in a fermenter using *Z. mobilis*, one of the problems is how ethanol can be separated and glucose can be retained. With the choice of the right membrane, it proved possible to achieve this goal and to control the mass balances.

Recombinant DNA Research

Research in this area is done by a number of institutes. Originally, this work was carried out only in the Medical Biological Laboratory, but now several institutes (the Radiobiological Institute, the Institute for Experimental Gerontology, the Primate Center, and the Gaubius Institute for Cardiovascular Diseases) have topics in their research program which require the use of recombinant DNA (rDNA) techniques. A great deal of effort is devoted to the development of vaccines. The Medical Biological Laboratory has cloned so-called "auxiliary proteins" which are of importance for the eventual preparation of a polio vaccine. In collaboration with the Biogen Company, the Primate Center has tested the first active recombinant DNA hepatitis B vaccine in chimpanzees. The other forms of hepatitis (non A, non B, and delta) are also being studied.

The other DNA research currently being undertaken is primarily concerned with the area of genotoxicity (damage caused to DNA by environmental factors) and the possibilities of repairing damage to the DNA which has already occurred. In the area of host-vector systems, progress has been made with *Aspergillus*. This fundamental research is essential in order to achieve the optimum production of rDNA products.

Immunology

Immunological research is carried out by a number of institutes within the Division for Health Research. The work is aimed at solving both immunological and nonimmunological problems using immunological techniques. The wide-ranging nature of this research is illustrated by the number of different applications of monoclonal antibodies (Mabs) in the program of the various institutes. In the Institute for Experimental Gerontology, Mabs are produced in connection with the early detection of tumors and also for the detection of small quantities of bacterial toxins in food.

In the Primate Center, Mabs are produced as tracers against certain subclasses of white blood corpuscles which are a factor in the rejection of foreign tissue. In the Gaubius Institute for Cardiovascular Diseases, Mabs are produced against hormones and apoproteins for use in basic research studies and in assay procedures.

The organ and bone marrow transplant research within the so-called "REP" group (Radiobiological Institute, Institute for Experimental Gerontology, and Primate Center) has acquired a considerable reputation in the field of preclinical research (in rhesus monkeys). In this work, Mabs play an important part, both diagnostically and therapeutically. It has been shown that certain Mabs from mice, directed against human tissue determinants, can be used to prevent the impending rejection of a kidney transplant. The immunological research is also carried out in conjunction with genetic research in view of the hereditary transmission of certain tissue characteristics which can predispose a person to disease. In this context, work is being carried out with rhesus monkeys using model systems for rheumatism, multiple sclerosis, and AIDS.

The Central Institute for the Breeding of Laboratory Animals supplies laboratory animals to customers outside TNO (industry, universities, and other institutions). The center also produces special laboratory animals for specific purposes closely linked to the program of various institutes. In the field of the breeding and maintenance of rhesus monkeys and chimpanzees, the TNO Primate Center occupies a unique position in Europe. There is a clear tendency to concentrate research on nonhuman primates where the most expertise is available. This means that clients often subcontract their work to the Primate Center. An isolation building developed by TNO is available for carrying out tests under conditions of strict isolation. In this building, work on primates involving viruses and other potentially dangerous material can be carried out under safe conditions.

Ionizing Radiation and Cancer

The Radiobiological Institute's research program is concerned with the role of ionizing radiation in the genesis and also in the treatment of cancer. Particular attention is paid to the possible effects of regular exposure to

relatively small amounts of radiation. Among the methods used are tissue-culture techniques which are extremely useful in investigations into the occurrence of malignant changes in cells after exposure to radiation. Epidemiological data from fundamental research that relates to the occurrence of cancer in humans after exposure to relatively high doses of ionizing radiation are used to calculate the risks of the occurrence of cancer at low doses.

The Radiobiological Institute also does a great deal of fundamental research into the treatment of cancer. Because of the institute's close links with the Rotterdam Comprehensive Cancer Center, Dijkzigt Hospital, and the Rotterdam Radiotherapeutic Institute, the results obtained from the research are quickly available to the medical specialists concerned. The institute is also taking part in a combined experimental and clinical research program in which the use of heat in combination with radiation is studied in connection with the treatment of certain types of cancer. One of the Radiobiological Institute's important tasks is the preparation of a cancer registration system for the entire Rotterdam region.

In the treatment of a number of malignant blood diseases (such as leukemia) the use of bone marrow transplants is part of the therapy of choice. For this purpose, it is important that the parent cell of the bone marrow is isolated as completely as possible. Using advanced cell separation equipment it has proved possible to identify this cell. It is now possible to study the role of the parent cell in leukemia caused by radiation.

Rehabilitation Technology

Concern for the situation of disabled people in the Netherlands has grown considerably during the past few years. As a result, TNO has devoted more attention to research which benefits disabled people and to work on rehabilitation, particularly in terms of expansion and coordination of research. In this context, work carried out by the Institute of Medical Physics has been used as a foundation for further research. There are now 10 TNO institutes involved in rehabilitation research.

Nutrition and Food

Virtually all TNO research in the area of nutrition and food is carried out by the Division for Nutrition and Food Research. Among the important aspects of the division's work on basic and luxury foodstuffs are quality, hygiene, toxicology, and technology.

Nutrition Research

An important project carried out by the Institute of Toxicology and Nutrition concerns the setting up of a nationwide system for the continuous monitoring of the nutritional status and dietary pattern of various sections of the Dutch population. In the initial system, attention was concentrated on the elderly. Blood samples are analyzed for, among other things, vitamin B6 and components which are a measure of iron intake because a preliminary study showed that the blood iron level and vitamin B6 level were significantly lower in the elderly as compared with younger people.

Toxicological Food Research

There are numerous indications that nutrition could play a part in the genesis, course, or treatment of a number of diseases, including cancer. Studies have also shown that nutrition can have an effect on the hormonal system. Therefore, the institute set up a study into the effects which fat, protein, carbohydrate, etc. have, via the hormonal system, on two of the most common forms of cancer; i.e., breast cancer and cancer of the prostate. Data on hormonal reactions to nutrition are obtained by determining androgens, estrogens, and prolactin in blood plasma, and androgen and estrogen receptors in mammary and uterine tissue of rats. A start has also been made on a large-scale experiment in which the effect of the amounts of fat and linoleic acid on existing carcinogen-induced tumors is being investigated. A series of different feed compositions is used so that interactions between the two elements can also be observed.

Some nutritionists have reported that lactobacilli in foods such as yogurt, cheese, sausage, and sauerkraut provide protection against cancer of the intestine. This was investigated in rats by researchers at the Institute of Toxicology and Nutrition. The production of glycocholic acids, the activity of certain enzymes and the bacterial composition of the feces--factors which play a part in the genesis of intestinal cancer--did not show any significant differences in the test group. However, further research is being carried out to find out whether the incidence of induced tumors is affected by the diet.

Food hygiene, food analysis, and technology are additional areas of research by the TNO Institute of Toxicology and Nutrition.

Conclusion

TNO, The Netherland Organization for Applied Scientific Research set up

by the Dutch government, provides a means of transferring research know-how to industry and government agencies quickly and efficiently. The biological research carried out by the institutes of the TNO organization is of high quality both at the basic and applied levels.

3/19/86

CENTER OF IMMUNOLOGY, MARSEILLE-LUMINY, FRANCE

by Claire E. Zomzely-Neurath.

Introduction

The Center of Immunology of Marseille was created following an agreement between the two French governmental research agencies, Institut National de la Santé et de la Recherche Médicale (INSERM) and Centre National de la Recherche Scientifique (CNRS). The center was opened in September 1976 and represents the first Institute of Immunology built in France.

The center's two buildings, one built by INSERM (1976) and the other by CNRS (1978-80) are located on the University Campus of Luminy (University of Aix-Marseille II) between Marseille and Cassis on the Mediterranean Coast. Dr. C. Mawas is the present director.

The staff of the Institute was initially constituted from the voluntary regrouping of scientists from various parts of France and from foreign countries. The staff is continually growing and now consists of more than 120 persons including 80 scientists distributed into 12 research teams.

The organization of the Center of Immunology deserves special mention because some features are not commonly encountered in French Research Institutes. The director and deputy director are nominated for a maximum of four consecutive years. The composition of the research teams, as well as their heads, may be frequently changed; team size is limited to a few permanent members. The presence of foreign postdoctoral and visiting scientists is deliberately favored and, for this purpose, vacant, equipped laboratories are made available permanently. The local organization favors the coordination of research activities, and collaborative projects between members are actively encouraged. This constitutes an interesting potential due to the complementary skills provided by scientists and technicians in various fields of immunology. In addition, immunology courses common to medicine and science are organized at the graduate (3rd cycle) and postdoctoral level with a major part of the teaching done by the research workers of the institute.

The installation in surrounding hospitals of several laboratories associated with the Center of Immunology has encouraged the development of medical applications. These are: Research Group in The Immunology and Pharmacology of Anti-Cancer Drugs (GRIPAC); Laboratory of Histocompatability of the Center for Blood Transfusion; Transplantation Unit of Moelle Osseuse; Laboratory of Genetic Recombination *in vitro* of Luminy and Immunotech.

The objective of GRIPAC is to develop, in a clinical environment, the study of the pharmokinetics of anticancer drugs using immunoassay techniques developed at the Center of Immunology and to allow the benefits of fundamental research to be passed on to patients.

Immunotech, an organization for commercial development of INSERM in the sphere of immunology, has been located at Luminy since 1982. It is concerned with the industrial extension of research in immunology and, in particular, with applications of monoclonal antibodies. It is allied with the Center of Immunology through a scientific and technical assistance arrangement with INSERM. The research team is composed of specialists in tissue culture, hybridoma technology, and diverse fields of biochemistry. The research program deals with traditional applications of immunology (immunoassay of hormones, identification of viruses) as well as novel applications deriving from monoclonal antibody technology: immunopurification of active components of drugs for the pharmaceutical industry, reagents for cytofluorography and cell sorting, and techniques for purification of lymphocytes for use in clinical therapy. More than 20 products are under processing for commercialization.

The general objectives of the research carried out at the Center of Immunology is the analysis of the mechanisms of immune reaction and integrating cellular, genetic, and molecular aspects. Objectives in basic research are combined with objectives for applications of immunology. Programs in research on the major histocompatibility complex, the functions of T cells, and immunoglobulins have been greatly influenced by methods developed by molecular genetics and by the use of cloned cells. However, research on cellular functions is also emphasized by most groups. In

1984, two new groups, one involved with the molecular biology of differentiation antigens, the other interested in immunoparasitology, were installed at the Center of Immunology.

