Physics in Canada
La Physique au Canada

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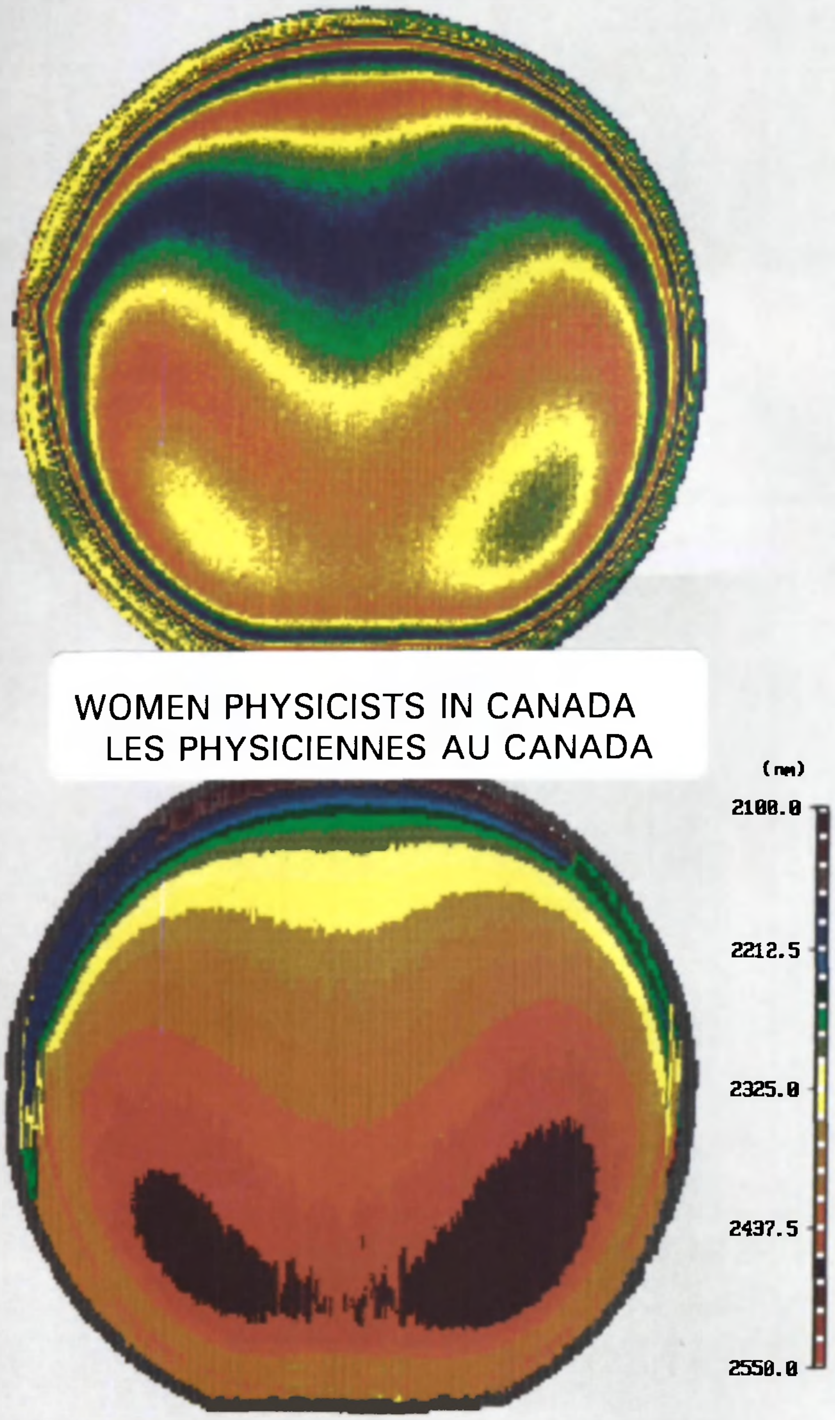

WOMEN PHYSICISTS IN CANADA
LES PHYSICIENNES AU CANADA

FEATURING:

Canadian Publications Product Sales Agreement No. 0484202/ Envois de publications canadiennes numéro de convention 0484202

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OF PHYSICISTS

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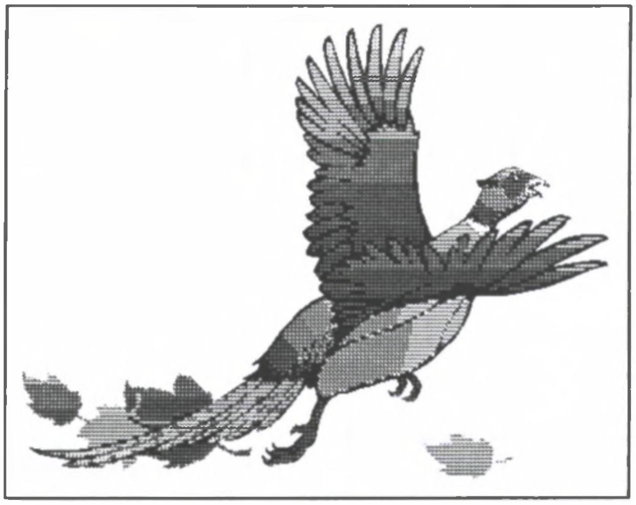
151 RUE SLATER STREET, SUITE 903, OTTAWA, ONTARIO CANADA K1P 5H3
TELEPHONE: (613) 237-3392 FAX: (613) 238-1677 E-MAIL: CAP@physics.carleton.ca

WE

ARE

MOVING!!



Effective **1996 May 14**, the Canadian Association of Physicists can be reached as follows:

BY MAIL (or in person)	Suite 112 McDonald Building 150 Louis Pasteur Ave. OTTAWA ON K1N 6N5
BY TELEPHONE	(613) 562-5614
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BY IUTS (Ontario Univ.)	Station 6B
OFFICE HOURS	8:00 a.m. to 4:30 p.m.

We look forward to our continuing interactions with you.

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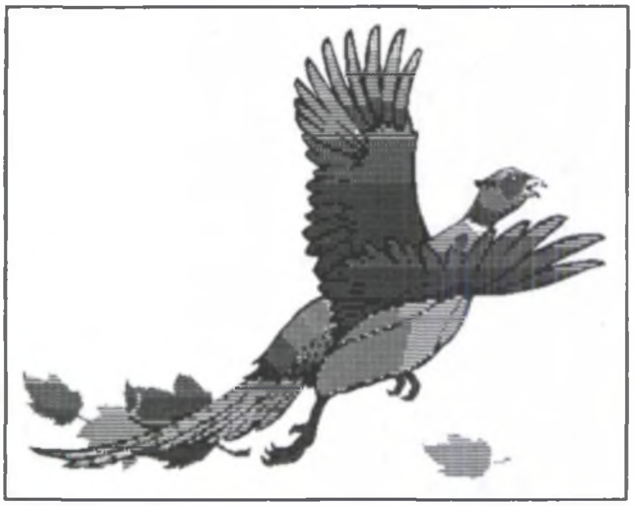

NOUS

DÉMÉNAGEONS !

Le **14 mai 1996**, l'Association canadienne des physiciens et physiciennes occupera ses nouveaux locaux dont les coordonées sont les suivantes:

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TÉLÉCOPIEUR	(613) 562-5615
ADRESSE ÉLECTRONIQUE	CAP@physics.uottawa.ca
IUTS (Univ. d'Ontario)	Station 6B
HEURES D'OUVERTURE	0800 h à 1630 h

Au plaisir et à bientôt.

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INDEX

FEATURE TECHNICAL ARTICLES:

FEATURE NON-TECHNICAL ARTICLES:

FRONT COVER: Fig. 2, "III-V Semiconductor Characterization for Optoelectronics" by C.J. Miner (pg. 90). (Top) The reflectance at a wavelength of 1000 nm is displayed for an InP layer grown on an $In_{.53}Ga_{.47}As$ marker layer. (Bottom) With the additional information inferred from at least one reflectance spectrum for each fringe, the sRS map can be translated to this thickness map.

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The Bulletin of The Canadian Association of Physicists

Bulletin de l'Association canadienne des physiciens et physiciennes

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EDITORIAL -

It is an honour to be the first woman invited to be the special editor of Physics in Canada, in particular for a special issue on Women Physicists. I made a presentation at the CAP Congress on the subject of "Women in Physics - a Matter of Education" in Edmonton in 1986. Thus, it is especially interesting for me to revisit the subject of woman physicists after a decade and a particular delight to present this special issue of Physics in Canada celebrating their contribution and presenting their view of physics in Canada. However, it is with some trepidation that I write an editorial on this subject. Special editors that have not "stuck to their knitting" have not received particularly gentle treatment in Canadian physics journals in the past.

"Woman physicist"....some feel that this expression is an oxymoron. On the other hand, many people, indeed many women, feel that barriers for women who want a career as a physicist have been effectively dealt with through policies on maternity leave, wider access to day care, universal medical benefits and the like. "Suffragettes" of yesteryear who chained themselves to fences to win the vote for women would undoubtedly be amazed to see the changes in today's world in which it is possible for women to integrate career and family life in a seamless way. Yet, the survey of university physics departments reported on in this issue indicates that only 13% of Canadian PhD students in physics are women and there remain major university physics departments which have no female faculty members.

Indeed, there has been substantial cultural change in Canada with respect to the role and position of women. "Women in Canada, A Statistical Report" released by Statistics Canada in August, 1995, summarizes the status of women in Canada in the early ninetys. There is good news and not so good news. There has been an increase in the participation of women as university students in general. In the 1992-93 academic year, women accounted for 52% of all full time university students. In some scientific disciplines representation of women has increased dramatically. In 1994, women made up 32% of all doctors and dentists, up from 18% in 1982. An education pays. While at all levels of educational attainment women's earnings remain lower than those of men, female university graduates employed full-time, earned 75% as much as their male colleagues in 1993, while the average pre-tax income of all women aged 15 and over was only 58% of the average income of men. The employment rate of women increases dramatically with educational attainment. In 1994, 77% of female university graduates as compared with 82% of male graduates were employed.

There is also some not so good news for women. This same report says that in 1982, 15% of professionals employed in the natural sciences, engineering and mathematics were women and in 1994 this has risen to only 19%. Though women do make up more than half of full time university students, in 1992-93 women made up just 35% of those working full time toward their doctorates. In 1994, 70% of all employed women worked in teaching, nursing and related health occupations, clerical positions, or sales and service occupations compared to 31% of men. Thus, many women continue to pursue career paths that are traditional to them, and physics is not one of these. It is interesting to reflect on these statistics in the context of Alison Prentice's article on women in physics decades ago in Canada.

These dry statistics show that while advances have been made over recent decades, for whatever reason, there are career differences between women and men which persist in our culture. Reasons are too many to explore here and the discussion could become long, and riddled with non scientific opinion and debate. The facts speak for themselves.

The objective of this issue is to present an overview of woman physicists in Canada as we approach the end of the millenium. As you will see, we have much to celebrate in the contributions of women to physics in Canada. As you will also see, these contributions go far beyond the intellectual...the presence of these women is beginning to strengthen the fabric of our profession and to stretch it, as some of the profiles of student, married couples and newcomers to Canada illustrate.

The Canadian Association of Physicists has supported a Committee to Encourage Women in Physics (CEWIP) since 1983. Interestingly enough, the committee was initiated by men and has been supported by them throughout its history. The "two Jim's" as they have come to be affectionately known are Jim Prentice and Jim Megaw. Both now retired, these two acted as mentors and examples for many women who participated in the committee over the past decade. Remarkably, it has been men who like women and respect their contribution to the community who have made the committee workable. In the early years, Mona Jento, then Secretary of the CAP and herself a science graduate and pioneer, was an active supporter and participant. A major problem has been getting women to become involved with the committee and to take on work associated with it. The common thread is that women have too much to do.

The current chair of the committee is Debbie Poirier, whose profile is featured in this issue. Please provide comments and advice on the direction of the committee to her. Her e-mail address is

The CEWIP has been a truly national committee with corresponding membership of about 20 people from coast to coast. Each individual member of CEWIP undertakes their own slate of activities which typically include career talks, collection of *information on some aspects of* the issue, or liaison with other organizations interested in women in science. For, example Jim Megaw undertook a survey of all the universities in the world to obtain data about the participation rates of women in physics and reported on "Gender Discrimination in the World's Physics Departments" at the Gender and Science and Technology meeting in Australia in 1991. The committee has undertaken some additional specific actions:

- Until 1987 there had rarely been a woman on the CAP Lecture Tour. In order to change this situation, names of outstanding woman speakers were included (with the Education Division's permission) on the CAP list for several years. Inevitably the women received more speaking invitations on average than the men. Mary Anne White, whose profile appears herein, was one of the first and most popular. Lately, the departments have been nominating woman speakers directly.

- A Directory of Women in Physics in Canada has been developed. This directory is now with the CAP office for use by potential employers, seekers of graduate students. The committee is looking for someone to take on the continued responsibility of updating the list and ensuring its availability.

- Meetings are held several times a year, always at the CAP Congress in whichever city it occurs and, additionally, in Quebec or Ontario. There was a women's session at CAM 95 in Quebec City which included Mexican and American physicists.

The Canadian committee has chosen a low keyed approach to the equity issue and tries to weave a thread of consciousness about the issue into the business of the CAP. The APS has taken a more high profiled approach and some of their excellent programs are described in this issue.

This issue takes *the Canadian approach*. We have no strident demands to present. We do have an overview of the tremendous present and potential future contribution of women to physics in Canada. We have a collage of technical writings over a broad selection of fields, some nontechnical papers on a variety of topics related to women, and some profiles of woman physicists and physics couples who say in their own way what physics is all about in Canada today. These profiles capture the enthusiasm and creativity of woman physicists and although none of them highlight major issues within the community, some common themes emerge. The one that emerges most clearly has little to do with overt barriers or discrimination. It is the difficulty of managing dual careers in physics. In today's tough economic climate it is difficult to manage one science career. It is not surprising that it is vastly more difficult to manage two. Numbers are part of the issue here. Most women in physics, according to the APS, if they marry, marry men in science (see Anna Hayes' and Steve Sterbenz' profile for numbers). The women are typically somewhat younger than the men and hence not as far along in their careers when they enter the marriage. Thus, when a family is desired, it is likely to make excellent sense for the woman to give up or postpone her career. Unfortunately, many of these highly competent and enthusiastic women never return to the field. On top of all the domestic issues they must deal with, there are a host of rules against nepotism, etc, that can limit a woman's opportunity to find suitable employment in the same geographical area as her husband. This issue arises again and again in the statements provided by women in this issue. Solutions range from long range commuting to challenging the system. Unfortunately, whatever the solution it is likely to have ongoing impacts on the woman's happiness and her career, not to mention her family. It is clear that one piece of advice that should be passed on to women students is to ensure that the man she marries is supportive of her maintaining a career. That support can be crucial to ensuring increasing participation of women in the physics community. Understanding the issue can help the physics community deal with such couples in a more humane way.

Please read on and enjoy. We are interested in your response to this issue.

Dr. Ann C. McMillan
Guest Editor

ERRATUM

In the "Ph.D. Degrees Awarded at Canadian Universities in 1995" section of the 1996 January/February issue of *Physics in Canada* Abdul Elezzabi was inadvertently listed as currently at a Post Doctorate Fellowship at the University of Edmonton. This entry should have read the University of Alberta. Our apologies to all current and former graduates/employees of the University of Alberta for this error.

Additional Reading Suggested by our Readers:

A Passion for Physics - The Story of a Woman Physicist
Joan Freeman
IOP Publishing, Bristol, England 1991

Another source of information is an international reference listing and biographical directory of some notable women scientists from ancient to modern times. "Women Scientist from Antiquity to the Present: An Index" was published by Locust Hill Press, West Cornwall CT in 1986, and is available from the publisher and is in most major university libraries. It includes women in mathematics, medicine, and engineering; there are over 2500 individual entries that will help you locate further biographical information on all of these women. You may find this book useful - it was developed in part to respond to such statements as "Women scientists? Other than Madame Curie, I can't think of any," which expressed an attitude that was even more prevalent before this book was published.

Carol Herzenberg

Women Scientists in America: Before Affirmative Action 1940-1972. By Margaret W. Rossiter, John Hopkins University Press: 1995.