The research activities of the scientists at the Center of Immunology are described briefly in the following section.

Research Programs

The Structure and the Expression of Genes Encoding the Antigens of Histocompatability (HLA of Class I) in Man. The methods of molecular biology have made it possible to study the structural and functional analysis of genes of the major histocompatibility complex (MHC) which plays a central role in immune responses and reactions of graft rejection. The effort of many groups at the Center of Immunology is concentrated in the area of the genes encoding the classic histocompatibility antigens (called Class I antigen in the human [HL A-A, B, and C antigens]). The first complete sequence of a human HLA Class I gene was determined by research groups at the center. The isolation of other cloned genes, the study of their structure, and their expression in mouse cells by these researchers has considerably increased our knowledge of these genes.

The Role of Products of MHC in the Activation and the Functions of T Cells. It is clear that the histocompatibility antigens encoded by the MHC play a major role in the induction and development of immunologic reactions, but the precise mechanism of their action remains to be established. It is by investigation of the functions and the activation of immunologically competent T cells that their mode of action is best studied. The approach of the researchers at the center has been based on the use of lines of functional T cells cloned in culture, and on the knowledge acquired during the past few years on the genetics and the seriology of histocompatibility antigens. In the mouse, the I-A^k antigens have been defined seriologically and functionally in a very precise way using 60 Mabs with well-defined specificity against I-A and I-E. In man, C. Mawas and his group have obtained a large panel of typed cells from donors and from informative families which has permitted the genetic analysis of the HLA-D region and the definition of a new locus (HLA-SB). The availability of monoclonal anti-HLA-D antibodies in conjunction with considerable experience in the culture of functional T cells has made it possible to study interactions between HLA-D antigens and T cells.

The study of the interactions between alloreactive human T cell clones and human HLA Class II histocompatibility antigens has been performed with a series of Mabs with well defined reactivity towards epitopes of HLA-DR or DC. As for the mouse, the majority of these Mabs react with the molecule HLA-DR or DC at the level of stimulating cells, thus inhibiting the reaction of T cell clones specific for that molecule. Nevertheless, variations in this inhibition have been observed which may derive from interactions between these antibodies and the responding T cell clones.

Functions and Membrane Structures of T cells. Studies at the Center of Immunology directed towards the understanding of the mechanisms of immune reactions are concentrated on the function of T cells. Using previous experimental results on the mechanisms of the final stage of cytolysis and on the steps of differentiation and mechanisms of action of subpopulation of T cells, the researchers have progressively concentrated on the membrane molecule of T cells which intervene in these functions in man and mouse. Numerous groups are involved in this approach (P. Goldstein, G. Gorides, C. Mawas, M. Pierres, etc.) using, for the most part, Mabs and cultured lines of functional T cells.

The general approach to the characterization of functional structures of the membrane of human and mouse T cells has been to obtain Mabs using cloned T cells as immunogens and to screen these antibodies by their inhibitory effect on the function of T cells; this is followed by biochemical analysis of the target molecule in the membrane. This has already permitted the characterization of membrane structures (LFA-1) implicated in T cell cytolysis.

In the murine system, a large series of rat Mabs has been obtained. One of these permits the identification of a mouse equivalent (called $L3T_4$) of the human T_4 antigen. The inhibitory effect of this antibody on the induction and proliferation of cloned cytotoxic T cells directed at antigens of Class I or Class II is quite specific. Another antibody has permitted the biochemical analysis of the transferrin receptor of the mouse, and another Mab defines the presence of a sodium potassium ATPase on T lymphocytes.

A similar approach has enabled the production in the rat of Mabs which recognize the Il-2 receptor, proteins of the family T_{200}, the human equivalent of LFA-1 (lymphocyte functional antigen), and numerous molecules expressed by T cells after activation. Some of these

antibodies block the function of T cells *in vitro* and are at present used in clinical experimentation.

B. Rubin and his colleagues are studying the receptor of T cells using rabbit serum to define idiotypic determinants of mouse alloreactive (B6 anti-CBA) T cells. The structural genes encoding this idiotypic are close to the V_H genes, the idiotypic determinants being carried out by molecules of molecular weight 75,000. These molecules do not possess MHC determinants. The amino acid composition of these molecules is close to that of immunoglobulin heavy chains and their structure seems to be composed of six domains of molecular weight of approximately 12,000. Antigenetically similar molecules have been found in a helper factor produced by a T hybridoma (T85, specific for chicken immunoglobulins) and are associated with a particular anti-I-A^k monoclonal antibody.

P. Goldstein et al. are studying promotor factors (LPF or lymphocyte promoting factors) derived from T cells stimulated by xenogenetic serum. The inducing structure for cytotoxic T cells (T-LPF) is copurified with Il-2. The promotor factor of B cell differentiation appears to be different in its action from other factors. The measurement of forces of interaction between cytotoxic T cells and their target has permitted the demonstration of the great variability of these forces and of the importance of nonspecific interactions in the establishment of bonds between cytotoxic cells and target cells.

Structure and Genetics of Immunoglobulins. The knowledge of the structure of immunoglobulins and of their genes has advanced considerably during the past several years, leading to the development of a remarkable model of genetic organization. However, the questions posed by antibody diversity are not as yet resolved. At the Center of Immunology, the activity of previous years, principally oriented towards the correlation between idiotypy, antigen specificity, and the structure of antibodies has been enriched by the methods of molecular genetics. Thus, research begun in 1983 has been carried out in two experimental systems which benefit from a large number of monoclonal-antibody-producing hybridomas which are well characterized. The idiotypic analysis of Mabs directed against murine histocompatibility antigens (anti-Ia) has permitted the establishment of the correlation between idiotypic specificity and antigen specificity; it also permits an approach to the problem of the correlation with the structure of immunoglobulin chains. The group of M. Fougereau, using methods of molecular genetics, has analyzed the V_H repertoire and the V_H and V_k repertoire of the antibody response to the synthetic copolymer GAT, and has demonstrated a series of genetic events intervening in this repertoire.

Immunology and the Nervous System. The methods of immunology have been very useful in other disciplines, notably in neuroscience. At the Center of Immunology, C. Goridis and his group have developed a program for the analysis of membrane antigens of nerve cells, using for the most part monoclonal antibodies. Their isolation of a glycoprotein called BSP-2 implicated in neuronal adhesion is a good example of what immunology can bring to the study of the nervous system. In addition, the use of methods of enzymatic and chemical modification of peptides has enabled H. Cailla and colleagues to obtain antibodies against the enkephalins and their precursors, which are used for studies of localization and biosynthesis of these mediators in nervous tissue.

Among antigens found by C. Goridis et al. on the surface of the mouse nervous system, the glycoprotein BSP-2 was found to exist in a desialiated form which appears in the course of ontogenesis in certain tissues. The integration of BSP-2 molecules in liposomes has permitted the demonstration of its specific fixation *in vitro* to a membrane receptor, the fixation of which depends on the degree of sialyation of the molecule. The orientation of the molecule in liposomes, which has been studied by Mabs, seems to be transmembrane. Immunolocalization of this determinant in electron microscopy suggests that it has a particular role in the formation of fascicles by newly formed axons. In other studies, the use of γ interferon appears to be capable of inducing Ia antigens on the surface of astrocytes in culture. This observation is particularly interesting with respect to the role of these antigens in the induction of immune responses.

The production of specific antibodies, both monoclonal and polyclonal, against the opioid peptides and their precursors has opened the way to a series of studies on the physiology of these neuropeptides. The analysis of their immunolocalization at the level of the synapses in the cochlea of the guinea pig (demonstrated by electron microscopy) suggests a role of neuromediator for these molecules. Their biosynthesis in the striatum and the cerebral trunk is influenced by the dopaminergic system.

Cellular Physiology. The use, directly or indirectly, of immunological methods has led to interesting results in two other areas. In the first, the group of H. Cailla has obtained antibodies directed against the polyisoadenylates (2-5A), which have permitted the extension of the biological interest of these molecules, certain of which are important in the antiviral effect of interferon. The second result is from the analysis of the endocytosis of liposomes specifically fixed to the surface of cells by antibodies (system developed by L. Lesserman et al.) which has shed considerable light on the role of membrane receptors in the endocytic process.

2-5A is a term which denotes a family of oligoadenylates (polyisoadenylates) of which the phosphorylated forms are implicated as intercellular mediators of interferon. The obtention and the use of Mabs has shown that nonphosphorylated forms of these molecules ($A_2'p_5'$) can be found not only in all the tissues of mammalian cells but also in yeast and in bacteria *(E. Coli)*. This observation suggests that the biological role of a 2-5A is greater than merely that of intercellular mediator of interferon. In fact, the presence of 2-5A in the liver and in the normal kidney can be seen in the absence of a viral infection. The study of intracellular enzymes responsible for the synthesis of 2-5A (2-5A synthetase) and others which degrade the polyisoadenylates confirm the existence of an ubiquitous system of metabolism which uses 2-5A. However, it has been demonstrated that viral infection, in addition to interferon or poly I poly C, provokes an accumulation of the phosphosylated polyisoadenylates to the detriment of nonphosphorylated polyisoadenylates. The plasma level of these polyisoadenylates may thus be an excellent indicator of viral infections in man.

In their study of the endocytosis of liposomes bound specifically to membrane receptors, the system developed by L. Lesserman et al. uses liposomes of variable sizes coupled to Mabs with specificity for various determinants of the cell membrane, notably MHC molecules. They developed a method for the direct measurement of the kinetics of internalization of these liposomes using the techniques of fluorescence dequenching. The pharmacologic effect of drugs encapsulated in liposomes is also being studied. The use of mouse fibroblasts carrying human HLA genes by transfection has established the fact that the information necessary for endocytosis of MHC molecules is contained within the sequence of the molecule. The use of liposomes for transfection of cells with encapsulated DNA or for the selection of cells transfected by cloned genes or noncloned DNA has been developed.

Applied Immunology. It is clear that immunological research is rich in applications, especially in medicine. In the area of diagnosis, a series of immunoassays developed in the group of analytical immunology of H. Cailla with the aid of chemical or enzymatic modification of hormones, neuromediators, and peptides have been commercialized by Immunotech. More than 20 Mabs from the Center of Immunology, directed against membrane antigens or soluble antigens, have been commercialized and new hybridomas obtained. A program of research is being carried out on the development of immunoassays of the polyisoadenylates (2-5A) as an indicator of viral infections in man.

In the area of therapy, programs using liposomes *in vivo* as drug carriers have been pursued in the animal. In man, two programs have been carried out:

1. Clinical pharmokinetic studies of anticancer medications and their metabolites with the aid of newly developed immunoassays for the vincaalkaloids (vindesine), methotrexate and 5-hydroxymethotrexate, etc.

2. Treatment of patients with bone marrow transplants, by C. Mawas and his group using a protocol of immunodepletion of mature T cells with the aid of a pool of Mabs and complement, and of the evaluation of the lytic effect *in vitro* of Mabs coupled to toxins in attempts to circumvent rejection of bone marrow transplants.

Studies of the pharmokinetics of cyclosporine-A by immunoassay are also being pursued. Finally, methodologies have been developed in the area of flow cytofluorometry, especially quantitative measurements of fluorescence polarization and the direct measurement of endocytosis of liposomes.

Conclusion

The relatively new Center of Immunology, Marseilles-Luminy, founded in 1976, represents the first Institute of Immunology built in France. The institute today consists of excellent laboratory facilities and equipment acquired over a period of a few years. The scientists are carrying out top-level research in immunology, as well as in applications of immunology to problems in neuroscience and cellular physiology. Affiliated with the Center is Immunotech, a laboratory that develops industrial products and research in

immunology. Its close collaboration with the Center of Immunology facilitates the Center's links with industry. Many immunological techniques and products have already been developed by this collaborative arrangement.

3/19/86

Material Sciences

COMPOSITE MATERIALS RESEARCH IN TWO FRENCH UNIVERSITIES

by Kenneth D. Challenger. Dr. Challenger was until May 1986 the Liaison Scientist for Materials Science in Europe and the Middle East for the Office of Naval Research's London Branch Office. He is Associate Professor of Materials Science at the Naval Postgraduate School.

Tsu-Wei Chou reviewed the research on composites at the Laboratoire de Mécanique et Technologie, Cachan, and the Université de Bordeaux in *ESN* 38-7:378-379 (1984). There are, however, at least two more university research programs in fiber-reinforced composites that are noteworthy in France: Centre des Matériaux of the École Nationale Supérieure des Mines de Paris and the Université de Technologie de Compiègne. This article combined with Chou's should then complete the review of the major composite research programs in French universities.

Centre des Matériaux

Professor A.R. Bunsell moved from the UK to the Centre des Matériaux about 15 years ago and began the research on composite materials at this laboratory. At present he has two postdoctoral associates and 11 Ph.D. students. He is the head of the composites group at the center (for a general description of the research activities at the Centre des Matériaux see *ESN* 40-3:95-97 [1986]). He is active in two separate, but related research topics involving composites: single fibers and fiber-reinforced plastics.

Single Fibers. The characterization of the mechanisms of fracture and deformation of single fibers is, in my opinion, his more exciting research topic. He has published on this topic for over 15 years: recently he has begun to examine the high-performance carbon and ceramic (SiC) fibers. He was one of the pace setters during the early research on the failure mechanisms of synthetic organic fibers. Now, he is expertly applying this knowledge and experimental expertise to the new high-performance fibers. The experimental facility that he has built over the years is unique. Single fibers can be tested under creep, tensile, relaxation or tensile-fatigue loading by servo-controlled closed-loop systems capable of maintaining the load to an accuracy of 0.1 gm over a temperature range of -150°C to 1600°C; the humidity of the testing environment can be controlled up to 100°C. Infrared spectrometry, x-ray diffraction and transmission, and scanning electron microscopy have been used to determine the failure mechanisms of many different fibers.

His current research on single-fiber properties is focusing on Nicalon fibers (SiC) produced by Nippon Carbon. (The French have very close connections with the Japanese fiber producers.) The Nicalon SiC fibers have been creep tested by Bunsell and his students up to 1300°C. They find that free carbon, present as particles that are about 2 nm in diameter, tends to inhibit creep at temperatures up to about 1100°C. However, above 1100°C, the carbon chemically reacts with the oxide present in the fibers, causing a degradation in the creep strength. The rate of the degradation in strength depends on the oxidizing potential of the environment, decreasing as the oxidizing potential increases. Bunsell believes that the oxidizing environments produce an oxide on the fiber that blocks the diffusion of gaseous $C+SiO_2$ reaction products out of the fiber. Thus, when used as reinforcement, the $C+SiO_2$ reaction will probably be influenced by the matrix material. (That is, the matrix material may or may not inhibit the diffusion of these reaction products. If the matrix inhibits diffusion of the reaction products, the reaction may cease.) Two different initial SiC fibers were studied, one amorphous and one microcrystalline--both produced in a similar way from polycarbosilane precursors. The room-temperature strength of these fibers is similar; the strength limiting parameter appears to be a function of the distribution of defects on the surfaces of the fibers. Above 1100°C the amorphous fibers recrystallized, resulting in a decrease in creep strength (due to primary creep deformation that occurred during the recrystallization). The initially microcrystalline fibers

attained an equilibrium grain size of about 3 nm, after which grain growth seemed to cease; thus, the primary creep strains were much smaller for this material.

The effect of the $C+SiO_2$ reaction on the creep strength was similar for both fibers, suggesting that the free carbon content should be reduced (the presence of carbon is due to the molecular structure of the precursor, specifically the number of CH_3 groups, and the conditions of pyrolysis). The SiO_2 present inside the fiber is undesirable for two reasons. Firstly, its reaction with the free carbon is undesirable and secondly, it has a low viscosity above 1000°C and thus will increase the creep deformation. The elimination of the SiO_2 poses a problem for the fiber manufacturers because the initial polymeric fiber is cross-linked by oxidation in air.

Bunsell's research on the mechanisms controlling deformation and fracture of single fibers is superb and contributes in a significant way to the improvement of the fibers.

The Nicalon fiber research has now evolved into a collaborative research program with Nippon Carbon. Bunsell is characterizing the properties of a continuous SiC-fiber-reinforced aluminum wire, 0.5-mm diameter containing about 500 SiC fibers. The information generated by this project will be relevant to the development of metal-matrix composites.

Fiber-Reinforced Plastics (FRP). The second topic under investigation by Bunsell's research team is the determination of the failure mechanism for FRP materials when they have been subjected to different types of loading and environments. Acoustic emission (AE) techniques have been combined with careful microstructural and fractographic examinations in an attempt to identify the "sound" of each failure mechanism. They have been moderately successful and have encountered a few surprises. For example, the highest amplitude events for a carbon-fiber-reinforced epoxy material corresponded to matrix cracking parallel to the fibers, whereas fiber failures produce a much lower amplitude signal. Bunsell still is not confident that AE signal analysis will be successful in quantifying the damage state of a CFRP component, but simple acoustic monitoring and analysis of the AE signal may be of technological use for simple shapes subjected to simple loading histories.

The fracture of other fibers is often more complex because carbon fibers do not seem to suffer creep or fatigue damage whereas glass fibers, for example, do fail by these time-dependent mechanisms. Understanding the failure mechanisms of these materials is a key step in predicting the damage tolerance of a given material. The uncertainty in the damage tolerance of these materials when subjected to impact loading is a critical issue preventing a more widespread use of these materials in primary load-bearing components. Hence, Bunsell's research is making a valuable contribution in the development of these materials.

Université de Technologie de Compiègne

Two separate yet intertwined research groups exist in the Department of Mechanical Engineering at Compiègne. It is not clear to me exactly how they are separated except that originally (perhaps 10 years ago) one group focused on the properties of polymeric materials and the other on metallic materials. Today, however, both groups work on similar topics with respect to the development of fiber-reinforced epoxy, their major focus is specifically on carbon-fiber-reinforced plastic (CFRP). Professor F.X. de Charentenay heads the Polymer Composites Division, and Professor C. Bathias heads the Institute for Advanced Technology and Materials. When we discussed the research on composites I found it difficult to see a boundary separating the activities of the two groups.

Most of the composites research at Compiègne is funded by the Ministry of Defense, the Office National D'Étude et de Recherche Aérospatiales (ONERA), or Aérospatiale; this includes fracture testing of polymeric matrix materials; creep and fatigue damage analysis; Modes I and II delamination testing using fracture mechanics approaches; testing of component-type materials; and microstructural characterization of carbon fibers using transmission electron microscopy.

The majority of their research to date has been on the characterization and modeling of the damage accumulation in CFRP subjected to creep, fatigue, or combined creep-fatigue loading. This work has focused on the behavior of a ±45-degree laminated CFR epoxy. One interesting result from this research is that under combined creep-fatigue loading, creep may either reduce or extend the fatigue life depending on the stresses imposed during the periods of creep. If the creep stress exceeds 80 percent of the ultimate tensile strength (UTS) of the laminate, then the fatigue life is reduced; however, if the creep stress is less than 80 percent of

the UTS the fatigue life is actually increased.

They have also defined a damage parameter (D) that correlates with the changes in Young's modulus that occur as a result of fatigue damage. During fatigue loading damage occurs in three stages. The first stage is associated with the damage caused by the first loading cycle, hence the extent of damage is a function of the magnitude of the cyclic stress in this stage. The second stage, which is the most interesting aspect, involves a linear increase in the damage state with increasing number of cycles until, at 90 percent of the fatigue life (independent of the cyclic stress), stage III begins and a very rapid loss of stiffness (decrease in Young's modulus) is accompanied by a rapid increase in D, and failure occurs. The stiffness loss that corresponds to the beginning of stage III is about 5 percent. Thus, if the stiffness of a component can be monitored, it is possible to predict when the component will begin to suffer a catastrophic loss of strength. Damage-tolerant design concepts need a material parameter to monitor the change in the damaged state in order to predict the safe life remaining. For metals, this parameter is the fracture toughness of the material; by monitoring the crack length and knowing the stress in the vicinity of the crack it is possible to predict when stable crack growth will change to catastrophic crack growth. Composites do not form a single crack when loaded in fatigue, but suffer from damage that is uniformily distributed throughout the material. Thus, the fracture mechanics crack-growth methodology is not applicable. The use of stiffness to monitor the damage state may prove useful, but measuring stiffness losses in real components is not easy.

Several other topics are currently under investigation: (1) transverse cracking and the growth of delaminations from holes in laminated CFRP; (2) stress concentrations around holes loaded biaxially in-plane; (3) mixed-mode fracture-toughness testing methods; (4) structural design methods for CFRP materials are being developed (buckling and post-buckling behavior, optimum minimum weight, and optimum maximum life); and (5) environmental effects on the properties of CFRP (thermal and humidity cycling).

Bathias' group is also involved in research on the mechanical properties of a wide range of metallic materials, but Charentenay focuses only on the polymeric matrix composite materials.