D. Poirier
INRS

CALENDAR / CALENDRIER

1996 JUNE TO 1997 JUNE

Combinations and Group Theory
The Centre de recherches mathématiques is hosting a year-long program in combinatorics and group theory in 1996-97. The year will be organized around a certain number of workshops spread throughout the year. For a schedule of events, please contact: Louis Pelletier, CRM, Université de Montréal, CP 6128, Succ. Centre-Ville, Montréal, QC, H3C 3J7 or e-mail to: ACTIVITES@CRM.UMontreal.CA; WWWhttp://www.CRM.UMontreal.CA

1996 JUNE

7-11 European Research Conference on Fundamental Aspects of Surface Science: Semiconductor Surfaces, C. Sebenne (Paris) - Blankenberge, Belgium. More information can be obtained on the World Wide Web server at: http:\\www.esf.org

9-12 CNA/CNS Annual Conference, New Brunswick. For more information, please contact: Ms. Tatiana Wigley, CNA/CNS Office, Toronto Ontario. Tel: (416) 977-6152; Fax: (416) 979-8356.

16-19 CAP Annual Congress, University of Ottawa, Ottawa, Ontario. For Congress Information see 1996 January/February Physics in Canada or Congress section of Univ. of Ottawa home page at http://www.physics.uottawa.ca/

1996 SUMMER

Physics in Industry International Conference, Nyzhny Novgorod, Russia. For more information, please contact: Professor S.P. Kapitza, Euro-Asian Physical Society President, 17 Kursovoy, Moscow 119034, Russia. Fax: (095) 943-76-77; E-mail: marina@eaps.msk.ru.

1996 JULY

8-10 Third International Workshop on Laser Beam and Optics Characterization / 3e Atelier international sur la caractérisation des faisceaux et de l'optique laser, Québec, QC. Pour plus d'information, veuillez contacter Michel Morin, Institut national d'optique, 369, rue Franquet, Sainte-Foy, QC, Canada, G1P 4N8, Tel: (418) 657-7006, Fax: (418) 657-7009; cour.élec: morin@ino.qc.ca.

1996 AUGUST

5-9 Zeeman-Effect Centenary/ International Conference on Atomic Physics XV (ZICAP), Van der Waals-Zeeman Laboratory, University of Amsterdam, Valckenierstraat 65, 1018 XE Amsterdam, The Netherlands. For more information, please contact: A. Donszelmann at Tel: +31 (20) 5256334, Fax: +31 (20) 525 5102, e-mail: zicap@phys.uva.ni.11-23

11-23 CRM Summer School/Combinatories and Group Theory, Banff, Alberta. For more information contact: CRM Summer School, CRM, Université de Montréal, CP 6128, Succ. Centre-ville, Montréal, QC, H3C 3J7, e-mail: ACTIVITES@CRM.UMontreal.CA, Fax: (514) 343-2254, Tel: (514) 343-2197

17-24 8th International Organization of Science and Technology Education (IOSTE) Symposium, Edmonton, Alberta. For more information, please contact: Continuing Professional Education: Faculty of Education, University of Alberta, 4-116 Education North, Edmonton, Alberta, T6G 2G5, Tel: (403) 492-0394, Fax: (403) 492-0390.

19-23 17th General Congress of the International Commission for Optics, Taejon, Korea. Theme: "Optics for Science and New Technology". For more information, please contact: ICO-17('96) Secretariat, Prof. B.Y. Kim, Department of Physics, KAIST, 373-1 Kusong-dong,Yusong-gu,Taejon 305-701, Korea. Tel: +82-42-869-2527; Fax: +82-42-869-5527.

27-30 2nd International Conference on hyperons, charm and beauty baryons, Concordia University, Montreal, Quebec. For more information, please contact: Lynn Chapman-Baker, Physics Dept., Concordia University, Montreal, QCH3G1M8;Beauty@vax2.Concordia.ca

1996 SEPTEMBER

Aug.31- Sept. 5 European Research Conference on Advanced Quantum Field Theory: Integrability, Conformal Invariance, Topological Field theory and Applications, V. Rittenberg (Bonn) - La Londe-les-Maures, France. More information can be obtained on the World Wide Web server at: http:\\www.esf.org

9-13 EPS 10 Trends in Physics, 10th General Conference of the European Physical Society, Sevilla, Spain. For more information, please contact: Organizing Secretariat, Proconsur, Avda. San Francisco Javier nº 15, 4°, E-41018 Sevilla (Spain) Tel: (34-5) 492 27 55

16-19 Deep Geologic Disposal of Radioactive Waste, Winnipeg, Manitoba. For more information, please contact: Mr. C. Vandergraaf, AECL Research - WL, Pinawa, Manitoba, ROE 1LO. Tel: (204) 753-2311 ext 2592.22-26

21-26 European Research Conference on Quantum Optics, K. Burnett (Oxford) - Castelvecchio Pascoli, Italy. More information can be obtained on the World Wide Web server at: http:\\www.esf.org

22-26 Physics and Industry (PHYSIN-96), Nyzhny Novgorod (Russia). For more information please contact: Euro-Asian Physical Society, 17, Kursovoj bystr., Moscow, 119034, Russia. Tel: (095) 943-7677; Fax: (095) 943-7686, e-mail: marina@eaps.msk.ru.

24-26 BEM 18: 18th International Conference on Boundary Element Methods, Braga, Portugal. Abstract deadline December 18, 1995. Final paper due April 29, 1995. Sponsors: International Society for Boundary Elements. for more information contact Liz Kerr, Wessex Institute of Technology, Ashurst Lodge, Ashurst, Southampton SO40 7AA, UK. Tel: (44)(1703) 293223, Fax: (44)(1703) 292853, E-mail: cmi@ib.rl.ac.uk.

1996 SEPTEMBER

Sept. 28- Oct. 3 European Research Conference on Chaotic Phenomena in Nuclear Physics S. Aberg (Lund) - Aghia Pelagia, Crete, Greece. More information can be obtained on the World Wide Web server at: http:\\www.esf.org

1997 JULY

1-7 Joint Scientific Assemblies: International Association of Meteorology and Atmospheric Sciences / International Association for the Physical Sciences of the Oceans, Melbourne, Australia. For more information, please contact: IAMAS/IAPSO Secretariat, Convention Network, 224 Rouse Street, Port Melbourne Victoria 3207 Australia. Tel: +61 3 9646 4122; Fax: +61 3 9646 7737; e-mail: mscarlett@peg.apc.org.

25th International Cosmic Ray Conference, Durban, South Africa. For more information contact: National Organizing Committee 25th ICRC, Space Research Unit, Department of Physics, Potchefstroom University for Che, Potchefstroom 2520, South Africa. Tel: +27-148-2992423, Fax: +27-148-2992421, E-mail: ICRC97@PHYSICS.PUK.AC.ZA

MARK YOUR CALENDARS
-- FUTURE CAP CONFERENCES --

CAP 1997 Annual Congress, 1997 June 8-11, University of Calgary.

CAP 1998 Annual Congress, 1998 June 14-17, University of Waterloo.

Any universities interested in hosting a CAP Annual Congress can send a letter of interest to the CAP Office, Bur./Suite 112, Imm. McDonald Bldg., 150 Louis Pasteur, Ottawa, ON K1N 6N5. The letter should include an indication of what year you are interested in, keeping in mind that the Congress travels Central-East-Central-West.

SCIENCE POLICY UPDATE / MISE À JOUR SUR LA POLITIQUE SCIENTIFIQUE

At the start of his term as CAP President, P.S. Vincett stated that the most important task for his Presidency would be (with the help of many others) to establish CAP as a truly effective voice for science, one which would speak to governments clearly and effectively on behalf of physics and of science as a whole. After an enormous amount of effort, it appears that this is becoming a fact; there are many in Ottawa who would now tell you that the CAP is one of a handful of leading voices for science both nationally and in many provinces. Now that the CAP has the resources and expertise in place, P.S. Vincett believes that the CAP can play a critically important role in the challenges which continue to face physicists, whether they be in a university setting or elsewhere. The CAP must speak for physics as a whole.

A report on science policy activities undertaken recently follows. Comments and suggestions are invited from CAP members. Please direct them to F.M. Ford, Science Policy Officer, Canadian Association of Physicists, Suite 112, McDonald Building, 150 Louis Pasteur Ave., Ottawa, Ontario, K1N 6N5; email CAP@physics.uottawa.ca.

LOBBYING

National Consortium

The CAP wrote most of the briefing paper on the Importance of Research which the National Consortium of Scientific and Educational Societies used in their meetings with a large number of Ministers and senior civil servants in November/December 1995. This paper focused on the importance of the whole spectrum of research, and particularly emphasized the importance of long-term work.

The Consortium recently asked its members for input regarding a Consortium science policy. D. McDiarmid, Director of Professional Affairs, felt, in consultation with P.S. Vincett, that from the CAP's point of view there are two issues which we feel must, among others, be part of any Consortium science policy document. These are:

1. That any science policy have as a goal the creation of a sustainable distribution of effort between basic science, applied science, development and commercialization of the developments.

2. A major impediment to the commercialization of Canadian research and development is the reluctance of our financial institutions to provide financing for late-stage development and initial producation of new products of small and medium sized enterprises. While the government has recently announced several programs to address this problem, it should be recognized as an on-going challenge requiring additional responses.

Productive Meetings with Government

This year the CAP joined with the Chemical Society of Canada (CSC) to conduct the first joint lobby effort. The mid-February meetings with Jon Gerrard, Minister of State for Science, Research and Development, and other government officials were attended on behalf of the CAP by Paul Vincett, President; Bev Robertson, Vice-President; Don McDiarmid, Director of Professional Affairs; and Francine Ford, Executive Director. CSC representatives included President Ron Steer; Vice-President Vedene Smith, and Executive Secretary Anne Alper.

Discussions with Gerrard focused on the long overdue report on the federal Science and Technology Review, how advice on science and technology is provided to government, the effect of the cuts to the transfer payments on university research and the need for resources to bring proven technology to the marketplace.

Gerrard emphasized the need for independent advice on science and technology issues. He said that the science lobby is diverse and not well versed in what is possible in government. He urged the scientific community to take the initiative and create a structure for providing coherent, clear advice to government.

With respect to the need for resources to bring proven technology to the marketplace, Gerrard referred to programs such as the new NRC-NSERC Industry partnerships and the Western Diversification Fund initiatives. We stressed the fact that it is still extremely difficult for small knowledge-based companies to obtain funds for new ventures.

The effect cuts to the transfer payments will have on research infrastructure at universities was also raised. Gerrard pointed out that the federal government does not get credit for the funds it invests here.

Gerrard advised us that the report on the federal S&T Review was to be released with the budget. His Department will hold briefings on the report for CAP, CSC and other organizations.

The effects of the cuts to the transfer payments on the research capability of universities were also discussed with Peter Adams, M.P., Chair of the Caucus Committee on Higher Education. Adams said his Committee was formed to address higher education issues and realizes the impact of these cuts. Adams said that teaching is the more obvious product of universities and research is less visible. Although he pointed out that it was then probably too late to influence the upcoming budget, he did feel that immediate action may influence future strategy. On his advice, the CAP and the CSC Presidents wrote to the Prime Minister urging that he give some indication in the Speech from the Throne on how this will be addressed in the longer term. The CAP's letter was distributed to CAP members by email on 1996 February 20. Subsequently a significant number of CAP members wrote similar letters to the Prime Minister expressing their concern over the current situation and urging a national solution in the longer term. Adams also urged our organizations to bring the message about the importance/existence of university research to the MPs in their local ridings. In a later meeting, Adams stated that the follow-up to these meetings by the physicists and the chemists has been very impressive.

The need for science and technology to have a higher priority on the government's agenda was raised in all our meetings. Arthur Carty, FCIC, President of the National Research Council, said that this will not happen until people are convinced of the value of S&T. He sees an important role for scientific societies in building science awareness with the public. Without this, future cuts to S&T budgets are inevitable.

Carty said that the government priorities are jobs and growth. We must work with industry to convince government of the role of science in this process. He said that a recent study has shown that the IRAP Program created 9,000 new jobs and saved 6,000 existing jobs. Funding for IRAP sunsets in 1998-99 and he would like our assistance in publicizing the value of the program.

The Economic Policy Secretariat in the Department of Finance provides advice to the Minister of Finance on macroeconomic policy and program design and development including advice on proposals brought forward by other Ministers. Peter Cameron, Group Chief, Industry, Regional and Corporate Policy in this Department, said there is a large science and technology effort currently in government departments which, with the thrust of the present government, he sees as moving to the private sector. The current low level of R&D done by industry, despite the relatively low cost of conducting research in Canada, was raised. Government procurement and world product mandates were explored as possible mechanisms for improving the situation.

The positive benefits of bringing new-technology to the marketplace and the need for start up funds for new knowledge based companies were also discussed. The government is doing things to make venture capital available but doesn't identify where it should be applied. Cameron said that the quality of graduates and the research coming out of Canadian universities is recognized internationally as extremely high. The need for programs to build on this research was identified.

The Science Promotion and Academic Affairs Branch of Industry Canada is responsible for policy on university research, science education and public awareness. Doug Hull, Director General of this Department, said strategic thinking in the science policy area has declined in government in recent years. He said that he is working to bring more people with scientific backgrounds into his Department. He also stressed the need for the science community to develop a mechanism for giving advice to government.

Hull expressed concern about the future viability of the Canadian university system and the ability of universities to cope with current cutbacks and address new challenges, such as education supplied to Canadians from abroad using computer networks.

Lobbying Can Have Results - University Advisory Committee

Usually one expects lobbying to be a long-term process with little of immediate interest to report. This does not appear to be the case for the CAP/CSC lobby effort in mid-February. Following the meeting with Doug Hull and some of his staff at Industry Canada, Bev Robertson, CAP Vice-President, received a call from Sue Milne of the University Liaison Section of Industry Canada in early March. The discussions with CAP/CSC triggered the establishment by Industry Canada of a consultative group of university people.

The University Advisory Board will be providing advice to Doug Hull, Director General, Science Promotion and Academic Affairs and through him to Industry Canada. The recently-released strategy document, Science and Technology for the New Century (http://canada.gc.ca/depts/science/main_e.html), emphasizes the importance of a national innovation system with strong linkages between job creation, economic growth, quality of life and advancement of knowledge - and notes the need for effective partnerships to provide the federal government with expert advice. This University Advisory Board should be in an excellent position to respond to this interesting challenge and opportunity.

Initial topics for discussion by the University Advisory Board include the commercialization of university research; distance education; international marketing of post-secondary institutions; S&T indicators; and research infrastructure.

Members of the University Advisory Board (from Western Canada to Eastern Canada) include:

Brett Finlay, University of British Columbia, Department of Microbiology and Immunology

Martha Piper, University of Alberta, Vice-President (Research and External Affairs)

Elizabeth Cannon, University of Calgary, Department of Geomatics Engineering

Ron Steer, University of Saskatchewan, Department of Chemistry

Bev Robertson, University of Regina, Department of Physics

Katherine Schultz, University of Winnipeg, Associate Vice-President (Research and Graduate Studies)

Heather Munroe-Blum, University of Toronto, Vice-President (Research and International Relations)

Bruce Hutchinson, Queen's University, Director of Research Services

Roger Lecomte, University of Sherbrooke, Department of Nuclear Medicine and Radiobiology

Gilles Delisle, INRS Telecommunications, Directeur de centre de recherche

Kelvin Ogilvie, Acadia University, President

Jaap Tuiman, Memorial University of Newfoundland, Vice-President (Academic)

PARTNERSHIP ACTION GROUP ON SCIENCE AND ENGINEERING (PAGSE)

As part of the CAP's thrust to improve interactions among science-based organizations, P.S. Vincett (CAP President), B.E. Robertson (CAP Vice-President), D. McDiarmid (Director of Professional Affairs), and F.M. Ford (Executive Director) met with Michael Dense of the Royal Society of Canada. The meeting focussed on the state of support for science within government (and the public in general). All parties agreed that a broad based science lobbying activity was becoming critical if the community was to have any influence on science policy in the future. Dr. Dense raised the possibility of the Royal Society taking a leadership role in this activity, which was strongly supported by the CAP representatives provided a clear mandate and terms of reference were presented to the potential participants at the outset.

Several meeting have now taken place,

at which the CAP has been represented by D. McDiarmid and B. Cyca (CAP Councillor-at-large). Although there is still a question as to whether this group will, in fact, form the national science lobby organization, one activity that was recently undertaken was the development of a joint response on the S&T Review report "Science and Technology for the New Century, A Federal Strategy". The CAP provided considerable input to this response, a copy of which follows this report.

This response was carefully drafted with the purpose that it open some doors for further PAGSE input to the government and its bureaucracy.

PROVINCIAL ENGINEERING ACTS

The efforts summarized in the October-December 1995 issue of Physics in Canada continue and have experienced success in Nova Scotia. The following is a resume of the more significant current activity.

NOVA SCOTIA: The new Nova Scotia Engineering Act is proceeding through the legislature. APENS has done what they said they would do, so we are close to our having first full province using the exemption clause.

MANITOBA: The proposed revisions to the Manitoba Act do not contain an exemption clause and the proposed definition of engineering practice leaves much to be desired. In addition to the proposed revisions, the Manitoba Association has also distributed to its membership the CCPE definition of engineering practice, including the CCPE/NSSC exemption clause, for feedback. Several CAP officials, including P.S. Vincett, have written the Manitoba Association urging them to adopt the exemption clause. Discussions with the Association continue with the very significant help of R.C. Barber.

SASKATCHEWAN: The Government of Saskatchewan has proposed a two stage revision process, making some changes now and conducting further study before making others. The NSSC/CCPE exemption clause will be considered during the second phase of this exercise. In the meantime, a different exemption clause will pertain. discussions continue with B. Robertson taking the lead.

ALBERTA: We recently discovered that the Association of Professional Engineers, Geologists and Geophysicists of Alberta is exploring the possibility of a specified scope of practice under its Act. This would allow some who do engineering-related work but do not have the required credentials for P.Eng. status to operate under the Act. Those receiving such status would not be full members of the Association and would not have final say on the conditions of their registration. The CAP wrote to urge the Association to first reduce the need for such status by including the NSSC/CCPE excemption clause in their Act.

NSERC-RELATED ACTIVITIES

The upcoming Review of Physics is an extremely important CAP response to the problems caused to university physics by the last NSERC Reallocation exercise.

The CAP has submitted two major position papers to NSERC: one on the Rellocation process and one on the Strategy Implementation Report. Recent informal indications are that many of the suggestions in the CAP's Reallocation paper will be followed next time; indeed, the future process may have much in common with our Review of Physics.

A CAP-NSERC Liaison Committee has been established and has been operational for approximately one year.

NATIONAL FACILITIES (NFs)

As you know, the CAP is particularly urging action on the looming university research infrastructure issue (arising from the reduction and redirection of the federal transfer payments to the Provinces) and on the threatened National Facilities. There are some significantly encouraging signs that the government seems to be starting to notice the concern of the CAP. However, further pressure from the community is still essential to build on this.

Within the last month letters have been written to Ministers Manley and McLellan and to Dr. Jon Gerrard regarding the impact of recent decisions regarding funding to Canada's national science facilities (Atomic Energy of Canada/Sudbury Neutrino Observatory, the Centre Canadien de Fusion Magnetique, and the Saskatchewan Accelerator Laboratory). On 1996 May 2, representatives of each of the affected parties, led by the CAP President, P.S. Vincett, met with Dr. Gerrard to discuss this matter. Also present was Paul Stottart who is on the political staff of NRCan Minister McLellan. We were told that Minister Manley had wanted to attend but was not able to clear his calendar. Gerrard indicated that he had been asked by Manley to find out more on the issues and that he would give him a full briefing. We continue to pursue meetings with Ministers McLellan and Manley. (We have been told informally that there is a good chance Minister McLellan will agree to our request for a meeting.)

During the meeting with Dr. Gerrard, Dr. Vincett again explained the community's alarm about (i) the university research infrastructure issue, and (ii) the National Facility problem and the lack of an integrated policy for NFs. He explained how the overall situation as a major national crisis for long-term research.

Dr. Gerrard indicated that they are now looking at a program to support the research infrastructure, although (even if they are successful) this could not see the light of day until the next budget. It is believed that the letters the physics community has already sent to the Prime Minister are starting to be of consequence; further pressure from the community could play a *crucial role*, especially if there is opposition to the program from other Ministers.

On the NF issue, Dr. Gerrard made some encouraging comments on the Neutron Scattering portion of AECL. In the cases of AECL-TASCC and CCFM, however, he was much less sanguine; the group sensed real concern but also felt that the dollars may be too large for Industry Canada to pick up the slack. When asked if he would be willing (with Minister Manley) to help the CAP set up a meeting between the Minister of Finance, some of the five Canadian Nobel Laureates who are helping the CAP in this campaign, and P.S. Vincett, Dr. Gerrard agreed to try to help.

This group of representatives also met with the editorial page editor of The Ottawa Citizen. The Citizen has carried a number of supportive articles and may be willing to do more. The CAP was asked to provide more information on this issue and to keep them informed on future actions. Interestingly, the editor felt that with enough grass roots pressure this could become a major public issue, and that if it did it could radically improve the government's approach to research generally.

In other developments, the Bloc has asked a series of questions in the House on CCFM (the Tokomak de Varennes), and the deputy Premier of Quebec (M. Landry) has written to the federal government. The Montreal Gazette has carried supportive articles, and the NF issue was on Quirks and Quarks on May 4th. P.S. Vincett will, in the near future, be sending a full review of the whole long-term research issue to the Globe and Mail. We hope that this will further raise the visibility of the situation.

GENERAL OBSERVATIONS AND COMMENTS

While the National Facility issue is very serious and urgent, it represents only one aspect of a much more serious problem: that the federal government as a whole (and there are honourable exceptions) does not really understand the importance of long-term research, and is pursuing policies which (perhaps unintentionally) are likely to seriously damage it. The infrastructure issue is perhaps the most obvious example. We must draw a 'line in the sand' now and say 'enough is enough'. If we do not do this, and if we do not defend physics with one clear voice, we have been told many times by politicians and civil servants that things will only get worse. The whole community must come to the defence of whichever part of us is under attack at any given moment. If we wait until our own institution or our own type of research is threatened, then the government will simply play the game of divide and conquer. One senior civil servant said to the CAP some time ago that 'we can pick scientists off one at a time'. To prevent this, we must speak as one community whenever a key part of the overall fabric of research is threatened.

In defending several specific parts of the community, we must always address broader issues and appeal to broader principles which all physicists can support. We must be very careful not to suggest that some other part of research be sacrificed to support another. There is no evidence that the situation is really a zero sum game. After all, the funds lost to science as a result of the actions on the national facilities have not been transferred to NSERC! Nor, as far as we are aware, was there any significant impact on the rest of science when TRIUMF received its renewal of funding last year. The fact is that money can be found if the government is convinced that the arguments re good and that enough people care. It is up to CAP to ensure that the arguments are stated clearly. However, it is up to the community to make sure that enough people speak out in support that the government is forced to listen.

The CAP will continue to do everything in its power to defend high quality research in all sectors from the effects of future budget cuts. The task of forming the next generation of researchers, and the scientific and technical leadership of tomorrow's Canada should be a primary objective of our society. CAP's task is to help create an environment where our universities and our other oustanding research institutions have the resources necessary to carry out these tasks. CAP will continue to work tirelessly to these ends.

We thank all the CAP members (and others) who have written in support of the CAP's April letter to the Prime Minister. We are now seeing that sustained and reasoned pressure can be heard. Those who have not written to Dr. Gerrard, Minister Manley, and the other Ministers involved should give serious consideration to doing so now (the fax numbers are given below). Equally important - as stressed by almost every government representative we have met - call or write your local MP and MPP/MLA/MNA. Emphasize whichever issue is of most concern to you, or discuss them both, but let's keep up the pressure!

The Rt Hon. Jean Chretien: (613) 941-6900

Dr. Peter Adams, M.P. (Chair, Liberal Caucus Committee on Higher Education): (613) 996-9800

Hon. John Manley (Minister of Industry): (613) 992-0302 or 995-1534

Hon. Jon Gerrard (Secretary of State for Science, R&D): (613) 990-4056 or 947-4250

Hon. Anne McLellan (Minister of Natural Resources, which has responsibility for AECL and CCFM): (613) 996-4516

Hon. Paul Martin: (613) 992-4291 or 995-5176

SCIENCE AND TECHNOLOGY FOR THE NEW CENTURY: A Federal Strategy

Response by the Partnership Group on Science and Engineering

The government of Canada's long awaited document on science and technology focuses on evaluation and management issues, with considerable emphasis on performance assessment, in government departments and agencies. The socio-economic benefits of commercialization, and the job and wealth creation potential of research and development are the centerpieces of the strategy.

Considering the impressive amount of consultation undertaken by the Government with the different stakeholders across Canada, the Partnership Action Group for Science and Engineering (PAGSE) had high expectations for a strategy document with a timetable for deliverables. It anticipated a form of "white paper" with an action plan for implementation of new tools and new directions. We also expected the document to specify, in a fiscally defined sense, the value and significance of the full spectrum of research (i.e., the continuum from basic to applied) and development for enhancing the quality of life of our citizens. While the document does not attain these goals in a substantive way, PAGSE does enthusiastically endorse some of the points made in the report. These include the:

(a) Recognition of the need for constructing a broad base of scientific enquiry in all major fields of endeavour.

(b) Statement that "research, both basic and applied, provide a continuous, renewable source of skills, ideas, technologies, and policies ..."

(c) Support of funding and performing scientific research within government departments and agencies; research in post-secondary institutions; corporate research and development; centers of excellence.

(d) View that quality science is central to sound policy development.

(e) Formation of a new Advisory Council on Science and Technology/ Innovation which would provide direct input to cabinet on research and development and other priority issues. PAGSE anticipates that the Council will address some of the concerns of the science community.

(f) Requirement that government departments and agencies establish mechanisms to secure external assessment of the extent of achievement of milestones, and advice on future programs and priorities.

(g) Creation of partnerships and networks between combinations of individuals from the private sector, government, and universities.

Some of the concerns which PAGSE has include:

I. Some of the positive points, especially a-d above, while laudatory, are "motherhood statements" and are not "front and center" in the document. These statements will not have any lasting value unless there is a specific allocation of resources, concurrent with a draft plan for policy implementation, developed in concert with the S & T community.

II. PAGSE is well aware of the existing and anticipated budgetary constraints. Consequently, although all major fields of endeavour merit some support on the basis of excellence, allocation priorities must be made (by appropriate bodies which serve the different communities universities, government, corporate sector) to a much greater extent and at a more detailed level, than those described in the strategy document.

III. Canada lags far behind our major competitors in terms of percent of GDP invested in R & D. As pointed out in the Red Book, this is largely the result of underfunding for industrial science and technology by the private sector. Until research and development is given a higher priority by government, Canada will continue to lose in the race for technological competitiveness.

While the paper is commendable in promoting partnership agreements, collaborative programs, and an open-door policy for laboratories, nowhere does it address the issue of the underfunding of research in Canada. A partnership between two underfunded groups (eg., universities and government research laboratories) is not necessarily a prescription for success. Furthermore, there is little point in government laboratories having an open-door policy when the university researchers who need to make use of the facilities cannot afford to pay the technical support costs required to get the work done!

Clearly, in accord with II, should government decide that there is no prospect for a marked increase in the funding of research in Canada, in the next 3-4 years, priority decisions must be made in allocating resources for research across government departments, and amongst the three principal granting councils. The planned Advisory Council (subject to its detailed terms of reference) or other bodies (i.e. cross government departments, cross granting councils) could make recommendations in this regard. The successful British example of a Technical Foresight Committee may be instructive in this regard.

IV. While PAGSE is cognizant of the need by government to emphasize the commercialization of science and technology, the group was struck by the inattention (except statements a and b above) to specifics on basic research as the foundation and galvanizer for technology development and commercialization of new processes, as well as for the manufacture of new products (and more economical routes to existing commercial items).

V. A major impediment to the commercialization of Canadian research and development is the reluctance of financial institutions to provide financing for late-stage development and initial production of new products of small and medium sized enterprises. While partially addressed by the S & T Strategy, this needs to be recognized as a continuing problem requiring additional responses.

VI. PAGSE agrees that the Information Highway is a valuable tool for facilitating communication and networking amongst researchers and others i.e. it contributes to the research infrastructure. The strategy document gives readers the impression that the IH is more than a tool. Redundancies resulting from the expansion of the IH will in our view be substantially, if not completely, offset by the need to create new positions for information analysis and dissemination.

VII. While the recommendation is made that federal departments and agencies develop explicit plans to promote international S & T collaboration for the benefit of Canadian firms, little is said concerning the collaboration of university and government researchers on an international basis. The cost benefit analysis to our researchers, the enhanced opportunities to perform cutting edge research, and the goodwill such collaboration brings to Canada, are substantial indeed.

There is no central fund to encourage and foster Canadian participation in international S & T. Given the fact that NSERC has eliminated international programs, that other government agencies and departments (e.g. Foreign Affairs) have also significantly reduced their budgets in these categories, some acknowledgement of the vitality of international collaboration was in order, as one mechanism for Canadian researchers to compete on a global basis.

VIII. The overriding concern of the document is research performance and accountability in government agencies and departments, with only a "broad-brush" treatment of university research and, for that matter, research and development in the private sector. The latter two are central to any successful S & T strategy leading to job creation and economic success.

IX. There is a major concern about mechanisms of governance and provision of S & T advice. The effectiveness of a new Advisory Council on S &T/Innovation will heavily depend on the quality of its membership. It would be inappropriate to have such a Council selected entirely from the private sector (as has been suggested). In Canada, private sector research and development is weak and it would be unfortunate if strong representation from practicing scientists or engineers in the academic and government communities were not involved. Also an international presence would be very useful.

In conclusion there are, as in any document of this type, positive and negative components. Some elements are sensible, realistic, and merit follow-up. This document is one of "process" and PAGSE urges the development and implementation of an "action plan." We are ready to work with government on this and other issues of relevance to science and technology.

NEWS / NOUVELLES

MANLEY ANNOUNCES TWO APPOINTMENTS TO NSERC

On January 18, 1996, Industry Minister John Manley announced the appointment of Angus Bruneau and Julie Payette to the Natural Sciences and Engineering Research Council (NSERC).

Angus Andrew Bruneau is the Chairman, President and CEO of Fortis Inc. The holder of a doctorate in Physical Metallurgy from the University of London, his experience in business and academia is vast. It includes 10 years with Memorial University of Newfoundland and 7 years at the University of Waterloo, and acting as director of a wide variety of companies over the last thirty years. Dr. Bruneau has also served on committees and the boards of several national and international research and economic development organizations, including the National Research Council, NSERC, and the OECD.

Julie Payette was selected as a member of the Canadian Astronaut Program in 1992. Building on a Bachelor's degree in Engineering from McGill and a Master of Applied Science from the University of Toronto, she is currently working towards a doctorate in Electrical Engineering at McGill. Ms Payette's design and research experience includes areas such as human computer interfaces, speech processing in adverse environments, and the application of voice technology to space. She has worked with IBM Canada and the Speech Research Group at Bell-Northern Research. Ms Payette is one of two nominated Canadian specialists on the NATO International Research Study Group on speech processing.

REQUEST FOR PROPOSALS (RFP)

Technology Development Program in Intelligent Systems and Robotics

On January 26, 1996, PRECARN Associates Inc. issued a Request for Proposal (RFP) for their next wave of funded research programs. PRECARN in association with CATA, seeks the participation of industry members in its industry-led, collaborative research program. PRECARN will contribute up to 40% of eligible project costs (in intelligent systems and robotics) up to $1 million, inclusive of early stage commercialization. Total investments will exceed $65 million between 1996 and 2000.

This RFP is open to all PRECARN Members and to new partners which commit to become PRECARN Members, if their projects are approved. Research areas are classified in these categories: robotics, machine sensing, human machine interface and intelligent computation.

CATA is publicizing RFP information on its Technogate World Wide Web databases (http://www.technogate.com). Interested parties should click on the Technogate "Partners and Allies" icon and search under "R&D" or "PRECARN" or click on "Hot Links" and then "Research and Development."

NSERC 1996 NATIONAL COMPETITION RESULTS ANNOUNCED

(Gov't of Canada Press Release dated Apr. 4/96)

Dr. Tom Brzustowski, President of the Natural Sciences and Engineering Research Council of Canada (NSERC) in announcing the results of the Council's 1996 national competition for research grants and scholarships (4,125 new awards totalling $122 million) stated that "Our researchers and university training in research rank among the best in the world, in terms of both quality and productivity. We have in this country developed excellent systems for assessing the quality of our research activity, and we know that in all the important areas of research Canadian universities are achieving a great deal with resources that are modest by international standards."

Dr. Brzustowski said the Council was resuming the annual announcement of its awards because of growing public interest in science and technology. "Today, we are all very conscious of the economic implications of activities on which we spend public funds. Basic research is an extremely important activity. It builds the stock of knowledge in our society. But promoting awareness of it and using the results productively are equally necessary activities."

A full list of the results of the 1996 grants competition can be obtained from NSERC's Web site on the Internet at http://www.nserc.ca/news1.htm.

The Impact of the Research Investment

- 40% of the annual total Canadian industrial investment in university research is directly linked to NSERC funding for basic and project research. More than 1,000 companies have directly contributed over $300 million to date to university projects, the majority of which build on the outcomes of earlier NSERC investment in basic university research.

- Companies along the section of road in Kanata that runs from Digital to Newbridge Networks Corp. produce total annual sales in excess of $3 billion - of which more than 80% is from exports. These firms are highly dependent on the quality of young recently trained engineers and scientists. The companies employ 9,000 people directly, with the companies that service them employing a further 27,000. Canada's largest R&D performer, Nortel, attributes its significant global success and future prospects to its high investment in R&D and to the quantity and quality of talent recruited from Canadian universities.