Summary

This article when combined with *ESN* 38-7:378-379 (1984) presents a survey of most of the active research on composite materials in French universities. One other program, not really related to the materials aspects of the research on composite materials, which should be considered relevant to the increased use of these materials is a program directed by Professor G. Verchery at the École des Mines de St-Étienne. I have not visited him, but I know that he has a research group developing structural mechanics design methods for fiber-reinforced materials and bonded joints based on a finite element approach.

The university research on composite materials in France is extensive. France is a world leader in carbon-carbon composites and intends to develop a leadership role in CFRP materials. A few years ago, in fact, the government encouraged French industry to enter into a licensing agreement with a Japanese carbon-fiber producer--the French can now produce 250 tons per year and have plans to increase this to over 1000 tons per year within the next 4 years. More importantly, France has the capability to perform complex 3-dimensional weaving with the fibers (developed for the carbon-carbon composites used in the rocket motor cases for Ariane) and now has the capability to produce carbon fibers. These three factors combined with the more widespread applications of CFRP in the new European aircraft makes France a formidable competitor in this rapidly expanding field.

By involving the universities in this national effort, they are assured of graduates that are trained and ready to work with composites. Bunsell appears to be the central figure representing the universities' interest and viewpoint in this field.

3/17/86

FRACTURE MECHANICS AND WELDING RESEARCH AT THE TECHNICAL RESEARCH CENTER OF FINLAND

by Kenneth D. Challenger.

Research on the fracture toughness and weldability of steel and the development of fracture mechanics methods is performed in the Metals Laboratory of the Technical Research Center of Finland (VTT). This research is done in support

of the offshore oil, shipbuilding, and electrical power generation industries in Finland. Finland is one of the world's leaders in the design and construction of ice breakers; thus, the technology for welding materials that will be used in arctic conditions is very advanced. Most of the development work to support this technology has been done in the Metals Laboratory of the VTT.

Background

VTT conducts research and also offers testing and inspection services to Finnish industries. It is involved in many different facets of research for both the public (government support) and private contractors. VTT consists of 31 laboratories employing a staff of over 2300, of which about half are university graduates. The budget for 1984 was FIM390 million (∿$70 million). Most of the VTT laboratories are located in Otaniemi, a park-like technical campus shared by VTT with the Helsinki University of Technology. Otaniemi is located just across the bay from Helsinki.

I visited the Metals Laboratory, Dr. Jarl Forstén, director, where my host was Dr. Karri Vartiainen. The Metals Laboratory is the largest of the VTT laboratories. It has a staff of 155 including about 65 graduates and an annual budget of FIM28 million (∿$5 million); about 10 percent of this funding is from industrial contracts. The scope of the research at this laboratory is very broad; it includes materials, structural engineering, welding, machine and machine shop technology, and nondestructive testing. I reviewed their research programs on welding, fracture, and fracture mechanics during my visit. The highlights of these programs are summarized in the following three sections.

Welding

About 60 percent of the welding research in Finland is performed by this laboratory. The activities related to welding include the characterization of the mechanical properties of weldments, weld procedure development, weldability testing, automation, high productivity welding methods, and, as a service to industry, welder qualification. The two key personnel at VTT involved with welding development are my host, Dr. Karri Vartiainen, and Dr. Risto Karppi.

Automation and Mechanization. A few years ago there were no welding robots used in Finland, today over 100 arc welding robots are in use. The Warsilia shipyard, where 60 percent of the world's ice breakers are built, will be automated this year. A large gantry welding robot is under development for shipyard applications. The people and the development work at the Metals Laboratory have been instrumental in the automation of the Finnish welding industry. From 1976 to 1980 VTT was involved in a large Scandinavian collaborative development program on adaptive control methods for fillet welds.

At present VTT is evaluating the possibilities of using CAD/CAM systems for programmable welding and are developing a visual seam-tracking system that is based on a combination of laser illumination and matrix cameras for visualizing the weld seam. Karppi has written the procurement specification for, and VTT has ordered, a Leybold-Heraeus 15-kW electron beam welding machine used for research and for demonstrating to Finnish industry the use of electron beam welding.

Procedure Development. This year a research program will be initiated to develop welding procedures for multiwire submerged arc welding of thermomechanically treated steel. The development of filler metals and procedures for welding high-strength aluminum alloys will also begin this year.

Weldability. A large Osaka University-VTT collaborative research program has been completed. This project produced a method to safely predict the welding conditions required to avoid hydrogen assisted cracking (HAC) of steel weldments. Steels with yield strengths ranging from about 300 to 780 MPa were used in the study. Implant tests and three different types of restraint tests were welded to evaluate the HAC susceptibility of a weld root pass for the various alloys. Basic coated electrodes were used with heat inputs of 1.0, 1.7, and 3.0 kJ/mm.

The thermal history of each weld was recorded from the peak welding temperature down to 100°C and the initial hydrogen content was measured using the Osaka University method (Terasak, 1979). After welding, each weld was sectioned and hardness measurements made at the critical locations in the weld cross-section. The results of these experiments have been used to evaluate a VTT model to predict the welding conditions necessary to avoid HAC. The model is based on semiempirical equations developed by both Finnish and Japanese investigators; the maximum heat affected zone (HAZ) hardness, remaining diffusible hydrogen content, restraint stress, and stress concentration at the weld root are calculated from these equations. The only information required to predict the maximum stress intensity allowed (in

order to avoid cracking) is the chemical composition of the steel and the cooling times between 800°C and 500°C, the peak temperature to 200°C, and the peak temperature to 150°C.

The model appears to accurately predict the conditions that will lead to HAC of real weld joints and thus it is worthy of detailed evaluation by the US Navy investigators involved in this type of research. The details of this model are published (Karppi, 1984).

Mechanical Properties of Weldments. Many different mechanical testing programs are always in progress at VTT. The principal objective of these programs is to determine the effects of various welding parameters and chemical compositions of the materials on the mechanical properties of the weldment. As an example of this type of project, I have reviewed the results from one of these in the following paragraphs. This project began in 1982 and was just completed. It was a collaborative project with two institutes at the Technical University of Aachen--The Institute for Ferrous Metallurgy (ESN 39-4:152-156 [1985]) and the Institute for Welding and Fabrication Technology (ESN 39-4: 149-152 [1985]).

Five different constructional steels with yield strengths ranging from 300 to 700 MPa were welded by conventional and high-efficiency welding processes. A final report for this entire project is in preparation and should contain much valuable information. I have requested a copy of this report and will announce my receipt of it with a future [illegible]. The following information represents the VTT test results on one steel, N-A-XTRA 70, a quenched and tempered steel with a yield strength of 700 MPa.

The chemical composition of the steel is 0.16C, 0.68Si, 0.89Mn, 0.012S, 0.014P, 0.80Cr, and 0.45Mo. This steel has a 40 joule transition temperature of -70°C with a relatively high fracture toughness, K_J (225 MPam$^{\frac{1}{2}}$), at this same temperature.

Multipass shielded metal arc welds (SMAW) and single-wire submerged arc welds (SAW) with heat inputs of 1.7 and 3.0 kJ/mm were performed on preheated (150°C) 40-mm-thick plates using a K-type weld preparation geometry.

All of the welds were [illegible] tioned for microhardness and microstructural analysis subsequent to welding. The near-surface hardness of the heat affected zone is quite high, 470 HV, for the SMAW higher heat input welds. This location had the highest hardness in all of the welds, but both SMAW welds had a higher hardness than either SAW weld.

The microstructure of the weld metal is mainly acicular ferrite for all four welds. The increased heat input did not seem to affect the weld metal microstructure. The HAZ microstructure is a mixture of martensite and bainite; increased heat input caused a coarsening of the grain size in the near fusion line HAZ.

The toughness of the weld metal was not affected by the heat input; however, the HAZ toughness was markedly lower (both the transition temperature and the K_J values were degraded) for the 3.0 kJ/mm weld, especially the SAW weld. The conclusion of this study is that the heat input for this steel should be kept low, around 1.7 kJ/mm, to achieve good fracture toughness in the HAZ/near-fusion-line region of weld. These results are similar to those reported by US Navy researchers on the effect of heat input on HAZ toughness of the HY-series steels. The results of the portions of the project where tandem-SAW, high-speed electro-slag and other high-efficiency processes have been evaluated should be of special interest to US Navy researchers active in this field.

Fracture Mechanics

VTT researchers are performing all the conventional fracture mechanics tests, but have two rather unique testing capabilities. The first is used for fracture toughness and fatigue crack growth tests in environments simulating those present in a nuclear reactor. VTT has an autoclave chamber where they perform standard constant strain-rate tests, and they also have a facility that uses a hydraulically actuated servo-controlled testing machine to load the specimens contained in the autoclave. This experimental facility is used for materials characterization and for the development of novel nondestructive testing techniques to monitor cracking, e.g., potential drop techniques.

The other test facility is an instrumented Charpy testing machine used to measure dynamic fracture toughness. This equipment is unique because it uses an inverted test geometry. Conventional instrumented machines use a stationary test specimen that is impacted by a moving hammer, Figure 1. The hammer is instrumented to measure the load-time history of the test. When the hammer strikes the specimen, the specimen must be accelerated to the speed of the hammer. This force of inertia sets the specimen and the load transducer on the hammer into rapid vibration; thus, the force measured bears no resemblance to

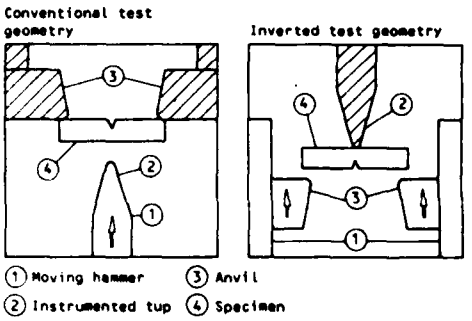

Figure 1. Descriptions of the inverted and conventional geometry (from Rintamaa et al. [1984]).

the actual force bearing on the specimen, especially during the beginning of the impact. This makes the determination of K_{Id} (the dynamic fracture toughness) difficult and wrought with uncertainty.

By attaching the specimen to a stationary hammer and impacting with the anvil (hence the term inverted impact geometry) the inertial loading that causes the uncertainty in the initial loads is reduced. The arrangement of the specimen, hammer, and anvil are compared to a conventional set-up in Figure 1.

This new impact tester has been patented, and a detailed analysis of the specimen response during impact loading with this machine has been completed and reported by Rintamaa (1984).