- Surveys of the career status of previous holders of NSERC's national scholarships consistently indicate a very low rate of unemployment (less than 3%, compared with the current national average of 9.6%). Two-thirds of these graduates are active in R&D. A significant proportion of the others are involved full time in such professional activities as teaching, product development, consulting, and management.

More information about the impact of NSERC-assisted research and training can be found on their Web Site in the publication *Research Means Business*.

PUBLIC HEARINGS FOR NUCLEAR FUEL WASTE MANAGEMENT AND DISPOSAL CONCEPT ANNOUNCED

Public hearings to review Atomic Energy of Canada Limited's proposed nuclear fuel waste management and disposal concept were held in Toronto, Pickering, Thunder Bay, Sudbury and Chalk River from March through May, 1996. On February 1, 1996, a detailed schedule for the hearings were released by the federal environmental assessment panel reviewing the waste management and disposal concept.

Phase I hearings took place in Toronto and Pickering, March 11-15 and 25-29, 1996 and Thunder Bay, Sudbury and Chalk River from April 29 to May 2, 1996. This phase focused on the presentation and round-table discussion of broad societal issues related to the long-term management of nuclear fuel waste. Discussion papers are available on request from the panel secretariat.

Phase II hearings, to take place in Toronto from June 10-14 and 17-21, 1996 will consist of technical sessions focusing on the long-term safety of the Atomic Energy of Canada Limited concept of geologic disposal from scientific and engineering viewpoints. More information concerning these will be available at a later date.

Phase III hearings will consist of community visits in New Brunswick, Quebec, Ontario, Manitoba and Saskatchewan where participants will have an opportunity to provide their final opinions and views on the safety and acceptability of the concept for disposal of nuclear fuel waste including any other issues relevant to the panel's mandate. The schedule will be announced later.

For more information, please contact Ghislaine Kerry by telephone at (819) 953-0179 (collect), by fax at (819) 994-1469 or by internet at Kerryg@fox.nstn.ca.

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NSERC CANCELS CPG PROGRAM

(Contact Vol.20(3), Written 1995)

At its meeting in October, NSERC approved the phase-out of the Collaborative Project Grants (CPG) program, as recommended by the Strategy Implementation Task Force. Although there will be no more competitions, commitments made in the 1994 and 1995 competitions will be respected. Given the financial environment projected for the coming years, it was clear that resources would not be sufficient to allow the CPG program to achieve its objectives, and that Council's efforts would be better spent in encouraging collaboration across all programs.

Reiterating its commitment to collaborative research, Council mandated staff to work closely with the research community to ensure that practices both in the peer review process and in the universities promote the emergence of excellent collaborative proposals. As a first step, the distinction between NSERC individual and team Research Grants will be removed. Staff was also encouraged to develop closer ties with universities to try to break down barriers to collaboration arising from the university promotion and tenure process.

Council took another significant step towards implementing the recommendations of the Strategy Implementation Task Force by approving the regrouping of activities in the Targeted Programs area. The new Research Partnerships Program has three main components: Strategic Projects, University-Industry Projects and Research Networks.

Council and staff are continuing to work on suggestions for implementing the Task Force's recommendations regarding NSERC's Scholarships programs, and Accountability and Communications.

Information on the implementation of the Task Force's recommendations will be available through *Contact* and NSERC's Web Site (http://www.nserc.ca).

TELLING THE RESEARCH STORY (from University Affairs, March 1996)

Tom Brzustowski is not afraid of straight talk. And he thinks it's crucial that Canadian university researchers get just as fired up about communications as he is.

"Communications is a short term and a long term priority for me," says Dr. Brzustowski, who took over the helm at the Natural Sciences and Engineering Research Council last September after a career as a university researcher, administrator and senior provincial civil servant. "At every opportunity that arises, we will explain what the research community does in a way which is interesting and memorable, giving examples, giving illustrations of outcomes, and all in plain language, not jargon."

In times of shrinking resources, university professors can no longer afford to stay cloistered in their research labs or isolated in their classrooms. Instead, they have to be prepared continually to explain what they do, justify it, and then convince a jaded and tax-weary public of the importance of funding it.

"Take nothing for granted," Dr. Brzustowski tells researchers. "Just because what you are doing is very, very good, it's elegant and it's important in your discipline, and just because it's already being funded, doesn't mean that anybody is interested in it outside of your discipline."

The days when researchers could view any media questions or politicians' inquiries about their research as an unwelcome intrusion or interference are gone, Dr. Brzustowski adds. "The attitude that somehow the quality of your work is sufficient to justify whatever amount of support you get - that was a very nice attitude to have. But resources can't keep up with that."

Dr. Brzustowski's career path has left him equipped to understand the point of view of both university professors and political leaders. A professor of mechanical engineering at the University of Waterloo for 25 years, he also served as vice-president, academic, and provost of the university. After leaving the academic world, he was appointed deputy minister of colleges and universities in Ontario, then deputy minister of the Premier's Council of Ontario, a body charged with developing strategic policy advice to the government.

But he says it was his stint in the university classroom that now serves him best. "It's amazing how 25 years of classroom teaching, particularly teaching in the lower years of undergraduate education, can alert you to communicating in simple terms. It's nice to teach a graduate course in your own jargon. But when you're facing intelligent questions in simple terms, from people who haven't learned the jargon yet, then you have to scramble."

Eventually he hopes the result of his crusade to focus public attention on science and engineering will be increased public understanding - and financial support - for university research. "I would like to see widespread recognition in this country, and great conviction, that it is essential to invest in research, science and technology and graduate training of researchers, just for the good of the country," he declares. "I really would like to see research considered as something essential to Canada, and not as just a sop to the egos of academics, not as just another kind of social consumption, but something that is the mechanism by which we build the future."

The communications challenge is particulary important these days, with university researchers squeezed by multiple pressures. Science and engineering disciplines are breaking new ground; ideas and new directions for investigation are emerging daily. At the same time, granting council budgets are decreasing, and operating grants from the provinces to universities, which help pay the costs of university research infrastructure such as libraries or laboratories, are also on the decline. In order to cope, many researchers are turning to NSERC with requests to fill the gap, to provide funding out of operating grants to equip laboratories or pay for other infrastructure-related costs.

"It seems that, increasingly, grantees are facing universities that are asking to be paid for the (research infrastructure), because universities can no longer afford to provide these things for free. So we're getting a trickle, turning into a flow, and probably a flood of requests" to spend NSERC money on research infrastructure. But such requests have a direct impact on the bottom line. "Every time we do that, there is less money available for other things."

Dr. Brzustowski says he is becoming increasingly concerned that NSERC funding is being seen on campuses as the sole source of funding for science and engineering research. And he's worried that, sooner or later, university administrators may refuse to sign NSERC grant applications, including those for major equipment, on behalf of their researchers, because the institutions simply can't afford to supply the infrastructure needed.

But although NSERC officials are worried, it's difficult to track how much impact any crumbling in university infrastructure is having. Dr. Brzustowski fears the effects may show up first in decreased applications for NSERC grants. "We won't begin to see this until the grant selection committees begin to point to it, maybe not in this year's competition, maybe only in next year's. But if, in key areas in the basic disciplines, holes develop, not just in the capabilities of individual institutions, but across the country, then no amount of networking will be able to patch that up. And as a national agency we're going to become very concerned about it."

Dr. Brzustowski says he is interested in proposals - such as one made recently by the Association of Universities and Colleges of Canada - that would see the federal government pay directly for the infrastructure costs of the research it sponsors, rather than relying on transfer payments to the provinces.

But such a proposal, too, raises a communications challenge, Dr. Brzustowski notes. How will universities convince the public that such a move does not represent increased budgets for the granting councils, but rather simply shifts the method of allocating the funding? "The issue isn't doubling the councils' budgets, it's finding the other half of research costs. That has to be communicated with precision," Dr. Brzustowski says, "Otherwise the public would be right to reject the move."

Although communications with the general public is evidently his priority, Dr. Brzustowski is clear he also intends to build bridges to the university research community. In fact, he makes it a point not to distinguish between the granting council and the community. "I see NSERC as almost an organ of the community," he says. "I don't see it as having goals distinct from the research community. It really is a voice of the community."

But, he admits, in the past there may well have been some communication breakdowns between the granting council and a number of university researchers. And, after several months on the job and visits to several university campuses, he is surprised how little some professors know about how NSERC is funded and how it conducts its business. Some professors, for example, continue to believe that NSERC council members give up their academic careers and move to Ottawa once they are appointed. Surprisingly, some faculty are also unaware of the volunteer commitment needed from academics across Canada to maintain the granting council's peer review process.

In building up trust between NSERC and the academic community, Dr. Brzustowski believes it is important to allay researchers' concerns that NSERC may be turning its back on basic research. "I think one of the things that the community will need to be informed about, and to become less anxious about, is the notion that somehow there is room within NSERC for both kinds of research, both the basic research and project research."

One problem may be that researchers fear that NSERC will take a "one size fits all" approach to science, a fear Dr. Brzustowski says is groundless. Too often, he notes, applied or project-based researchers fear that the values of basic research - counting the number of publications, for example - will be applied to them, while basic researchers worry they will be asked to demonstrate the immediate economic relevance of their work.

In fact, says Dr. Brzustowski, NSERC will apply "appropriate measures" to each activity. In the meantime, he calls for a kind of truce between faculty involved in basic research and those working on applied projects. "Let's not create anxieties where they don't have to be created." he urges researchers. "Let's not have any sneering across the interface ... you know, well, what you do is irrelevant, and what you do is not intellectual enough."

Dr. Brzustowski says he is optimistic such differences between researchers can be worked out - just as he is optimistic that decision-makers will eventually heed his message about the importance of university research in science and engineering.

"Let's put it this way," he explains. "I've had nobody come around and tell me there's good news for NSERC in the next (federal) budget. But on the other hand, I've met an increasing number of elected officials here in Ottawa who acknowledge the importance of university research funding. Now at some stage of the game, something's got to give."

UNIVERSITY NEWS / ÉCHOS DES UNIVERSITÉS

COOPERATIVE EFFORTS FUND RESEARCH

(University of Toronto Medal Release January 25/96)

Cooperative efforts between the National Sciences and Engineering Research Council (NSERC), international technology company Lumonics, Inc. and the University of Toronto are helping ensure that one of Canada's most important "natural" resources remains in Canada.

Dwayne Miller, a top researcher in laser technology, has returned to his native Canada after several years in the United States to join the University of Toronto as the holder of the NSERC-Lumonics Chair in Quantum Optics. His return follows more than 11 years at the University of Rochester where he conducted pioneering research in solid-state laser technology and spectroscopy. Although he was born in Canada and received his BSc (honours) degree from the University of Manitoba, he says the United States provided greater research opportunities, especially for new faculty.

"Canada has not been willing to sufficiently invest in their young scientists and consequently has lost some outstanding talent," says Miller. "I was really impressed by the level of support and enthousiasm generated by Lumonics, NSERC and the University of Toronto to reverse the trend. This was an opportunity to make a difference to Canadian science I could not refuse." In the U.S., Miller was a recipient of an NSF Presidential Young Investigator Award, Dreyfus Teacher-Scholar Fellowship, Alfred P. Sloan Fellowship and his research was further supported by the National Science Foundation, National Institute of Health, and the Department of Energy.

INTERNATIONAL NEWS / NOUVELLES INTERNATIONALES

A LIGHT NIGHT READING?

(IOP Press Release, undated)

Researchers worldwide can now gain online access to developments at the frontiers of physics from the comfort of their own desks, 24 hours a day, seven days a week.

In a major international initiative, the UK-based Institute of Physics Publishing is making all its research journals available on the Internet to scientists whose institutions subscribe to the well established paper versions of the journals. Not only will articles be available electronically up to three weeks before they appear in print, researchers will also be able to access them via the World Wide Web at no extra cost.

The journals produced by Institute of Physics Publishing cover the full gamut of physics research, with topics as diverse as nanotechnology, plasma physics, physiological measurement, nonlinearity and the public understanding of science.

The Institute of Physics Publishing journals now available on the Web are: *Journal of Physics A: Mathematical and General; Journal of Physics B: Atomic, Molecular and Optical Physics; Journal of Physics D: Applied Physics; Journal of Physics G: Nuclear and Particle Physics; Journal of Physics Condensed Matter; Measurement Science and Technology; Classical and Quantum Gravity; European Journal of Physics; Nonlinearity; Physics in Medicine and Biology; Plasma Physics and Controlled Fusion; Pure and Applied Optics; Semiconductor Science and Technology; and Superconductor Science and Technology.*

Further information and demonstration material is available at http://www.iop.org

CANADIAN PHYSICISTS / *PHYSICIENS ET PHYSICIENNES CANADIEN(NE)S*

Excellence in Teaching Awards
(Extract from Simon Fraser News, Feb. 8/96)

Howard Trottier, physics, was selected as one of the three winners of SFU's excellence in teaching awards this year. In an interview with Simon Fraser News reporters, Dr. Trottier had the following to say about his teaching ...

Are there any special techniques you use to motivate your students?
Demonstrations. They're a big part of teaching physics, at least in our department. Actually measuring the acceleration of a ball as it's dropping will always be more convincing than working it out through equations. Things like that resonate with students. Often when I'm wheeling equipment down a hallway I can see that students are genuinely excited that there's going to be a demonstration in my lecture that day.

In your opinion, what are the top three qualities that make a good teacher?
Teachers need to *project themselves* - to make eye contact with students in the back row. I like to get right in the middle of a class and jump up and down. And I make no apology for putting entertainment value in my lectures. Second, teachers have to be *accessible*. I have open office hours. If I'm on campus, students can ask me questions anytime. And like other faculty in the physics department, I drop by our open labs to make myself available to students in an informal way as often as possible. Finally, everyone appreciates *a good joke* in class: 'Physics humour', as my wife calls it, because often the joke isn't funny outside the lecture. For example, I found a clip from *Star Trek* in which Captain Kirk and Spock are talking about anti-matter. It's become part of my teaching arsenal. I play the video in class after teaching the subject. Students can spot what's wrong immediately as the characters worry that if Lazarus meets his anti-matter twin, it will be the end of life as we know it. The overacting and overdrawn music add to the hilarity of the conversation, so it works very well in class.

What challenges do you expect to confront as a teacher in the immediate future?
It may be inevitable that class size will increase because of cutbacks and demand. I think big classes are a serious problem. They make students feel totally anonymous. In my experience, smaller classes (even in the 100-200 student range) provide for more teacher-student contact. For the physics department, low enrolment, particularly in the upper levels, has to be addressed. if we expect to attract more students, they have to be able to get jobs. This is a problem which my department is taking seriously.

What advice would you give to someone just starting their career as a university teacher? Be enthusiastic. Search for something great in the smallest detail and don't be shy about pointing it out. Students should know that you really want to be there.

McMaster University Researcher Captures National Science and Engineering Prize

On 1996 January 17 Dr. Tom Brzustowski, President of the Natural Sciences and Engineering Research Council of Canada (NSERC) announced the winners of some of the country's most prestigious awards. Recipients were selected from nominations from universities across Canada.

Four outstanding professors will receive the 1996 E.W.R. Steacie Memorial Fellowships. "These individuals are creating international recognition for Canada in some of the most exciting fields of science and engineering," said Dr. Brzustowski. "They underline the extraordinary high calibre of research and training in Canadian universities."

Dr. **Catherine Kallin** is an outstanding scientist in the Department of Physics, McMaster University. She has demonstrated exceptional leadership and accomplishment in theoretical solid state physics, particularly in the theory of high temperature superconductors.

Other recipients include Dr. Ming Li, mathematician at the University of Waterloo, Dr. Jed Harrison of the Department of Chemistry, University of Alberta, and Dr. Demetri Terzopoulos, Department of Computer Science, University of Toronto.

The NSERC awards provide the recipients with an opportunity to expand their research programs and obtain additional research assistance. The prizes will be officially presented in June along with the Canada Gold Medal for Science and Engineering.

Short Article on Dr. Kallin

McMaster University physics professor Catherine Kallin and her collaborators have been studying microwave measurements on high-temperature superconductors, and using the data to determine the electrical and magnetic properties of these superconductors and to understand why the materials are superconductors at all.

"Our traditional understanding of superconductors, which were discovered in 1911, strongly suggests that superconductivity shouldn't exist above 30 degrees Absolute (-243 degrees Celsius)," explains Dr. Kallin. But high-temperature superconductivity (above 30 degrees Absolute) was discovered in 1986, and in subsequent years the temperature escalated to the present record of 160 degrees Absolute (-113 degrees Celsius). "There's a large body of evidence that points to electron-electron interactions as the cause of high-temperature superconductivity. But we're just now starting to address the question of what this means for the electrical and magnetic properties of these materials."

It was only by chance that Dr. Kallin, now recognized as one of the top condensed matter theorists in the world, got into physics. In high school she dropped physics after Grade 10. It was a community college course in "physics for poets" that piqued her interest in the subject and led her to the honours physics program at the University of British Columbia.

(For more information on Dr. Kallin, see the family profile on Dr. Kallin and Dr. Berlinsky which appears later in this issue.)

NEWS FROM CORPORATE MEMBERS

L'INO FAIT UN DON D'ÉQUIPEMENT AU CÉGEP DE LA POCATIÈRE

Le président-directeur général de l'Institut national d'optique (INO), monsieur Jean-Guy Paquet, a été très heureux d'annoncer le 20 février 1996 à La Pocatière, le don par l'INO au Cégep de la Pocatière, du système d'écriture FAB pour des fins d'enseignement et de formation des étudiants en technologie physique.

Ce don a été possible suite au remplacement du système d'écriture FAB par un équipement plus performant rencontrant les nouveaux besoins des activités de l'INO. «Nous sommes convaincus que le système offert permettra au Cégep de réaliser plusieurs nouvelles activités pertinentes pour la formation des étudiants», a affirmé monsieur Paquet.

L'INO compte présentement à son emploi vingt-cinq technologues, dont vingt sont des diplômés en technologie physique du Cégep de La Pocatière. «Nous sommes parmi ceux qui connaissons, et reconnaissons, l'excellence des diplômés en technologie physique du Cégep de La Pocatière, et nous sommes heureux de pouvoir offrir un appareil qui contribuera de manière tangible à la formation des futurs technologues», a ajouté monsieur Paquet. D'ailleurs l'INO prévoit procéder d'ici le mois de mai prochain au recrutement d'au moins trois nouveaux technologues en physique parmi les finissants de cette année.

Rappelons que l'Institut national d'optique, qui emploie à son siège social de Sainte-Foy plus de cent trente personnes dont quatre-vingt scientifiques, est une corporation privée sans but lucratif qui a vu le jour en 1985. L'INO est l'un des chefs de file international de la recherche et du développement en optique, et vise à favoriser l'essor économique du pays en assistant les entreprises dans leurs efforts pour améliorer leur compétitivité.

THE PHYSICS OF DILUTE 2D ELECTRON AND HOLE SYSTEMS IN SI-BASED HETEROSTRUCTURES

by Marie D'Iorio
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INTRODUCTION

Starting with the discovery of the Quantum Hall Effect at the beginning of the 1980's, the field of low dimensionality electron systems has known an incredible expansion. In semiconductors, the confinement of charge carriers in two or fewer dimensions provides added richness from both the fundamental and the applied physics viewpoint. Solid state vocabulary has expanded to include the integer and the fractional Quantum Hall Effects (IQHE, FQHE), skyrmions, composite fermions, high electron mobility transistors (HEMT), modulation doped field effect transistors (MODFETs), resonant tunneling diodes (RTD) etc. In the quantum limit of low temperature and finite magnetic field where the mobility μ and the magnetic field B are such that $\mu B >> 1$, charge carriers confined at the interface between two semiconductors or between a semiconductor and an insulator behave as a gas of non-interacting particles (electron gas), while, in the extreme quantum limit where the cyclotron energy $\hbar\omega_c$ is much larger than the thermal energy k_BT, the fluctuations promote the formation of a liquid state. It was natural then to look for the third state of matter, the solid in two dimensions. This idea was not new, as it had been addressed by Eugene Wigner in 1934 [1] for three dimensional metallic systems. Wigner predicted that, at zero magnetic field, the density of the carriers could be reduced such that the Coulomb exchange would be larger than the thermal disordering energy, thus favoring the crystallization of electrons onto lattice sites. This was later applied to the two-dimensional case where the conditions for observing the electron solid are less stringent than in three dimensions [2,3].

BACKGROUND

There are two regimes for the formation of a solid phase depending on whether the competing fluctuations are thermal or quantum in nature.

(a) In the classical regime, the zero point energy is much smaller than the thermal energy k_BT:

$$k_BT_F = \hbar^2/(m^*a^2) << k_BT$$

where $a = (\pi n_s)^{-1/2}$ is the radius of the Wigner-Seitz cell, n_s is the carrier density, T_F is the Fermi temperature and m^* is the effective mass. The parameter of interest is the ratio between the Coulomb correlation energy and the thermal disordering energy. This is expressed as:

$$\Gamma = V_c/(k_BT)$$

where $V_c \sim e^2/\varepsilon\, a$ and ε is the dielectric constant.

When Γ is large, the formation of a solid is favored over that of the liquid. Electrons on a helium film provided the first observation of a classical Wigner solid at zero magnetic field and the melting temperature was found to occur at $T_{mc} = V_c/(\Gamma_m k_B)$ with $\Gamma_m = 127 \pm 3$ [4-8].

(b) The quantum regime occurs at low temperatures when $T << T_F$ and the parameter of interest is the ratio of the Wigner-Seitz radius, a to the Bohr radius a_B:

$$r_s = a/a_B = V_c/(k_BT_F)$$

and

$$a_B = \hbar^2\varepsilon/(e^2m^*)$$

The electrons order into a Wigner crystal when r_s is large and the Coulomb correlations dominate; as the carrier density increases and r_s decreases the quantum fluctuations grow until the long range order disappears and the solid melts. This occurs at a critical value $r_s^w = 37 \pm 5$ or critical density $n^w = \pi/(r_s^w a_B)^2$ as determined by a finite size, zero temperature calculation [9].

(c) It is also possible to induce the crystallization of electrons by applying a magnetic field perpendicular to the layer and localizing the electrons within a magnetic length $l_c = (\hbar c/eB)^{1/2}$, smaller than the Wigner-Seitz radius a. The quantum fluctuations are quenched and there is little overlap between the electron wavefunctions. The ratio of the zero point energy to the magnetic or cyclotron energy $\hbar\omega_c$ where $\omega_c = eB/m^*c$ is provided by the filling factor $\nu = 2(l_c/a)^2$. The magnetically induced Wigner solid is expected to form at finite temperature at a filling factor smaller than some critical value ν_c which has been estimated to be between 1/3 and 1/11. The phase diagram is illustrated in Fig. 1.

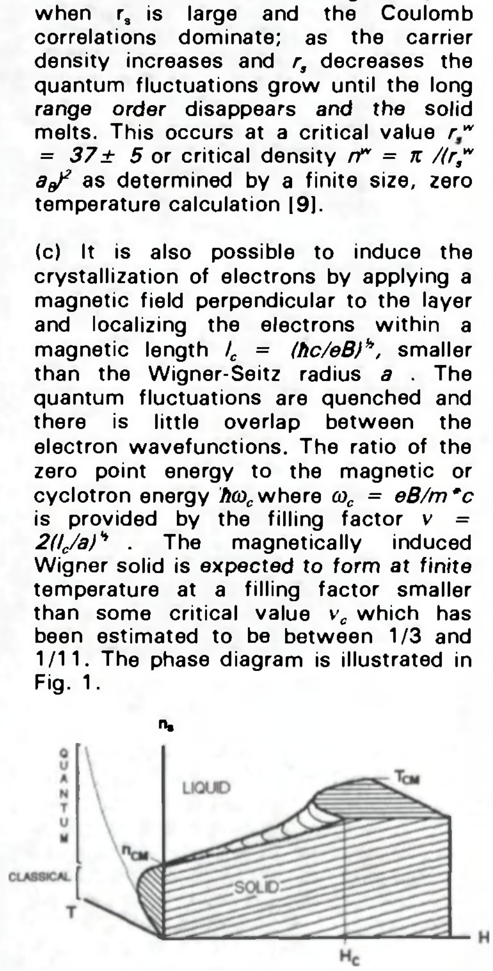

Fig. 1 The phase diagram for the classical and quantum Wigner solid indicating the classical melting temperature, the critical melting density and critical magnetic field.

Experimentally, the problem lies in the fact that the carrier density required for observing the quantum solid phase is very low in III-V semiconductors which typically have low effective masses and large dielectric constants: $r_s \sim 2\text{-}4 << r_s^w$. Electrons on helium have the opposite problem where the density is kept low to avoid a destructive instability of the helium surface: $r_s \geq 10^3 >> r_s^w$. The search should thus focus on material systems with a large effective mass, a low dielectric constant, and in situ density tunability. We should also search for other material features which favor the onset of crystallization. This is the approach that we will be discussing.

What are the signatures for the formation of the Wigner solid phase? Just like its liquid counterpart, the electron solid is a collective phase; this is in contrast to the gas phase where the picture of a non-interacting gas usually suffices. The solid, however, should have rigidity which will distinguish it from a collective liquid state. From magneto-transport experiments, one would expect some extremely large resistance associated with the localization of the charge carriers onto lattice sites and their inability to participate in the transport. But that in itself is not sufficient since single-particle localization will also lead to insulating behavior. The current-voltage characteristics could however provide unambiguous evidence for a solid phase. The presence of an electric field threshold conduction is indicative of rigidity: below threshold, the electrons are pinned which is not possible in a liquid phase, while, above threshold, a collective sliding motion of the depinned electron solid occurs. The resistance below threshold is usually activated due to electrons excited across a "single-electron" disorder induced gap. The conduction here can involve the transport of electrons along the grain boundaries of the Wigner solid or the transport of dislocation pairs. A low value of threshold field implies a long correlation length with respect to the Wigner-Seitz radius. Another signature of the Wigner solid is the increase of broadband noise as the threshold field is approached; this corresponds to the onset of sliding and the noise generated by the electron lattice sliding by the pinning centers. There also should be a temperature above which the thermal disordering energy takes over and the solid "melts" as well as a critical carrier density above which the zero point oscillation energy overtakes the Coulomb interaction [10].

The work on the formation of the classical Wigner crystal using electrons on a thin helium film set the stage for efforts in semiconductors. The substrate under the helium film can provide sufficient surface roughness to pin the Wigner crystal formed by the electrons. Associated with this pinning are non-linear current-voltage (*I-V*) characteristics which were first observed by Kajita [11]. Above a threshold electric field, the depinned crystal slides like a sliding *charge* density wave. Experiments on a two-dimensional sheet of electrons injected on a helium film (thickness 200-400 A), supported by a glass substrate, have shown that the transport properties of the pinned electron lattice are very similar to that of one-dimensional sliding charge density waves: characteristic non-linear *I-V* curves, melting temperature, and broadband noise generation [12].

The initial effort in identifying a Wigner crystal phase in semiconductors was carried out in GaAs/AlGaAs heterostructures [13-15]. There, it was not possible to decrease the density sufficiently to observe the Wigner crystal at zero magnetic field. Thus the experimental efforts were focused on the magnetic field induced Wigner crystal in the fractional quantum Hall regime. At low fields, the quantum fluctuations dominate the Coulomb correlations and the Integer Quantum Hall Effect (where $\rho_{xy} = h/\nu e^2$ and $\rho_{xx} \rightarrow 0$, ν is an integer) is observed when weak disorder pins the Fermi level in the gap between Landau levels. As the field is increased further, the electrons behave as a correlated quantum liquid which exhibits the Fractional Quantum Hall Effect (where $\rho_{xy} = h/\nu e^2$ and $\nu = p/q$ and p and q are integers and q is odd). A textbook example of these phenomena is shown in Fig. 2. Transitions to an electron solid phase are possible depending on which phase has the lowest ground state energy. Compelling evidence for the magnetic field induced Wigner solid have been provided by electrical, radio-frequency and optical magneto-transport experiments near filling factor 1/5, 2/7 in n-type GaAs/AlGaAs heterostructures and 1/3 in similar p-type samples [16].

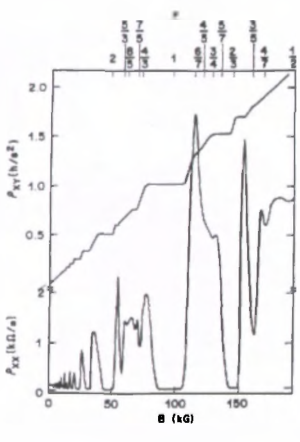

Fig. 2 Textbook example of the Integer and Fractional Quantum Hall Effects. From A. Chang, *The Quantum Hall Effect*, ed. R. E. Prange and S. M. Girvin, Springer-Verlag, New York, 2nd Ed. (1990).

In order to observe a quantum Wigner crystal, in the zero field limit predicted by Wigner, one must look for a material system with large effective mass to minimize the zero point oscillation energy and a small dielectric constant to maximize the Coulomb correlation energy. Moreover, it is important to be able to vary the density in a reliable and reproducible fashion. Almost optimal conditions can be created in several Si-based materials as shown in Table 1.

Table 1. Comparison of parameters of interest for Wigner crystallisation

Parameter	Si / SiGe	Si / SiO$_2$
Electron effective mass : m^*	0.44	0.19
Dielectric constant : $<\kappa>$	12	7.7
Bohr radius : $a_B = \frac{(4\pi\varepsilon_o)(\hbar^2\kappa)}{m^* e^2}$	14 Å	20 Å
Interelectron spacing : $a = \frac{1}{\sqrt{\pi \cdot n_s}}$	126 Å @ $n_s = 2 \times 10^{11}$ cm^{-2}	182 Å @ $n_s = 9.6 \times 10^{10}$ cm^{-2}
Wigner-Seitz radius : $r_s = \frac{a}{a_B}$	9	9
Critical concentration for quantum cold melting : $n_q^{cm} = \frac{1}{\pi \cdot (r_c \cdot a_B)^2}$ where $r_c = 37 \pm 5$	(0.92 - 1.59) x 10^{10} cm^{-2}	(0.43 - 0.70) x 10^{10} cm^{-2}

Other than the physical parameters of the material, it is possible to choose a system which, by its epitaxial layered growth, can enhance the formation of the Wigner crystal. It is known that the coupling between two electron systems separated by less than the interelectron distance favors Wigner crystallization [17-18]. Here, we will look at two systems: Si-SiO$_2$ field effect transistors or Si-MOSFETs (metal oxide semiconductor field effect transistor) and p-type Si-SiGe-Si heterostructures.

SAMPLES

A number of Si-MOSFETs grown in Russia were studied in detail. The electron mobility in these samples is an order of magnitude larger than that of commercial Si-MOSFETs and 2-4 times larger than that of the best Si-MOSFETs grown for research purposes. This mobility was achieved by careful processing to avoid highly diffusive contaminants such as Na and K ions, and repeated growth and stripping of the thermal oxide to ensure a smooth interface. The samples have the following low temperature peak mobilities: Si-15: $\mu = 7.1 \times 10^4$ cm^2/Vs, Si-5: $\mu = 4.3 \times 10^4$ cm^2/Vs, Si-11: $\mu = 3.63 \times 10^4$ cm^2/Vs, and Si-2: $\mu = 2.42 \times 10^4$ cm^2/Vs. By applying a bias to the Al top gate, the carrier density can be varied from 5×10^{10} to 10^{12} cm^{2}. The longitudinal resistance is measured using a four probe technique with a differential electrometer and DC currents as low as 0.1 pA. The Oxford Instrument low temperature system consists of a top loading 400 μW dilution refrigerator (25 mK < T < 4.2 K) and a superconducting magnet (H – 0-15 Tesla @ 4.2 K). One of the main differences between Si-MOSFETs and GaAs/AlGaAs modulation doped heterojunctions is the location of the dopants which control the scattering events and hence limit the mobility. In Si-MOSFETs the dopants are located in the Si close to the inversion layer. The scattering is short range in this case. In contrast, the III-V heterostructures have dopants separated from the two-dimensional layer by a spacer layer and the scattering is long range. Table 2 shows a comparison of these samples with those used in the study of magnetic field induced Wigner crystal from the point of view of "inherent disorder".

Table 2
Relative Disorder in Very High Mobility Si-MOSFETs and GaAs-AlGaAs Heterostructures

	Si-MOSFETs	GaAs-AlGaAs
n_i (cm^{-2})	1-3×10^{10}	10^{12}
n_i / n_s	0.1-0.3	10-15
setback distance d	50-100 Å	~500 Å
setback/Bohr radius: d/a$_B$	2.5-5	5

In the dilute limit, where impurity scattering dominates, the Si-MOSFETs and the GaAs/AlGaAs are equivalent systems.

RESULTS

In probing the dilute density regime below 1×10^{11} cm^{2}, a number of anomalous features were discovered in the magneto-transport measurements at half-filled Landau levels ($\nu = 5/2$, $3/2$).