Fracture Toughness and Fatigue

Dr. Kim Wallin has developed a statistical micromechanical model for carbide-induced cleavage fracture initiation in steels. This model has been shown to be applicable to both ferritic and bainitic steels and has been used to predict the temperature dependence and the scatter of macroscopic fracture toughness data. The model is based on a concept originally introduced by Curry and Knott (see *ESN* 38-9:491-492 [1984]) where carbide cracking is the initiation event for cleavage fracture in steel. The statistical nature of the model originates from the fact that the critical local stress needed to crack a carbide particle, and thus potentially trigger cleavage fracture, is dependent on the size of the carbide particles (decreasing with increasing carbide size). Wallin (1985) describes a fracture probability function that predicts the probability of finding a crack-nucleating carbide in the critical vicinity of the crack tip. This expression is then used to explain the somewhat controversial topic of how specimen size affects fracture toughness. He shows that ductile fracture initiation is specimen-thickness dependent for thicknesses less than a specific value, but that thickness effects in brittle fracture are due to statistical variations of the carbide distributions. He has developed a thickness correction factor for brittle fracture based on his statistical micromechanical model.

Wallin's results are still somewhat controversial, but in my opinion, they are worth serious consideration because many empirically observed phenomena that have not previously been explained on a physical basis (e.g., specimen-size effects and scatter in fracture toughness data can be explained using this model).

Summary Remarks

Many other interesting research activities are taking place in the Metals Laboratory. I have not had the opportunity to review all of these projects but they include high-temperature fatigue, fatigue crack growth, TiN coating using ion plating, many different nondestructive testing techniques, abrasive wear, structural design methods, diffusion bonding of ceramics to metals, and others. The facilities at VTT are excellent and fully used. The growth of the activities of the Metals Laboratory has been restricted by VTT management to about 3 percent per year. At the present, they have more demand for their services than they can meet. This situation has existed for many years now, but the management is holding firm to their carefully planned growth for the laboratory.

Most of the activities in the Metals Laboratory are relevant to the US Navy programs because their principal clients are associated with either the offshore oil and gas, shipbuilding, or electric power generation industries.

With the recently signed agreement on scientific and technical cooperation between the US and Finland, the time is right to develop collaborative research programs with VTT.

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3/17/86

Physics

CHARGE-DENSITY WAVE STUDIES IN NATURAL LOW-DIMENSIONAL MATERIALS AT BRISTOL UNIVERSITY

by Paul Roman. Dr. Roman is the Liaison Scientist for Physics in Europe and the Middle East for the Office of Naval Research's London Branch Office. He is on assignment until September 1987.

Professor J.C. Gill and his associates at the H.H. Wills Physics Laboratory, University of Bristol, UK, made several interesting discoveries concerning the unusual electrical properties of certain inorganic compounds which behave as quasi-one-dimensional metals. I will give a brief review of some studies I learned about during my visit in February, since this research is not only fascinating but may have long-range applications in microelectronics.

Background

The study of systems that, in certain respects, behave as if they had fewer than three spatial dimensions became, in recent years, a celebrated subfield of solid-state physics. In some materials (including some organic compounds) low dimensionality is imposed by the geometry of the specimen. (Metal monolayers, inversion layers in semiconductors, and oriented organic films are good examples of two-dimensional constructions.) However, the Bristol group concentrates on materials whose low-dimensional behavior is a natural consequence of their crystal structure. These systems can justly be called natural (as opposed to specifically fabricated), or quasi-low-dimensional, solids. Organic conductors, whose resemblance to ideal one-dimensional systems stems from a chain-like arrangement of their components, constitute one class of examples; but again, Gill's researchers are working with simple inorganic compounds. Since these scientists are concerned orimarily with metallic properties, their materials are usually compounds of transition elements. For example, $TaSe_2$ crystalizes to form two-dimensional layer compounds (see Figure 1a) where metallic properties develop along each layer, but between the layers nonmetallic characteristics emerge. Similarly, $NbSe_3$ gives rise to a natural linear compound (see Figure 1b), with metallic behavior along the Nb-Se-Nb chain.

It is not difficult to show that any defect in quasi-low-dimensional structures causes a strong localization of the electronic state function (this is called an Anderson transition) which leads to startling changes in conductivity. Earlier work of the Bristol physicists studied these effects. But more recently, they became fascinated by another class of phenomena: charge-density wave transitions and their consequences.

A common feature of quasi-low-dimensional metals is that the anisotropy of their structures makes them susceptible to an electronically driven instability. Perhaps surprisingly, even though this possibility was pointed out in the classic textbook by R. Peierls as long ago as 1955, very little was done until the past few years to study the processes related to this instability. The major consequence of the Peierls instability is that at sufficiently low temperatures a spatially periodic (and, under normal conditions, static) distortion of the crystal lattice develops

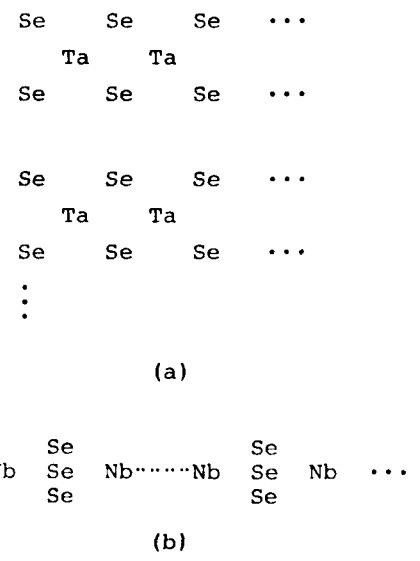

Figure 1. (a) A layer compound, $TaSe_2$ and (b) a linear compound, $NbSe_3$.

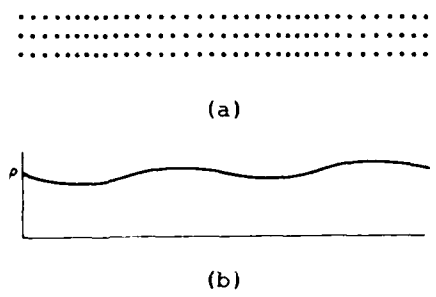

Figure 2. (a) Periodic structural distortion of lattice and (b) the associated charge-density wave.

(see Figure 2a). This periodic structural distortion (PSD) of the ions in the metal is accompanied by a corresponding spatial modulation of the concentration of the conduction electrons. Their redistribution occurs so as to attempt the restoration of electrical neutrality. Misleadingly, despite the fact that there is no intrinsic time-dependence involved, the phenomenon is called a charge-density wave (CDW). Figure 2b illustrates the CDW associated with PSD: the concentration of the conduction electrons is modulated by the factor ρ.

As a result of the CDW phenomenon, quasi-low-dimensional metals exhibit a variety of unusual phenomena in their electrical conduction and other electronic transport properties, and these form the topic of the Bristol researchers' work.

Some Highlights

Many of the effects studied by Gill and coworkers cannot be described by the usual independent-electron model of conduction in crystals. In quasi-one-dimensional metals there is a possibility that the PSD itself is made to move when a field acts on the electrons. Gill's work indicated that this will be the case especially if the periodicity of the PSD (determined by the electronic system) happens to be incommensurate with the periodicity of the underlying crystal lattice. Gill emphasized that in such "sliding" of a PSD and the associated CDW, current is carried through a cooperative motion of the electrons. (It is a historic curiosity that such a cooperative conduction mechanism was first proposed by Fröhlich in his celebrated but incorrect 1954 attempt to explain superconductivity.) Phenomena attributed to "Fröhlich conduction" and motion of the CDW's in quasi-one-dimensional metals include nonohmic conductivity in strong steady fields, enhanced ac conductivity in weaker fields, current noise, and a variety of hysteresis and memory effects. Since the detailed theoretical explanation of these phenomena is far from being complete, it is important that the Bristol group studies and carefully measures many of these effects.

In what follows, I will mention briefly only two topics that caught my fancy.

Nonohmic Conduction in Steady Fields. It is now well established that in all known quasi-one-dimensional metals nonohmic conduction occurs, provided the temperature is below the Peierls instability point. The resistance of the material goes through several maxima and minima as the temperature is further decreased. In addition, the R-versus-T curve depends quite strongly on the current density (substantial nonlinearity). Furthermore, after a temperature-dependent threshold field, E_T, has been reached, the resistance decreases steadily towards a value roughly equal to that which would have been obtained if no CDW had formed. E_T depends on the material and also on the individual specimen. In $NbSe_3$, near 45 K, Gill found values as low as 5 $mVcm^{-1}$. The sharply defined nature of the threshold is illustrated in Figure 3. This represents an experiment done at 90 K. I_C is the amount by which the current exceeds the ohmic contribution I_n (which is also used as an alternative label of the abscissa).

Gill emphasizes that the order of magnitude of E_T (at least in $NbSe_3$) cannot be accounted for unless the electrons behave cooperatively. This is so

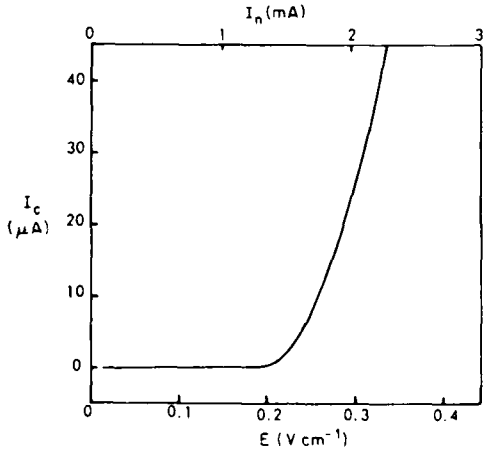

Figure 3. Nonlinear conduction.

because the energy acquired from the field by an individual electron, in traversing the mean free path (about 10^{-6} cm) appropriate to the ohmic conductivity, amounts only to no more than one-millionth of the thermal energy kT when E equals the threshold value, E_T.

Memory and Hysteresis. Because of the deformability of the CDW's and the competition between commensurate and incommensurate periodicities, electrical properties of CDW materials are influenced by their previous electrical and thermal treatment. Among the numerous hysteresis and memory effects Gill's group of Bristol scientists studied especially two.

Figure 4 clearly shows that the conductivity in weak fields depends on the direction in which the nonlinear current last flowed. Evidently, the CDW is left in a distorted metastable state, dependent on its direction of motion, and this influences the subsequent single-electron conduction. Gill and coworkers, who observed unusually strong electrical hysteresis in o-TaS_3, claim that the deformation of the CDW probably results, at least in part, from the obstruction of its motion by the electrical contacts.