Some of these are shown in Fig. 3:

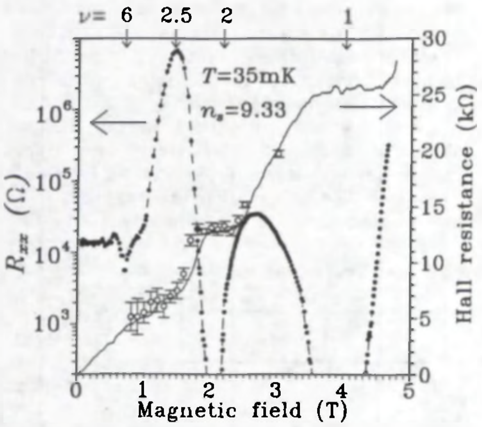

Fig. 3 The longitudinal and Hall resistances as a function of magnetic field for sample Si-5 at carrier density n_s = 9.33 × 10^{10} cm^{-2}.

- Instead of regular Shubnikov-de Haas oscillations obtained from measuring the resistance along the sample as a function of magnetic field, the maxima in the Shubnikov-de Haas oscillation at half-filled Landau levels become enormous with resistances ~ 10^{12} ohms depending on the carrier density. The resistance goes back down to the level of a few ohms as the magnetic field is swept into the quantum Hall minima at filling factors ν = 2 and 1.

- If the magnetic field is kept at one of the SdH oscillation maxima, and the current-voltage (I-V) characteristics are measured at constant density, the result is a sharp non-linear I-V curve with a low threshold field value which increases as the carrier density is decreased:

- The resistance at the SdH maxima is thermally activated below threshold with $\rho_{xx} \propto e^{\Delta/kT}$. The activation energy increases linearly with decreasing density.

- While the large resistance is developing along the sample, the Hall resistance across the sample remains metallic as it does in the high density regime.

These surprising observations [19] led us to believe that the two-dimensional electron gas was undergoing a series of re-entrant transitions from an insulating state characteristic of some new phase to the non-interacting gas of the integer quantum Hall regime. In view of the results attributed to a magnetic field induced Wigner crystal near filling factor 1/5 in GaAs/AlGaAs heterostructures, we looked into the conditions required for Wigner crystallization in Si-MOSFETs and found them to be quite favorable in theory. The large effective mass m^* = 0.19 m_o and the low dielectric constant ε = 7.7 set Si-MOSFETs apart from GaAs-AlGaAs heterostructures; in addition, Si-MOSFETs feature a two-fold valley degeneracy which is lifted by intervalley interaction and the asymmetric confinement potential (Δ_v = 2.4 K), and a large spin splitting which persists down to zero field (Δ_s = 4 K) due to the large spin-orbit coupling [20].

Because the Fermi energy is comparable to these splittings, polarization effects will be important. While the ground state energetics of the liquid phase is sensitive to the polarization state, the solid phase is relatively unaffected by polarization due to the weaker exchange energy. Whereas the Monte Carlo simulation for a pure system suggests that the transition to the Wigner crystal should occur at r_s = 37 [9], a fixed node and variational Monte Carlo simulation incorporating the valley degeneracy and impurity effects in Si-MOSFETs yield a partially polarized fluid to a fully polarized solid transition at r_s = 7.5 [21]! It should be possible then to observe the quantum Wigner crystal at zero magnetic field in very high mobility Si-MOSFETs!

Theoretically, there is little doubt that, for zero disorder and zero temperature, the 2D electron gas will crystallize into a Wigner lattice upon lowering the density. It is also accepted that, in the limit of strong disorder, single-particle localization will set in. Our samples with minimal disorder provide an intermediate regime where a collective insulating state like the pinned Wigner solid [22] or the pinned charge density wave [23] might exist. The study of the zero field longitudinal resistance as a function of carrier density and temperature led to the following experimental observations:

- Below a critical carrier density n_{sc} ~ 10^{11} cm^{-2}, the longitudinal resistivity exhibits insulating behavior characterized by an exponential rise shown in Fig. 4(a) and a negative slope in the temperature dependence $\partial R_{xx}/\partial T$.

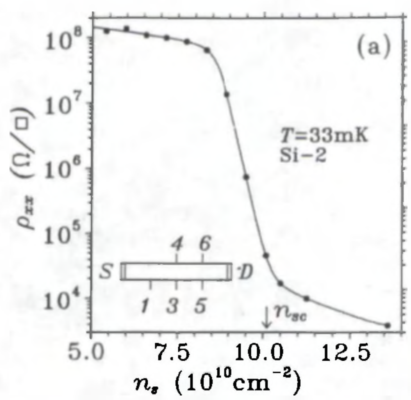

Fig. 4(a) The longitudinal resistivity as a function of carrier density for sample Si-2 at zero magnetic field.

- In the temperature range 100-650 mK, the temperature dependence of R_{xx} can be described by $R_{xx} \propto e^{\Delta/kT}$ where the activation energy Δ drops linearly to zero at n_{sc} as shown in Fig. 4(b).

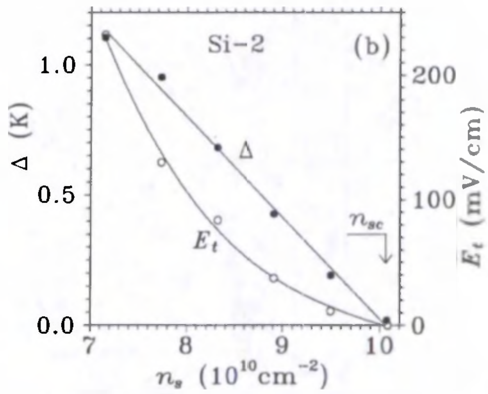

Fig. 4(b) The carrier density dependence of the activation energy and the threshold electric field for sample Si-2. The critical density is n_{sc} = 10.05 × 10^{10} cm^{-2}.

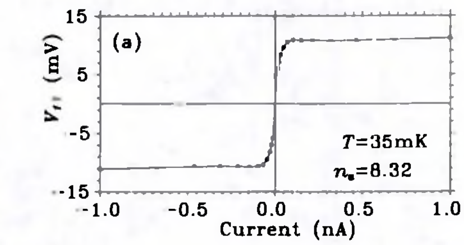

Fig. 5(a) The current-voltage characteristics at carrier density n_s = 8.32 × 10^{10} cm^{-2} and zero magnetic field for sample Si-2.

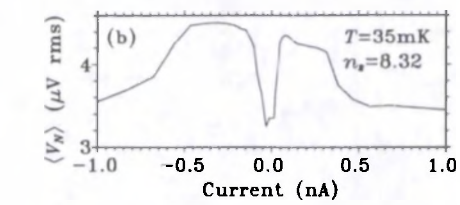

Fig. 5(b) The broadband noise voltage measured between potential contacts as a function of the source-drain current.

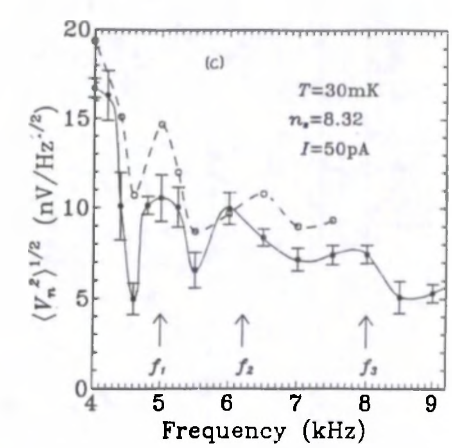

Fig. 5(c) Two independent spectral measurements of the narrowband noise driven by the DC current.

- The current-voltage characteristics exhibit a sharp drop in $\partial V/\partial I$ above a threshold electric field E_t as shown in Fig. 5(a).

- The threshold field goes to zero smoothly at n_{sc} as shown in Fig. 4(b). The data can be fitted well by a power law $E_t \propto \delta n_s^{\gamma}$ where γ = 1.7-1.8 and $\delta n_s = (n_{sc}-n_s)$ (see Fig. 6). More accurate measurements have actually revealed a small discontinuity at n_{sc} pointing to a first order transition [24].

- The dependencies of the activation energy and the threshold field on carrier density is sample independent. However, the critical carrier density is lower for higher mobility (less disordered) samples.

- The sharp rise in conduction is accompanied by a steep increase of the broadband rms-noise voltage $\langle V_N \rangle$ as a function of current (see Fig. 5(b)). The broadband noise was measured at two nearest potential contacts in the 1-300 kHz frequency band.

- The narrowband noise shown in Fig. 5(c) has a reproducible frequency spectrum which shifts to higher frequency as the driving current is increased. The maxima in the signal amplitude occur at frequencies which can be related to the 2D electron lattice constants.

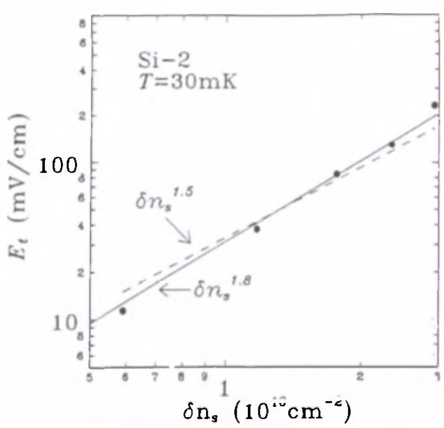

Fig. 6 **The dependence of the threshold electric field on the carrier density variation n_{sc}-n_s for sample Si-2. The solid line is a fit to $E_t = \delta n_s^{1.8}$ while the dashed line is the theoretical dependence $E_t = \delta n_s^{1.5}$.**

These zero magnetic field transport signatures are similar to those observed in the classical Wigner solid of electrons on helium and the magnetic-field induced Wigner solid near fractional filling factor 1/5. In the very high mobility samples, these features are also seen at filling factors 3/2 and 5/2 at magnetic fields below 5 Tesla. But let us forget this for a moment and play devil's advocate. Could this be simply a manifestation of single-particle localization (SPL)? In disordered semiconductors at low temperature, transport takes place by means of phonon-assisted tunneling to states which are close in energy. The tunneling distance to a state within k_BT of the Fermi energy increases with decreasing temperature. This variable range hopping process has a characteristic power law dependence of the resistivity on the temperature: $\rho(T) = \rho_0 \exp(T_0/T)^x$ where x = 1/3 for single particle localization in 2D without Coulomb interaction [25]. Experimentally, we cannot fit our data to variable range hopping but observe an activated temperature dependence with x = 1; more recent results, in similar samples, have provided evidence for a Coulomb gap (x = 1/2) in the density of states at the Fermi energy, in an intermediate temperature range [26]. In SPL, the threshold conduction is associated with the breakdown of localized states when $eE_t\xi_0$ (where E_t is the threshold and ξ_0 is the localization length) is comparable to the Fermi energy E_F. For the low threshold field at $\delta n_s = 0.1 \times 10^{10}$ cm^{-2} and E_F = 6 K, the localization length would have to be longer than the sample itself i.e. ξ_0 = 6 mm. The threshold field typical of SPL is of order 2.9×10^3 V/cm [27] for our experimental conditions. Our threshold fields are five orders of magnitude smaller. A series of capacitance measurements on these samples also show that the effective area for conduction does not change as the carrier density is decreased [28]. Our experimental results are therefore not consistent with single-particle localization. However, single-particle localization is expected to become dominant in the regime where the number of carriers has been decreased so much that it is equal to the number of pinning impurities in the oxide layer. The more rapid increase of the threshold field below 7.5×10^{10} cm^{-2} is a precursor of this phase.

Let us consider the data in the framework of a pinned Wigner crystal. By drawing an analogy to a charge density wave (CDW), it may be easier to understand the experimental results. Charge density waves are predominantly a one-dimensional phenomenon although they also occur in materials with two or three-dimensional band structures [29]. Chain and layer structures in which CDW transitions have been studied include organic conductors such as TTF-TCNQ (tetracyanoquinodimethane) and linear chain inorganic materials such as TaS_3, $NbSe_3$ and blue bronze $K_{0.3}MoO_3$. In these materials, the electron density is spatially dependent consisting of the unperturbed electron density in the absence of electron-phonon interaction given by $\rho_0 = \pi/k_F$ in one-dimension, and a collective mode formed by electron-hole pairs involving the wave vector $q = 2k_F$:

$$\rho(r) = \rho_0 + \rho_1 \cos(2k_F r + \Phi)$$

where k_F is the Fermi wavevector and Φ is the phase. The collective mode results from the pairing of electron and holes on either side of the Fermi suface to form a condensate called a charge density wave and an accompanying lattice distortion. As in superconductivity, there is a gap in the single-particle excitation spectrum, a collective mode described by a complex order parameter, and a phase whose time and spatial derivatives are linked to electric current and condensate density. Both amplitude and phase fluctuations can occur but whereas the amplitude mode has a gap, the phase excitations are gapless. Pinning is a central concept in CDW physics as the translational symmetry is broken by electrostatic potentials caused by impurities and grain boundaries which serve to pin the collective mode. The CDW systems are composed of normal electrons coexisting with a condensate and scattering with the normal electrons reduce the coherence length. Among the transport properties associated with the dynamics of the collective mode are (1) non-linear electrical conduction with a threshold electric field, (2) a metal-insulator or a metal-semiconductor transition below a distinct melting temperature accompanied by a periodic lattice distortion incommensurate with the underlying lattice, (3) anomalous microwave conductivity, (4) dc and ac excitations dominated by the collective mode dynamics, and (5) strong frequency dependent response in a broad frequency range. In studying such systems it is essential to examine intrinsic defects due to thermal fluctuations as well as defects, vacancies and dislocations induced by quantum fluctuations as they are believed to play an important role in the melting transition.

What drives the conduction in the CDW? Let us imagine that a CDW is pinned by the electrostatic potential well of an impurity . If an external electric field is applied, the CDW deforms around the pinning center but electrons remain constrained by the phase coherent CDW. The electrons which have not condensed in a CDW can still contribute to conduction by thermal activation across the gap but because of their low density the resistivity of the pinned CDW is high. At low temperatures when all electrons have frozen out, the activation energy is related to the energy required to change the phase of the local CDW in a coherent domain by 2π. Above a critical threshold field, the entire CDW can become depinned and slide coherently in the direction opposite to that of the applied electric field. The differential resistivity drops sharply giving rise to sharp non-linear I-V characteristics. The larger the number of pinning impurities, the greater the loss of phase coherence and the smoother the I-V characteristics. As the CDW slides past stationary impurity potentials, the voltage noise generated by the perturbation of the impurity potential will depend on the current, the carrier density and the period of the CDW. The size of the phase coherent domains is defined by the correlation length which can be measured from the transverse shear modulus, the threshold field, the interelectron spacing, and the carrier density.

In analogy to CDW systems, the electron solid forms in the presence of a neutralizing background charge which fixes the density when the potential energy between the localized electrons dominates all other energies in the problem. In most samples, the solid phase coexists with uncrystallized electrons. However, the phase coherence length remains large compared to the interelectron spacing in the electron solid (in GaAs: 4.8 μm > > 100r_s ~ 300 Å). Thus quantum depinning and defect waves or dislocation pairs are possible in electron systems but unlikely in CDW. The type of pinning, weak or strong, will depend on the location, nature (acceptor or donor), and number of pinning impurities. A successful model for the conduction mechanism in the Wigner solid has been developed by Chui. The model assumes that the charge carrying excitations are bound dislocation pairs. A single dislocation can be visualized as a shift of the electrons from equilibrium position which can be described by a displacement field. A dislocation pair consists of two dislocations with displacement fields in opposite directions; there is a net displacement of charge between the dislocations and the motion of this locally altered density is possible with resulting conduction. This is equivalent to the phase slip model in CDW.

If we review the experimental results, the similarities between the pinned charge density wave and the pinned electron solid are striking. There is a critical density and a critical temperature below which the insulating phase appears. The transition at the critical carrier density is weakly first order in character. The non-linear I-V characteristics can be interpreted as showing that at small currents the Wigner crystal is pinned by the neighboring impurities until the threshold field is exceeded and the Wigner crystal slides. Over the range of densities 7.2×10^{10} - 1.0×10^{11} cm^{-2} the threshold field decreases as $E_t \propto (n_c - n_s)^{\beta}$ where $\beta = 1.7$-1.8. This is in agreement with a depinning mechanism involving the creation and separation of dislocation pairs [30]. The theoretical model agrees well with the experimental results as shown in Fig. 6. The fact that the sub-threshold activation energy below 100 mK is much smaller than that above is consistent with extended defect conduction [31]. If one ignores quantum coherence effects, the motion of extended defects and in particular that of dislocation pairs is equivalent to phase slippage in a charge density wave [32]. The σ_{xx} versus electric field curves can be fitted to a phase slippage equation of the type:

$$\sigma_{xx} = (I_0 / l_c E) e^{(-\Delta/kT)} \sinh [neE l_x / kT]$$

where l_c is the intercontact distance, I_0 is related to the current created by a single phase slip and l_x is a characteristic phase slip length. The value of l_x obtained from the fit in Fig. 7 is 0.23 μm, or ten times the interelectron spacing.

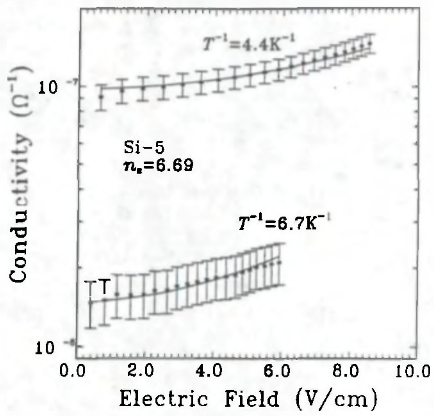

Fig. 7 Conductivity versus applied electric field for sample Si-5 at n_s = 6.69×10^{10} cm^{-2}. The solid lines are a single fit to the data at both temperatures using phase slip model.

What information can we get about the collective transport of depinned domains above the threshold field? By using the approach of elastic theory [33] as applied to charge density waves in the weak pinning limit, we can estimate the correlation length or domain size, L_D as $(K_T a/(2\pi e n_s E_t))^{1/2}$ where K_T is the transverse shear modulus, and a is the interelectron spacing. The experimental dependence of the threshold field on the carrier density shows that the correlation length diverges as $(\delta n_s)^{0.9}$ and thus L_D becomes smaller as the density is decreased, driving the system towards single-particle localization. Single-particle localization does have "its place in the sun" in the phase diagram.

The activation energy and the threshold field can be used to extract some characteristic length scale for the electron solid, e.g. the elementary crystallite size of the pinned Wigner solid. For a carrier density n_s = 8.4×10^{10} cm^{-2}, the sample typically consists of pinned crystallites approximately 0.7 μm $\times$ 0.7 μm in size each containing about 300 electrons with an interelectron distance ~ 400 Å!

The generated broadband noise shown in Fig. 5(b) is also consistent with depinning of the Wigner crystal or coherent defect motion above threshold. The narrowband noise should yield frequency peaks related to the principal lattice spacings. If we assume that the electron lattice extends across the entire 2D layer of width w and that the total current I is only provided by the sliding lattice, the spectral maxima will be related to the principal lattice spacing η_i as η_i = $I/(e n_s w \eta_i)$. For a hexagonal lattice sliding in a random field of point defects, η_1 = b, η_2 = $\sqrt{3}$ b, and η_3 = 2b where b is the distance between nearest neighbor electrons. Experimentalists have been urged to try this extremely difficult measurement as it could provide the definitive signature for lattice ordering of electrons- the "smoking gun" for Wigner crystallization. Although there are peaks in the narrowband spectrum and the frequency shifts with current, there is no simple relation that can be applied to link the results to a hexagonal or triangular lattice symmetry. It is likely that part of the current is provided by "uncondensed" electrons hopping beyond the lattice.

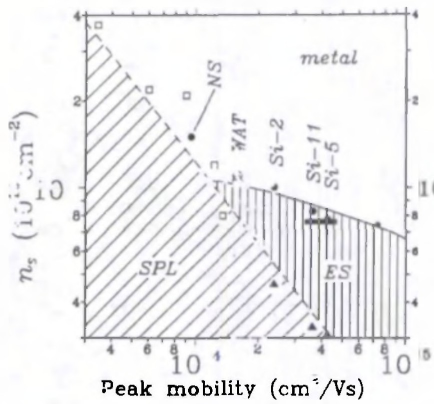

Fig. 8 Phase diagram for the two-dimensional electron system showing the critical density versus the sample peak mobility.

By studying samples in a wide range of mobilities and carrier densities, we have been able to probe the effect of "disorder" on the development of the insulating phase. Fig. 8 shows the phase diagram for the formation of the collective insulator phase or quantum Wigner solid confined between the metallic state above the cold melting boundary n_{cm} (full line) and the Anderson insulator or the regime of single-particle localization below the n_{spl} boundary. By using a calculation by Gold [34] for the mobility of Si(100) inversion layers, we obtain a satisfactory model for the peak mobility versus carrier density in our samples. The number of impurities n_i is a better indicator of disorder as the impurities are the main source of scattering at low densities (below 2×10^{11} cm^{-2}). The boundary for SPL is estimated from n_i and depicted by a short dashed line. This is the highest estimate for SPL in our samples where the surface roughness is much lower than that used to calculate n_i and n_{SPL}. The full triangles indicate n_{SPL} estimates if the domain length L_D is twice the interelectron distance L_D = $2a$. The solid line is the calculated dependence of the cold melting density on n_i using the mean square displacement as a function of n_i and an estimate of the cold melting density as n_i goes to zero. The calculation of the transition from a polarized WS to a partially polarized liquid at r_s ≈ 10 (n_s ~ 7.65×10^{10} cm^{-2}) is represented by a bar [21] and is in agreement with the data for Si-5 and Si-11. This phase diagram also explains why such a collective phase was not observed by other groups using lower mobility samples and suggests that we should be looking for a material system with as good if not better material parameters than the high mobility Si-MOSFETs studied here. Thus there is mounting experimental evidence for a low temperature transition to a collective insulator at zero magnetic field in high mobility Si-MOSFETs. This collective insulating phase has the transport characteristics of a Wigner solid.

The temperature dependence of the zero field resistance as a function of carrier density is also host to some more fundamental physics: that of scaling and universality. For more than two decades, it has been generally accepted that, at zero magnetic field, all states are localized in a two-dimensional system for an infinite sample as $T \rightarrow 0$ [35]. In contrast, a three-dimensional system can sustain a metal-insulator transition because the electrons are localized only when the Fermi energy lies below a mobility edge E_c. The conventional wisdom in 2D systems has recently been questioned as a result of a number of experimental results in superconducting thin films, and in high-mobility Si-MOSFETs [36-37]. In addition, a theoretical study of noninteracting 2D electrons in a model disorder potential with a random set of special scatterers showed that, at zero magnetic field, the system is localized only when $E_F < E_c$ [38]. In material systems where the range of the scattering centers is short (as in MOSFETs), similar to Azbel's model potential, a "true" zero magnetic field metal-insulator transition may be allowed in the limit of zero temperature. The resistivity as a function of temperature over a wide range of densities ($7.12 \rightarrow 13.7 \times 10^{10}$ cm^{-2}) in a high-mobility Si-MOSFET sample (Si-12b; μ_{max} = 3.0×10^4 cm^2/Vs) can be made to overlap by scaling along the temperature axis. The resistivity can be represented in terms of a ratio T/T_0 where T_0 depends only on the density. The data collapses on two separate curves one for the insulating side of the transition and the other for the metallic side as shown in Fig. 9. One of the signatures of a phase transition is the scaling of an appropriate physical parameter. It would seem then that the results are in agreement with Azbel's model but in contradiction with that of Abrahams and co-workers; this suggests that there is a "true" metal insulator transition in the two-dimensional electron system in Si at zero magnetic field.

Si-SiGe-Si QUANTUM WELL STRUCTURES

The experimental results on high mobility Si-MOSFETS have been reproduced in at least four different laboratories around the world. However, there is only one batch of such samples and it is very difficult, without a large investment in time and manpower, to fabricate more of these. We have thus turned to pseudomorphic Si-SiGe-Si heterostructures which are grown, either by molecular beam epitaxy or ultra-high vacuum chemical vapor deposition techniques, in a large number of laboratories and may be better suited for studying Wigner crystallization. The important features of the p-type Si-SiGe-Si quantum wells are that the 2D holes have a large effective hole mass, 0.42 m_e which is twice that of electrons in the Si-MOSFETs. This has been checked in our samples by analysis of the low-field Shubnikov-de Haas oscillations and by cyclotron resonance [39-41]. Although the dielectric constant $\varepsilon \sim 12.6$ is similar to that of GaAs-AlGaAs heterostructures, the symmetric confinement of holes in the SiGe well can lead to coupled 2D hole gases. As pointed out in Table 1, at a carrier density of 2×10^{11} cm^{-2} in Si-SiGe heterostructures, the Wigner-Seitz radius is identical to that in Si-SiO_2 and the quantum cold melting critical density is twice as large because of the larger effective mass!

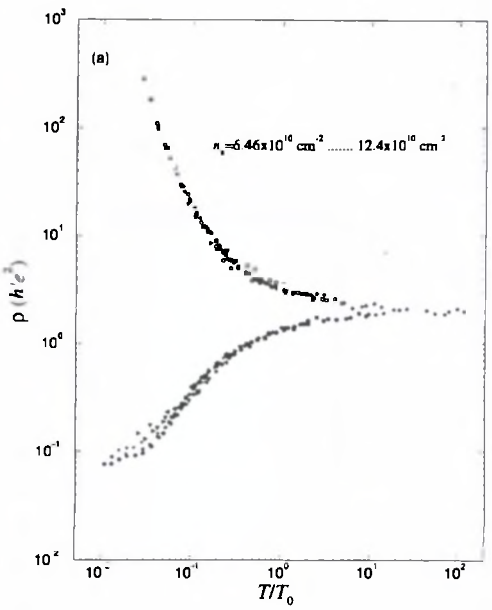

Fig. 9 Resistivity versus T/T_0 where T_0 is the scaling parameter. The open symbols correspond to the insulating side of the transition while the closed ones correspond to the metallic phase.

The Si-$Si_{0.87}Ge_{0.13}$-Si heterostructures were grown on an n Si (100) substrate by molecular beam epitaxy. The symmetrically-doped samples were grown on a 500 Å i-Si buffer and consisted of a 500 Å Si layer modulation-doped with boron acceptors at 10^{18} cm^{-3} and a 300 Å i-Si setback on each side of a $Si_{0.87}$ $Ge_{0.13}$ quantum well of thickness d . A set of samples was grown with d = 45, 65, 90 and 115 Å. The cap layer consisted of 400 Å of B-doped Si. This is shown in Table 3.

The samples were patterned as Hall bar structures 10 mm long and 2 mm wide. Ohmic contacts were made using Al evaporation and annealing below the eutectic point.

A number of unexpected results were obtained in these samples:

- The SdH oscillations in the 115 Å well are typical of two subband population as shown in Fig. 10. These are not oscillations from two independent hole gases at each interface as was observed in larger wells but rather the population of the heavy hole and the light hole ground subbands. This interpretation is borne out by **k•p** Luttinger Hamiltonian calculations [41].

Table 3
The MBE-grown Si-$Si_{0.87}Ge_{0.13}$-Si Heterostructures

Surface	
B - doped Si - 1x10^{18} cm^{-3} 900 Å	
i - Si spacer 300 Å	
$Si_{0.87}Ge_{0.13}$	
Sample #	d
SiGe 1456	115 Å
SiGe 1457	90 Å
SiGe 1458	65 Å
SiGe 1459	45 Å
i - Si spacer 300 Å	
B - doped Si - 1x10^{18} cm^{-3} 500 Å	
i - Si buffer 500 Å	
Si (100) n	

- There is a large peak in the longitudinal resistance at filling factor 3/2 followed by a deep minimum at filling factor $\nu = 1$. The Hall resistance is not anomalous at the half-filled Landau level and displays a well developed plateau h/e^2 when the longitudinal resistance is at its minimum.
- For the narrower 90 and 65 Å wells, there are large longitudinal resistance peaks at both ν = 3/2 and 5/2, re-entrant with deep minima at ν = 1 and 2.
- The temperature dependence of the current-voltage characteristics taken at ν = 3/2 for the 65 Å well reveal that the onset of the large resistance maxima ($>> h/e^2$) occurs around 500 mK (see Fig. 11).

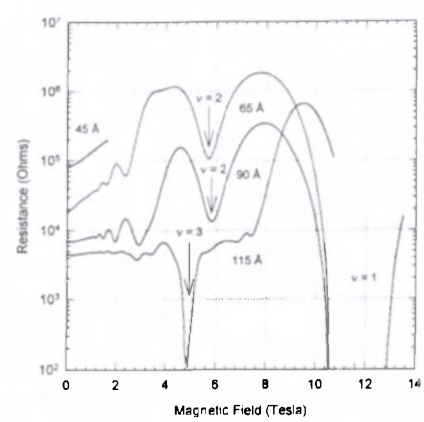

Fig. 10 Longitudinal resistance as a function of magnetic field for different SiGe quantum well widths at T ~ 25 mK.

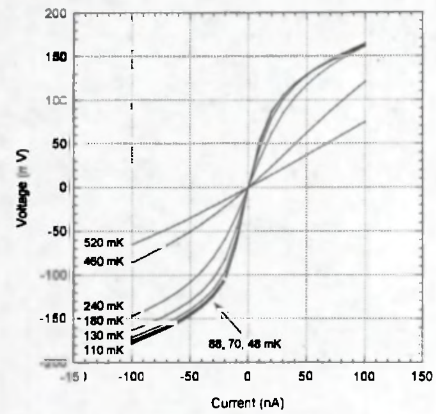

Fig. 11 Current voltage (I-V) characteristics as a function of temperature for ν = 3/2 at B = 7.75 T for the 65 A well.

- Similar results are shown in Fig. 12 for the 90 Å well with the sub-threshold resistance at ν = 3/2 increasing by two orders of magnitude below 500 mK. the inset shows the thermal activation of the differential resistance where $dV/dI \propto e^{-\Delta/kT}$ with $\Delta = 0.47$ K in the temperature range above 100 mK.

Although these results have been taken at a fixed density ~ 2×10^{11} cm^{2}, the basic features of large longitudinal resistances at half-filled Landau levels, non-linear I-V characteristics with low threshold fields, and thermal activation of the resistance are very similar in nature to those in the Si-MOSFETS. In the light of the scaling behavior of the zero magnetic field resistance in Si-MOSFETs, we have also looked at the temperature dependence of the longitudinal resistance at zero field for different well widths.

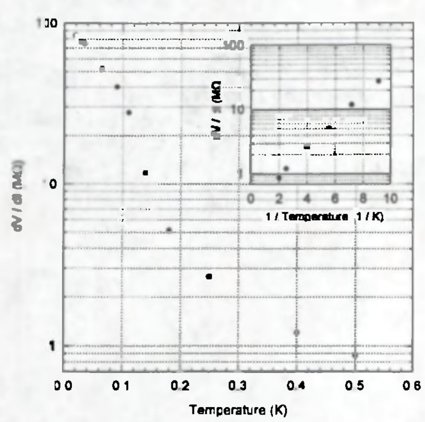

Fig. 12 Temperature dependence of the differential resistance for the 90 A well at ν = 3/2 and B = 7.95 T. The inset shows activated behavior in the higher temperature scale.

As shown in Fig. 13, there is a transition from an insulating phase where ρ_{xx} decreases with temperature for the 65 Å well to a metallic phase where ρ_{xx} decreases with temperature for the 90 Å and 115 Å wells. This is consistent with the fact that the carrier density is decreasing with decreasing well width.

The curves also appear to converge near a critical resistivity of $h/2e^2$. These features are similar to those observed in superconducting thin films of Bi as a function of thickness, and Si MOSFETs and GaAs-AlGaAs heterostructures as a function of carrier density. Further study of scaling parameters will require the variation of the density in the Si-SiGe-Si heterostructures. From other work [42], we know that the critical density in these systems is slightly above our fixed density. We must also investigate the role of disorder in the onset of these transitions by studying higher mobility and hence higher Ge content samples.

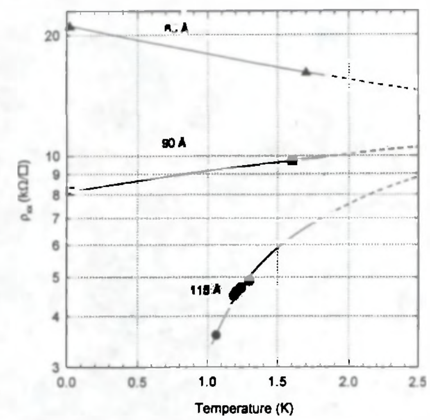

Fig. 13 Temperature dependence of the longitudinal resistivity in a vanishing magnetic field for different SiGe quantum well widths.

CONCLUSION

The work on Si-MOSFETs has provided a phase diagram for the formation of a quantum Wigner crystal at zero magnetic field as a function of disorder. It was also established that a fully spin-polarized Wigner crystal could exist re-entrantly with a partially polarized quantum liquid or gas in the quantum Hall effect regime in very high mobility samples only. The study of the re-entrant insulating phase in semiconductor heterostructures has also led to the definition of a new type of insulator, "the Hall insulator" [43], for which the Hall resistivity remains metallic while the longitudinal resistivity becomes infinite. The system par excellence to study the Wigner crystal state is one where the effective mass is large, the dielectric constant and the amount of disorder are small, the carrier density is tunable and the material system imposes some sort of inherent coupling either with non-degenerate valleys as in Si-MOSFETs, or by lifting the degeneracy between the symmetric and anti-symmetric states through the valence band anisotropy as in the Si-SiGe system. Finally, there is now mounting experimental evidence that the Abrahams-Anderson-Licciardello-Ramakrishnan theory for which a metal-insulator transition in an infinite 2D system, at zero magnetic field as T→0 is forbidden, is inappropriate in 2D systems with short range scatterers.