The effect the Bristol group is most proud of having observed, is an overshoot phenomenon which displays a remarkable memory property. The experiment is illustrated in Figure 5. We see that a transient enhancement of the nonlinear conduction (I_C) follows previous current flow in the opposite (but not in the identical) direction. The memory of the material is remarkably persistent: it was observed even one hour or more after the application of a pulse.

Gill proposed an elementary model of the overshoot phenomenon. He assumes that the transient is a Fröhlich current accompanying the transition of the CDW between two metastable states in which it is compressed upstream and expanded downstream due to the electrical contacts and other major obstacles to motion. However, x-ray diffraction measurements do not fully bear out this model and efforts toward a better understanding are under way.

A detailed review of Gill's work up to a year or so ago can be found in the hard-to-come-by *Proceedings of the International Symposium on Nonlinear Transport and Related Phenomena in Inorganic Quasi One-Dimensional Conductors*, (Sapporo, Japan: Hokkaido University 1984). Some more recent results have been reported in *Lecture Notes in Physics*, 217 (Springer, Berlin: 1985).

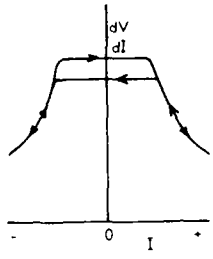

Figure 4. Electrical hysteresis (I: previous nonlinear conduction current; dV/dI: low-field differential resistance).

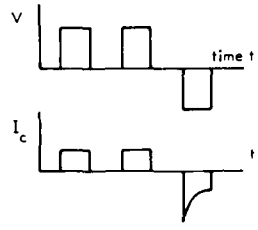

Figure 5. "Overshoot" memory effect.

Concluding Remarks

The Bristol scientists can confidently compare their work with that of other noted groups in this area in France, Japan, Hungary, and the US. In cooperation with other science departments at Bristol, Gill's researchers are involved in many theoretical and experimental studies relating to metallic low-dimensional materials; in addition, some of their work on electrical memory effects may soon find practical applications.

3/4/86

UK PULSED-POWER GROUP FORMED

by Anthony E. Robson. Dr. Robson is the CRT Research Coordinator and Program Director of the Experimental Plasma Physics Group at the Naval Research Laboratory, Washington, DC. He is currently participating in an advanced study program at Imperial College, London.

Pulsed power may be broadly defined as the technology of accumulating energy over a long time and delivering it in a

short time, thereby multiplying the power. Here, "long" and "short" are relative terms, and the techniques used depend upon the actual timescale involved. For example, rotating electrical machines may be used to store energy in minutes and deliver it in a second or less at peak powers measured in megawatts, while at the other end of the scale, water-dielectric transmission lines are charged in microseconds and discharged in nanoseconds to produce power pulses measured in terawatts. Many pulsed-power systems incorporate several stages through which a roughly constant amount of energy is transferred in successively shorter times, progressively increasing the peak power.

Pulsed power is a burgeoning area of research and development, driven by an increasing number of applications, both civilian and military. The greatest activity is in the US, where the largest generators are to be found; these produce tens of terawatts and are used for the simulation of nuclear weapons effects and for research into inertial confinement fusion. A considerable industry has grown up in the US around these great machines, yet the principles on which they are based were first developed in the UK by J.C. Martin and his group at the Atomic Weapons Research Establishment (AWRE) at Aldermaston, Berkshire.

The pulsed-power community in the UK is small and scattered, but its efforts are by no means negligible. Returning from the biennial IEEE International Pulsed-Power Conference held last vear in Arlington, Virginia (and dominated, as usual, by the US pulsed-power community), Dr. Hugh Bolton, of Imperial College, London, felt that the UK research would benefit from the creation of a Pulsed-Power Technology Group, whose broad charter would be to promote interest and involvement in pulsed power in the UK. On his initiative, a preliminary meeting of interested parties was held at Imperial College in October 1985, followed by a second one-day meeting in January 1986 at which representatives from industry, government laboratories, and universities gave technical presentations on their work. Although some of the smaller activities were not represented, this meeting was invaluable in providing an overall picture of the major pulsed-power efforts in the UK. What follows is a summary of the presentations.

The Atomic Weapons Research Establishment

The AWRE group continues to be the source of much innovative technology. Very little of their work has been published, but dog-eared, much-Xeroxed copies of J.C. Martin's notes are to be found wherever high-voltage pulse technology is practiced. In spite of the group's small size (seven on staff) they have built up an impressive collection of pulsed-power facilities, which are used mainly for radiography of explosive systems and for the simulation of nuclear weapons effects. The largest radiographic machine, Mogul-D, has a 100-kJ Marx generator which charges an oil-dielectric Blumlein line and can produce 170 R of 7-MV x-rays at 1 m from the diode. A more energetic machine, Eros (400 kJ, 4 MV), produces 1 kR at 1 m and is used for the simulation of internal electromagnetic pulse (EMP) phenomena in electronics, etc. Several lower-impedance generators, using water-dielectric lines, produce electron beams and x-rays of about 1 MV which are used to study the effects of rapid, nonuniform heating on materials and small structures. For impulsive testing of large structures there is the Grimm capacitor bank (2 MJ @ 30 kV) which can deliver up to 10 MA and can drive a 2-m^2 flyer-plate at up to 400 m/s. A capacitor-driven electric gun (Elgar) can accelerate plastic foils to 10 km/s and metal foils to 14 km/s. There are also a number of high-voltage, fast-rising pulse generators used to drive antennas to simulate EMP effects on military systems.

Imperial College, London

The AWRE group makes its technology available to British universities, but only the plasma physics group at Imperial College (IC), London, has really taken advantage of this. With advice and the loan of surplus components from Aldermaston they have built several Marx generator/water transmission line systems which they have used for experiments on the interaction of intense electron beams with plasmas and, more recently, to drive dense z-pinches. Here the aim is to establish a high-density plasma channel (typically by means of a laser-guided spark) and then generate a rapidly rising current which both heats the plasma and confines it magnetically. High voltages are needed to achieve the necessary rate of rise of current in the very inductive pinch. The largest machine at IC has a 3-ohm line operating at up to 750 kV that drives a current of up to 250 kA (rising at 5 kA/ns) into a laser-initiated pinch in hydrogen at 1-2 atmospheres pressure. A smaller generator drives a low-density compressional pinch. There is also a capacitor-driven gas-puff z-pinch, in which a hollow

shell of argon is imploded to form a dense hot plasma that is a source of intense, soft x-rays.

The IC group regard themselves as users, rather than developers, of pulsed-power but they make a significant contribution to the pulsed-power community by producing a stream of graduates who are trained in a technology for which no formal courses are given in the UK.

The Rutherford-Appleton Laboratory

The same kind of high-voltage technology is used in the Laser Division of the Rutherford-Appleton Laboratory at Chilton, Oxfordshire, to provide the electron beams for pumping the Sprite KrF laser, which has an output of 200 J at 249 nm in a 50-ns pulse. This laser is unusual in that it uses four large-area electron beams to pump a cylindrical laser cell from four directions. A 1-MV, 20-kJ Marx generator feeds a single 40-nF water capacitor which, in turn, charges four 5-ohm, 1-m-long water-filled coaxial lines through a single SF_6 spark-gap switch. Each line is connected to its corresponding electron-beam diode by means of an SF_6 switch. The most interesting feature of this system is the use of a small KrF laser whose beam is split into four to achieve simultaneous firing of the four output switches. With a laser energy of only 5 mJ into each switch, the jitter time is only 3 ns.

The Rutherford-Appleton Laboratory is also the home of the Vulcan glass laser system, a 12-beam facility used for research on laser-matter interactions and inertial-confinement fusion. This system uses well-established pulsed-power technology on quite a large scale. The flashlamps are driven from a 1.6-MJ capacitor bank through ignitron switches, and the coils for the Faraday isolators are driven by smaller, ignitron-switched capacitor banks. Various low-powered laser-triggered switches with subnanosecond risetime are used at the laser front end.

[For detailed information on this laboratory's laser activity, see *ESN* 39-5:209-211 (1985).]

University of St. Andrews

Ingenious pulsed-power technology is being applied, on a smaller scale, to the pumping of electric-discharge eximer lasers in the Department of Physics, University of St. Andrews, Scotland. A mercury-bromide laser (502-504 nm) is under development in which the discharge is preionized by a flash-x-ray generator. The discharge power supply consists of up to 12 lumped-component pulse-forming lines operating at up to 35 kV, each switched by a hydrogen thyratron. A unique fold-back structure involving secondary lines is used to couple the energy into a low-inductance laser discharge cavity, and to produce a voltage spike at the beginning of the pulse which ensures a uniform and stable discharge. Impedance matching is achieved by varying the number of lines in the circuit. The x-ray generator that supplies the preionization is powered by an unconventional stacked-transmission-line transformer which produces 100 kV into 100 ohms for 200 ns (a larger system is planned). The laser is designed to be repetitively pulsed at 10 Hz.

English Electric Valve Company

Repetitive-pulse technology, although not yet producing the enormous peak power available from single-shot devices, is well established in applications such as radar modulators and medical linacs, and more recently for repetitive electric-discharge lasers. The key switching element in these systems is usually a hydrogen thyratron, and the English Electric Valve Company (EEV), at Chelmsford, Essex, is the leading manufacturer of such thyratrons in the Western world. The company produces a range of thyratrons of conventional layout with glass, ceramic, and metal envelopes with operating voltages up to 40 kV and peak current capability of 15 kA. They also make a variety of special tubes. A small, metal-envelope tube with an extra grid has a recovery time of less than 3 μs and is used to drive metal-vapor lasers at up to 40 kHz. Multigap ceramic tubes are available that can hold off more than 100 kV. Double-ended ceramic tubes, with two cathodes, are produced for high-power bidirectional switching; these can also be of multigap construction and are used mainly for kicker-magnet and dump-magnet switching and for high-power crowbar protection. Hollow-anode thyratrons are made to withstand voltage reversal conditions, such as occur in laser-switching circuits, that would rapidly destroy conventional thyratrons.

EEV also makes switching ignitrons at its Lincoln plant. These are typically used for switching large capacitor banks for fusion experiments and for flashlamp supplies for large glass lasers; they are also used as crowbar switches for neutral-beam injection systems and high-power transmitting tubes. Triggered spark-gap switches are also manufactured at Lincoln for use primarily in pulsed laser systems, and there is development work to increase the repetition rate and lifetime of these switches, with a target of 10^8 shots before

replacement. Tungsten barium aluminate shows promise as a long-life electrode material, and photo-triggering is being investigated to overcome the problem of wear of trigger electrodes.

Overall, EEV has an aggressive development program and is clearly determined to maintain its position as the leading producer of switches for pulsed power. A new 35-kV, 200-μs test stand has been installed at Chelmsford to develop new thyratrons, particularly for the US market.

British Aerospace

An emerging area of pulsed-power technology is the use of nonlinear magnetic elements (saturable inductors) for sharpening pulses and "magnetic switching." Although the basic principle has been known for a long time, its application to very short, high-power pulses has only recently been made possible through the development of amorphous metallic glasses (usually known by the trade name Metglas™). Because these elements are passive, compact, and of almost unlimited life they are attractive for military and aerospace applications. British Aerospace (BAe), at its Sowerby Research Centre, Yorkshire, has a development program in collaboration with Bath University to study the long-term degradation of the properties of Metglas™, and another program in collaboration with Bristol University to design systems incorporating this technology. The principal application seems to be pulse compression lines for electric-discharge lasers. BAe has a general interest in repetitive-pulsed-power technology, with emphasis on systems of <1 kJ/pulse at >1 kHz, and conducts internally funded research in this area.

The Culham Laboratory

Research on controlled fusion has provided a major stimulus for the development of pulsed power, and at least one large capacitor bank was once a standard feature of almost every fusion experiment. As magnetic confinement experiments, in particular tokamaks, have grown in size, the timescale for the delivery of energy has increased and their pulsed-power needs are now provided by flywheel generators and inductive storage systems. The UK Atomic Energy Authority's fusion research laboratory at Culham, Oxfordshire, has a variety of capacitor banks of conventional design and up to 1 MJ energy, and has developed high-voltage modulators for the neutral particle beams and radio-frequency generators that are used for heating the plasma in tokamaks. These systems require multisecond pulses of 50 MW or more at up to 160 kV, and are switched and controlled with series tetrode tubes rated up to 1.5 MW.

In addition to housing the British fusion program and providing scientific and technical support for JET, the large Euratom fusion project on an adjacent site, Culham Laboratory undertakes contract research on electrotechnology, laser application, and electrostatics. Stimulated by the growing interest in directed energy applications, the laboratory has undertaken general exploratory studies of high-power microwave sources based on relativistic electron beams, electromagnetic propulsion, repetitive switching, and compact power supplies based on rotating machines. In the latter connection, a small experimental compensated pulsed alternator has been built.

Culham Laboratory has a unique pulsed-power facility in its Lightning Studies Unit where a combination of capacitor banks rated up to 700 kV, 200 kA, and 1 MJ provide simulation of lightning strikes on aircraft components and mockups. It is used for studies of direct damage and the effect of electromagnetic coupling on internal components. There is also a portable capacitor bank that is available for off-site tests on whole aircraft. The knowledge gained from the lightning simulation work is being increasingly applied to the study of EMP effects in general.

University of Strathclyde

The Power Engineering Research Group at the University of Strathclyde, Scotland, with seven permanent staff and about 20 research workers, is the largest university group actually doing research on general pulsed-power technology, rather than using it for a specific purpose. The background of the group is in high-voltage power engineering, but they are in a strong position to turn their expertise onto the more experimental aspects of pulsed power, and are particularly interested in the role of materials in pulsed-power engineering.

International Research and Development Company

Finally, at the heavy end of pulsed power represented by rotating machines, the International Research and Development Company (IRD) of Newcastle-upon-Tyne has a long involvement with homopolar generators and motors, principally for low-speed application such as ship propulsion. These machines, having great

inertia and formidable overload capability, are ideal sources of large amounts of electrical energy, albeit at rather slow rates of delivery on account of their inherently low voltage. Their best use is to charge inductors, from which energy can be extracted more rapidly by opening switches. IRD has recently built a complete energy storage system consisting of a 6.7-MJ homopolar delivering a peak current of 700 kA in 0.25 s into a toroidal inductor. A larger system, delivering 3-4 MA is in the design stage. The principal application is electromagnetic (EM) launchers, and the 6.7-MJ system, in fact, has been delivered to the Royal Armaments Research and Development Establishment (RARDE), at Sevenoaks, Kent, for this purpose.

A program on EM launchers was begun at RARDE in 1981. It now includes work on mathematical modeling of EM gun systems and an experimental program involving a number of EM guns. Two of these are railguns: Remgun 2 is driven by a 7.35-kJ capacitor bank and will accelerate a 2-g projectile to 500 m/s; Remgun 3, currently being installed, is driven by the IRD homopolar and will drive a 200-g projectile to over 2000 m/s. Two other launchers, Remguns 4 and 5, based on the linear induction accelerator principle (a pulsed version of the linear motor), will be installed in April 1986. There is some emphasis on the applications of the EM gun as a tank gun; it is estimated that this would require a 25-MJ pulsed-power system weighing no more than 3 tons.

Conclusion

This summary of the presentations at the second meeting of the UK Pulsed-Power Group should give some indication of the range of pulsed-power interests and activities in the UK. Further meetings of the group may bring to light other activities, and the existence of this group may stimulate new ones. A short course on pulsed power is planned for later in the year. Further information concerning the UK Pulsed-Power Group may be obtained from: Dr. Hugh Bolten, Department of Electrical Engineering, Imperial College of Science and Technology, Exhibition Road, London SW7 2BT.

3/20/86

News and Notes

FLUID MECHANICS AT THE UNIVERSITY OF GHENT

The fluid mechanics activity at the University of Ghent in Ghent, Belgium, is centered in the mechanical engineering department, which is headed by Professor H. Somerling. Of the 164 engineering students who are presently in their fifth (final) year at the university, approximately one-quarter are mechanical engineers. The teaching responsibilities in the department are divided amoung the three chaired professors in the areas of turbomachinery, internal combustion engines, and machine design. Professor Somerling serves as the Professor of Turbomachinery as well as the head of the department. The host on my visit was Dr. Erik Dick, a senior research assistant who received his Ph.D. from the University of Ghent in 1980. Dr. Dick is responsible for the computational fluid dynamics work in the department.

Dr. Dick is a very capable, enthusiastic, and productive faculty member. Since his dissertation, which he wrote on acceleration methods for the Euler equations, Dr. Dick has worked on Petrov-Galerkin methods for advection-diffusion problems, flux-difference and flux-vector splitting for both Euler and Navier-Stokes equations, multigrid methods, free vortex methods (in connection with vertical axis wind turbines and helicopter rotors), and numerical simulation of transitional boundary layers. The university's mainframe computer is a Siemens 7751. Dr. Dick's work represents a productive blend between pure computational and experimental methods. The department has a small wind tunnel for blade and cascade studies as well as a larger (approximately 4 ft by 4 ft) free jet propeller-driven tunnel for wind energy studies. Dick purposely limits his experimental investigations to those problems which support his computational modeling activities. In this connection he has done experiments on vertical wind turbines with articulated blades, concentrator concepts for wind energy systems, and helicopter rotor experiments. His wind energy work is currently supported by the Belgian National Science Foundation.

I was impressed by Dr. Dick's familiarity with, and contributions to, a wide variety of computational fluid

dynamic methods. By his own admission his contributions have not had the scientific impact which he had hoped they would. To some extent I feel this is due to the rather limited computational resources he has at his disposal, and to the limited exposure which he has to those individuals who are at the forefront of current computational fluid dynamics research. Three years ago he was able to overcome this isolation by spending 7 weeks in the computational fluid dynamics group at the NASA Ames Research Center headed by H. Lomax. He needs this sort of experience again. I would like to arrange for him to spend a similar length of time at one of the Naval Laboratories. If you have a suitable project please let me know.

Eugene F. Brown
3/27/86

INTERESTING FEATURES IN WEST GERMANY'S PROPOSED NEW RESEARCH AND TECHNOLOGY BUDGET

The total 1986 Research & Development budget of West Germany will amount to DM54 billion (about $19 billion), 4 percent above the 1985 figure. Of this, DM7.45 billion (over $2.6 billion) is to be earmarked for the Federal Ministry for Research and Technology (BMFT).

Within the BMFT budget, basic research is granted a very high priority in the 1986 budget. It increased by 8.9 percent relative to 1985. Large-scale equipment for basic research, including costs toward a European transsonic wind tunnel, continental deep-well drilling facilities, participation in the French Ariane V launch vehicle project, and the space station Columbus also play an important part. Key technologies will amount to 26.5 percent of the overall BMFT budget, an astounding 17.3 percent increase over last year's relative allocation.

An important feature of the new budget is an increase in the available resources for improving basic conditions for research, development, and innovation within the private economic sector and for promoting cooperation between the scientific and economic (industrial) sectors.

Table 1 is a list, by budget categories, of some of the specific research areas which show significant gain, and those which show notable loss, relative to the 1985 BMFT budget.

The new budget, especially the substantial shifts to basic research aimed at providing greater initiative in all areas to the economic sector (i.e., private industry) demonstrates that the new German research policy set forth in 1984 has now been effectively translated into action.

Table 1

Gains and Losses (percent)

Basic Scientific Programs	+13.3
Research in natural sciences	+18.4
Geosciences	+26.4
Arts & social sciences	+10.1
Long-Term Programs	+13.8
Space research/technology	+17.7
Polar research	+14.3
Living Conditions	+ 4.6
Water-related research	-14.9
Climate research	+26.5
Safety research	+11.1
Infrastructure Technologies	-15.5
Renewable energy sources	-10.5
Nuclear energy research	-20.0
Raw materials	-29.7
Key Technologies	+17.3
Information technology	+16.5
Biotechnology	+29.4
Chemical processing technology	-14.8
Physical sciences technologies	+22.6
Aviation research	+15.4
Technology transfer, economic improvements	+44.6

Paul Roman
2/13/86

BRISTOL PROFESSOR PLANS INNOVATIVE EXPERIMENTS IN MOLECULAR ELECTRONICS

Professor C. Honeybourn, at the Science Department of Bristol Polytechnic, is an expert in synthetizing and growing organic crystals with unusual electrical or optical properties. Another well established research line in his modern and well equipped laboratory concerns itself with the study of surface properties of doped organic films. But currently he is getting more and more involved in pursuing potentialities in the exciting but essentially yet untested area of molecular electronics and electro-optics. During a visit in February, I learned that he has three major projects in mind.

Two-dimensional organic systems with extremely high third-order nonlinear optical coefficients. Polydiacetylene chains are known to have a quasi-one-dimensional conducting spine. Honeybourn proposes to dope polydiacetylene chains with alternating acceptor and donor sidegroups. By proper crystallization procedures the spines would then align themselves so that donor (D) and acceptor (A) groups face each other. This will cause strong perturbation of the one-dimensional effects, and calculations indicate the emergence of unusually high 3rd-order nonlinear optical coefficients (χ_3). The proposed arrangement is sketched in Figure 1a, while Figure 1b and 1c give examples of possible D and A side-chains.

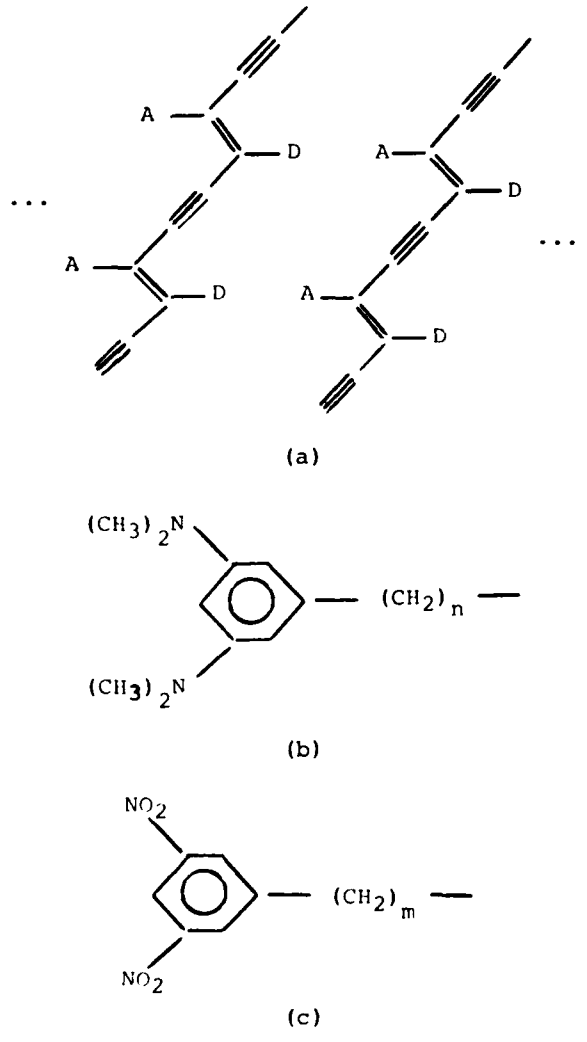

Figure 1. (a) Doped, aligned polydiacetilene chains; (b) a donor structure D; (c) an acceptor structure A.

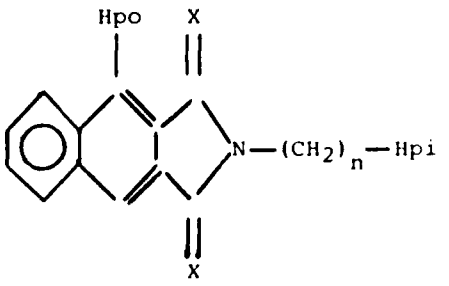

Figure 2. Ordered photochromic molecule.

Optical memories. It is well known that a group of simple multicyclic molecules, called photochromics, exist which, upon irradiation, undergo a rearrangement of conjugate bonds and thereby change their color. Honeybourn intends to affix on such molecules one hydrophobic (Hpo) and one hydrophilic (Hpi) group (the latter probably at the end of a chain). This would allow for fabricating a Langmuir-Blodget film. "Writing" on such a film could be done by an ultraviolet laser, and "reading" by a visible frequency low-power light source. An example of such a substance is shown in Figure 2. Here X stands for O, Se, or S. The Hpi attachment could be as simple as COOH.

Optomagnetic switching. Honeybourn synthetized recently a long, helical-structured molecule that exhibits exceptionally high optical activity (in the sense of the term used by the chemists; i.e., it has a very high molar rotation constant). He is also devising an effective method to separate the right and the left rotating stereomers. (Because of proprietary reasons, no further information can be obtained at this time regarding the precise chemical nature of the material.) Honeybourn pointed out to me that if a polarized laser beam with a sufficiently strong electric field propagates along the helical axis, electrons will be forced to move along the helix and generate a magnetic field just as it happens in a current-activated solenoid. If the active molecule does have an unusually high molar rotation constant, the magnetic field may be well above the level of detectability. Honeybourn proposes to make a one-dimensional solid from one (say the right-handed) stereomer, and build this layer on top of another one which senses the magnetic field. In this manner, making use of the magnetic interaction, a light-operated switching device could be constructed.

Honeybourn is well aware of the fact that, as is generally the case with current ideas in the newly proposed science of organic molecular electronics, there may be a long (and perhaps even hopeless) path from his new ideas to actual devices. Nonetheless, his ideas deserve serious attention, the more so since he has proved his sincerity and competence in more conventional areas.

Paul Roman
3/4/86

PHASE CONJUGATE RING RESONATORS AT IMPERIAL COLLEGE

Somewhat more than a year ago I gave an overview of the broad laser research activities pursued at the Optics Section, Department of Physics, at Imperial College, London, UK (see *ESN* 39-5:211-217 [1985]). During a recent visit I was fascinated by the progress made in the nonlinear optics area, under the direction of Professor M.H.R. Hutchinson, who cooperates with Dr. M.J. Damzen and Mr. W.A. Schroeder. Briefly, they succeeded in constructing phase conjugate ring resonators (PCRR) which incorporate stimulated Brillouin scattering (SBS) in four-wave mixing configurations.

It is known that when a phase conjugate mirror is used in place of a conventional resonator mirror, intracavity distortions produced by the laser amplifier or the cavity optics may be corrected. But if SBS is used for phase conjugate mirrors, a frequency chirp will be produced due to the successive Stokes shifts in the SBS medium. The Imperial College group circumvented this problem by building a PCRR. In such a device the successive Stokes and anti-Stokes scattering in a Brillouin enhanced four-wave mixing configuration nullifies the chirp.

In its simplest form the PCRR consisted of an SBS four-wave mixing cell and an Nd:YAG amplifier medium arranged in a ring cavity. A pulse from a single-mode, Q-switched Nd:YAG oscillator (ω_L) was injected into the SBS cell, and this, together with its phase conjugate Stokes beam ($\omega_S=\omega_L-\omega_Q$), formed a pair of conjugate pump beams. The ring also has been seeded with a small fraction of the oscillator pulse, and the corresponding cavity radiation at the laser frequency ω_L was phase conjugated by overlapping it in the SBS cell with the pump beam. The resulting down-shifted Stokes wave ($\omega_S=\omega_L-\omega_Q$) propagated through the laser amplifier, and was then injected into the back of the SBS cell. Here it was upshifted ($\omega_L=\omega_S-\omega_Q$) by a similar SBS four-wave mixing process.

Careful investigations were carried out concerning the effects of the states of polarization of the four beams in relation to achieving high reflectivity of the probe beams. Under appropriate conditions, reflectivities greater than unity have been obtained. But it was found that pump depletion can significantly reduce the Brillouin reflectivity and alter the cavity dynamics.

Current experiments proceed in two directions. First, a new scheme is being devised which will employ two separate SBS four-wave mixing mirrors. Second, the exciting possibility of self-pumping the currently built resonator is under advanced investigation.

Paul Roman
3/3/86

ONRL COSPONSORED CONFERENCES

ONR, London, can nominate two registration-free participants in the conferences it supports. Readers who are interested in attending a conference should write to the Scientific Director, ONRL, Box 39, FPO New York 09510.

The Interaction of Molten Salts and Metals: Current Understanding of Hot Corrosion and New Approaches to Practical Problems, York, UK, 2-4 July 1986.

International Optical Computing Conference, Jerusalem, Israel, 7-11 July 1986.

Naval Applications and Environmental Chemistry of Organotins, Padua, Italy, 11 September 1986.

Sixth International Symposium on Gas Flow and Chemical Lasers, Jerusalem, Israel, 8-12 September 1986.

Fractals and Chaos, Centro A. Volta, Como, Italy, 18-19 September 1986.

Aerodynamics at Low Reynolds Numbers, London, England, 15-17 October.

SCIENCE NEWSBRIEFS FOR MARCH

The following issues of *Science Newsbrief* were published by the ONR, London, Scientific Liaison Division during March. *Science Newsbrief* provides concise accounts of scientific developments or science policy in Europe and the Middle East. Please request copies, by number, from ONR, London.

Science Newsbrief Number	Title
4-5	Short Course on Adaptive Signal Processing with Applications to Underwater Systems, by J. Thomas Warfield
4-6	Air-Ocean Conference in London Sept '86, by LCDR Rich Kelley, USN.

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MARCH MAS BULLETINS

The following *Military Applications Summary (MAS) Bulletins* were published by the ONR, London, Military Applications Division during March. The *MAS Bulletin* is an account of naval developments in European research, development, test, and evaluation. Its distribution is limited to offices with the US Department of Defense. DoD organizations should request copies of the *Bulletins*, by number, from ONR, London.

MASB Number	Title
17-86	Helmet-Mounted Acquisition and Target Indicating System (HATIS)
18-86	Seastar-CIWS Target Designed in the UK
19-86	Aircraft Cockpit Direct Voice Input Technology From Smiths Industries in the UK
20-86	A 100-Ton Submarine Design From Italy
21-86	Low Maintenance Strip Heating Systems for Shipboard Weapons Systems
22-86	Fiber-Optic Crack-Detection Applied to Marine Welds
23-86	Ultrasonic, Non-Doppler Current Measurement
24-86	Oceanology International '86--Overview
25-86	15th Congress of the International Council of the Aeronautical Sciences London, UK, 7-12 September 1986

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ONRL REPORTS

To request reports, indicate the report number on the self-addressed mailer and return it to ONR, London.

C-1-86 *GAMM Conference on Numerical Methods in Fluid Mechanics*, by Eugene F. Brown. Presentations on aero-acoustic modeling, transition control, vortex shedding, domain decomposition methods, TVD calculations, viscous/inviscid interaction, and Euler solutions are reviewed. Papers dealing with methods (in contrast with applications) were stressed at this meeting.

C-2-86 *Turbulent Shear-Layer/Shock-Wave Interaction*, Eugene F. Brown. Presentations given at the September 1985 symposium of the International Union of Theoretical and Applied Mechanics (IUTAM) are reviewed. This report concludes that calculation of two-dimensional shock-wave/boundary-layer interaction problems is advancing well. For three-dimensional flows, accurate numerical calculation needs more experimental data to clarify the mechanisms and flow structure involved. Of greatest priority in this area is obtaining accurate unsteady measurements so that the mechanism of shock oscillation and its results on the flow field can be better understood.

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