We have only begun to explore the phase diagram for the formation of a Wigner solid in two-dimensional electron and hole systems. The mapping of the phase boundaries as a function of temperature, density, magnetic field and disorder is a challenging task. As better samples become available, a fuller story on the richness of the dilute density regime can be written.

ACKNOWLEDGMENTS

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(continued on page 71)

NOUVELLE SOURCE DE PLASMA POUR LE TRAITEMENT DES MATÉRIAUX: MAGNÉTOPLASMA À ONDE DE SURFACE

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INTRODUCTION

Au cours des vingt dernières années, on a vu croître de façon considérable l'emploi des plasmas pour le traitement des matériaux aussi bien dans les secteurs de haute technologie, comme par exemple en microélectronique et en photonique, que dans les industries plus traditionnelles (e.g., métallurgie et textile). Il faut se rappeler que dans le passé, les applications des plasmas au traitement des matériaux se sont développées sous l'égide de la communauté des utilisateurs, ceux-ci ayant fait appel aux plasmas pour pallier les limitations des méthodes conventionnelles. Les percées dans le domaine se sont donc appuyées sur des moyens plus ou moins empiriques de sorte que le fondement scientifique de ces applications demeure encore peu substantiel. Le progrès que l'on peut attendre d'une telle démarche est par conséquent limité et il est devenu nécessaire de mieux comprendre le fonctionnement des sources de plasma utilisées, d'en concevoir de nouvelles et de modéliser de façon adéquate à la fois le plasma et l'interaction plasma-surface si l'on veut relever les défis posés en microélectronique et en photonique. Bien sûr, cette recherche est de nature tout à fait fondamentale et elle requiert une expertise en physique des plasmas, aussi bien en modélisation qu'en caractérisation, et une interaction étroite avec les spécialistes des procédés et de la caractérisation des surfaces. Tout ceci a stimulé au cours des dernières années des activités de recherche portant sur la physique des plasmas dits froids et des plasmas réactifs dans de nombreux laboratoires à travers le monde.

Pour notre part, dans le contexte général présenté ci-dessus, nous avons mis au point une source de plasma originale, basée sur la propagation des ondes de surface et à laquelle on adjoint un confinement magnétique. Les propriétés de cette source sont mises à profit pour graver des couches minces à des dimensions sous-micrométriques. La conception de cette source, sa caractérisation et sa modélisation constituent un volet important des activités du Groupe de Physique des Plasmas de l'Université de Montréal. Dans cet article, nous décrivons brièvement les propriétés du plasma ainsi produit ainsi que l'influence sur les paramètres du plasma de la présence d'un substrat. Nous examinons également les performances de ce plasma pour la reproduction de motifs sous-micrométriques (0,2 μm) dans du tungstène.

NOUVELLES SOURCES DE PLASMA POUR LA GRAVURE EN MICROÉLECTRONIQUE

La source de plasma majoritairement employée en gravure des matériaux, pour prendre cet exemple, est la décharge capacitive. Bien que ce type de plasma soit employé de façon routinière dans la fabrication des microcircuits, entre autres parce qu'il permet le traitement simultané de plusieurs substrats, il souffre de sévères limitations. D'une part, la densité de particules chargées est faible (typiquement 10^9-10^{10} ions par cm^3) et d'autre part, ce type de source ne permet pas un bon contrôle du flux d'ions vers la surface. Or, il s'avère qu'un tel contrôle est devenu nécessaire pour atteindre l'anisotropie de gravure recherchée ainsi que l'optimisation des autres paramètres de gravure. De nouvelles sources de plasma ont vu le jour pour mieux répondre aux objectifs de plus en plus exigeants dans ce domaine. En bref, il s'agit de produire une source de plasma relativement dense tout en permettant de contrôler adéquatement le flux d'ions frappant la surface, et ceci indépendamment du mécanisme de création du plasma. Une source telle que la fameuse décharge dite de résonance cyclotronique électronique (RCE) en est un exemple. Il s'agit d'une source micro-onde (2,45 GHz) fonctionnant à très basse pression (10 mtorr et moins) et dont la densité d'ions peut atteindre selon les conditions plusieurs 10^{11} cm^{-3} avec un degré d'ionisation souvent supérieur à 1%. Le fonctionnement à très basse pression est rendu possible grâce à la présence d'un champ magnétique statique (environ 875 gauss) qui permet de confiner les particules chargées et assure également le mécanisme de transfert d'énergie onde-plasma. Les avantages de ce type de plasma sont notoires. Ainsi, la grande densité de particules chargées permet d'assurer un taux élevé de gravure assistée par les ions. Aucune électrode interne n'étant présente dans la décharge, les risques de contamination sont minimisés. La différence de potentiel entre la surface gravée et le plasma est en général inférieure à 20 volts, une valeur très en-dessous de celle rencontrée dans les décharges capacitives. Enfin, la pression très faible permet de limiter le nombre de collisions subies par les ions dans la gaine de plasma. Ainsi, on préserve mieux la directionnalité du mouvement des ions dans la gaine ce qui favorise l'anisotropie de gravure.

D'autres types de décharges similaires à la source RCE ont également été proposées comme, par exemple, le plasma hélicon dont le principe de fonctionnement demeure tout à fait comparable. Ce plasma est produit à des fréquences radio (e.g., 13,56 MHz) et nécessite également un champ magnétique; on note cependant que ce champ peut être beaucoup plus faible que celui employé pour les décharges RCE. Pour des conditions comparables de pression, de diamètre de tube à décharge et d'intensité de champ magnétique, la densité de particules chargées est comparable dans les deux types de plasma.

Pour notre part, nous avons souhaité capitaliser sur l'expérience que nous avons des plasmas produits par des ondes de surface, pour produire une nouvelle source avec des caractéristiques comparables à celles des plasmas précédemment décrits. Dès 1992, nous avons mis sur pied un prototype de réacteur destiné à la gravure de matériaux (RCE4). Son schéma est présenté sur la figure 1.

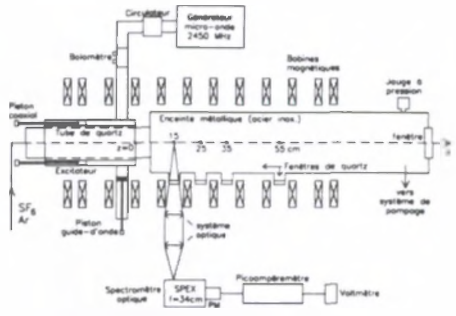

Figure 1. Schéma du réacteur RCE4 (magnétoplasma à onde de surface)

Le réacteur est alimenté par un plasma à onde de surface à 2,45 GHz produit dans un tube de silice fondue (quartz) de 15 cm de diamètre. Ce tube pénètre dans une enceinte métallique de 28 cm de diamètre le long de laquelle sont disposées plusieurs fenêtres destinées à visualiser le plasma et à insérer des diagnostics. Un ensemble de 12 solénoïdes est disposé le long du tube et du réacteur. L'espacement entre les bobines a été choisi de sorte que le champ magnétique demeure homogène sur environ 70 cm, incluant la source. Cet aspect de la conception du dispositif expérimental est basé sur le fait que les études de distribution en vitesse des ions dans des réacteurs de type RCE ou hélicon montrent que le mouvement des ions est très influencé par l'orientation des lignes de champ magnétique: les ions ont tendance à suivre ces lignes. Or, pour atteindre un bon contrôle du mouvement des ions vers la surface à traiter, il est nettement préférable que ceux-ci frappent la surface à la normale. L'utilisation fréquente de lignes de champ divergentes dans les magnétoplasmas est un obstacle à la recherche de l'anisotropie en gravure de couches minces.

Bien que les études que nous avons menées jusqu'à présent se soient essentiellement limitées à une fréquence micro-onde (2,45 GHz), le plasma produit par onde de surface présente l'avantage notoire de pouvoir fonctionner à n'importe quelle fréquence. C'est d'ailleurs cette extraordinaire flexibilité, bien adaptée à des études paramétriques, qui a permis à ce type de plasma d'acquérir ses lettres de noblesse, particulièrement en ce qui concerne la modélisation des décharges de haute fréquence (HF).

CARACTÉRISTIQUES DU MAGNÉTOPLASMA À ONDE DE SURFACE

La figure 2 montre un exemple de distribution en vitesse des ions métastables d'argon dans la direction parallèle à l'axe de la colonne de plasma dans un dispositif similaire à celui présenté ci-dessus (RCE5). Ces mesures ont été réalisées au moyen d'une méthode de fluorescence induite par laser.

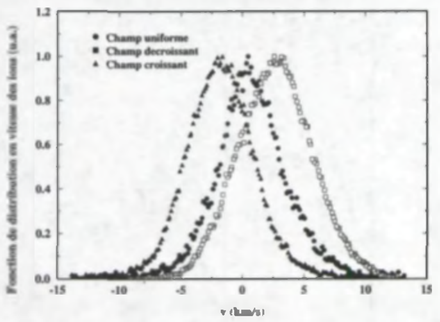

Figure 2. Fonction de distribution en énergie des ions métastables d'argon obtenues dans le réacteur RCE5 au moyen d'une méthode de fluorescence induite par laser. Noter que les profils ne sont pas déconvolués pour tenir compte de l'effet Zeeman et de la largeur de la raie du laser.

On y remarque que les ions suivent une distribution gaussienne centrée autour de zéro. Ainsi, pour un champ magnétique axialement uniforme, les ions ont une très faible vitesse de dérive axiale. À titre de comparaison, nous avons représenté sur la même figure les distributions de vitesse obtenues dans des régions de champ magnétique décroissant et croissant. Dans le premier cas, les ions sont accélérés loin de la source alors que dans le second, les ions ont tendance à revenir vers la source. Ces résultats illustrent bien le rôle extrêmement important que joue la configuration du champ magnétique statique sur le mouvement des ions. La conclusion évidente de ces résultats est que pour tirer tous les bénéfices de l'utilisation d'un champ magnétique de confinement, il est préférable d'avoir des lignes de champ magnétique aussi uniforme que possible. Ceci permet de limiter la dérive axiale des ions au minimum et donne à l'utilisateur plus de latitude pour contrôler indépendamment du plasma le mouvement des ions vers la surface à traiter, par exemple au moyen d'une polarisation auxiliaire (et maîtrisée) du substrat.

Le magnétoplasma a été diagnostiqué au moyen de plusieurs méthodes incluant des sondes électrostatiques, des ondes acoustiques ioniques et diverses méthodes spectroscopiques. Nous avons ainsi pu montrer que la densité des ions positifs pouvait atteindre localement 10^{12} cm^{3} dans l'argon et la température des électrons quelques eV. Dans un gaz comme le SF_6 utilisé pour la gravure du tungstène, on a obtenu des valeurs comparables pour la densité et la température; on a également mis en évidence par photo-détachement induit par laser une forte concentration d'ions négatifs, leur densité étant supérieure à celle des électrons à des pressions de seulement quelques mtorr.

Nous avons utilisé une source similaire, mais de plus petites dimensions pour effectuer une étude du bilan énergétique de la décharge [1]. Nous avons ainsi pu montrer que le bilan énergétique s'améliore lorsqu'un confinement magnétique est appliqué à la décharge, comme on pouvait s'y attendre, la présence d'un champ magnétique réduisant les pertes de particules chargées. Un modèle de magnétoplasma récemment élaboré [2] permet d'ailleurs de confirmer un certain nombre de nos observations. Cependant, contrairement à ce qui est largement affirmé dans la littérature, le fait de fonctionner à la résonance cyclotronique électronique ne constitue pas un avantage en termes de bilan d'énergie. En fait, plus le champ magnétique est intense, meilleur est le rendement énergétique. Les valeurs mesurées de la puissance absorbée par électron dans notre plasma ont été utilisées pour démontrer que l'ensemble des magnétoplasmas HF obéissent aux mêmes règles physiques; ainsi, pour des conditions identiques de fonctionnement, le bilan énergétique demeure le même pour n'importe quel magnétoplasma HF.

INTERACTION PLASMA-SURFACE

Nous avons étudié l'influence de la présence d'un substrat sur les caractéristiques en volume du plasma [3].

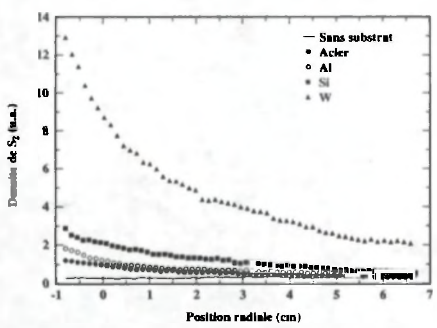

Figure 3. Densité de soufre moléculaire S_2 dans le plasma en présence de différents substrats. Le substrat est situé à -1 cm sur l'abscisse de ce graphique.

Cette étude a été menée sur un plasma de SF_6 au moyen d'une méthode de fluorescence induite par laser et d'une méthode d'actinométrie résolue spatialement avec double procédure de normalisation; les espèces examinées sont, d'une part, le fluor atomique et, d'autre part, le soufre moléculaire S_2, formé en grande concentration dans ce type de plasma. Les résultats de cette étude ont montré que le fluor atomique est fortement consommé par le silicium, comme on s'y attendait, contrairement aux matériaux plus inertes vis-à-vis des gaz fluorés, comme l'aluminium ou l'acier inoxydable. Le tungstène, quant a lui, n'a pas une influence systématique sur cette consommation qui peut être aussi importante que celle du silicium à basse pression (1 mtorr) ou comparable à celle de l'aluminium et de l'acier à plus haute pression (7 mtorr).

Outre son influence sur la concentration en fluor atomique dans la décharge, la présence d'un substrat modifie de façon importante celle du soufre moléculaire tel qu'illustré sur la figure 3.

Sur ce graphique est reportée la concentration de S_2 en fonction de la position à partir du substrat pour différents matériaux. On y remarque un accroissement de la concentration de S_2 non seulement au voisinage immédiat du substrat, mais également à grande distance de celui-ci. À partir de ces résultats ainsi que de mesures complémentaires effectuées en post-décharge temporelle, on a pu montrer que la présence d'un substrat, et particulièrement d'un substrat de tungstène, influence l'ensemble de la chimie du réacteur, incluant le coefficient de collage de ses parois d'acier. En outre, nous avons pu mettre en évidence que le soufre moléculaire est principalement détruit par impact électronique contrairement à ce qui a été observé dans une décharge capacitive de type RIE (Reactive Ion Etching) [4], ceci résultant bien sûr du fait que le magnétoplasma est considérablement plus dense que la décharge de type capacitif.

GRAVURE SOUS-MICROMÉTRIQUE DU TUNGSTÈNE

La source que nous avons conçue nous a permis d'effectuer, en utilisant un plasma de SF_6, la gravure de motifs sous-micrométriques de tungstène à des températures de substrat variant de -45° à + 15° [5]. Ainsi, nous avons pu reproduire des motifs de très petites dimensions (0,2 μm) sans faire appel à une polarisation externe du substrat. Dans une telle situation, les ions interagissant avec la surface ont une énergie relativement faible, ce qui réduit les dommages causés à la surface. Une photographie de motifs de 0,2 μm est présentée sur la figure 4. La gravure demeure anisotrope tant que la pression est inférieure à une valeur seuil, fonction de la température de la surface. Ainsi, pour une température de -20°, le seuil se situe autour de 0,75 mtorr alors qu'il est plutôt de 1,5 mtorr lorsque la température est abaissée à -45°.

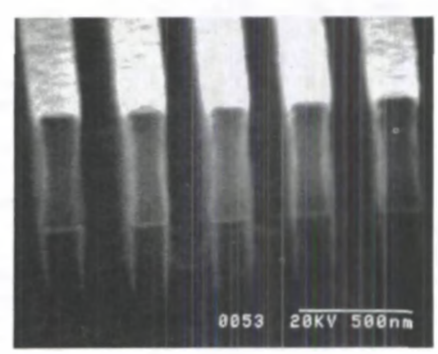

Figure 4. Photographie de motifs de tungstène ayant 0,2 μm de largeur, obtenus à partir d'une image par microscope électronique.

Les résultats obtenus montrent que notre réacteur possède d'excellentes caractéristiques. En particulier, le fait de ne pas devoir recourir à une polarisation auxiliaire du substrat pour atteindre une anisotropie parfaite constitue un atout majeur par rapport à d'autres types de sources. Nous pensons que le fait que le champ magnétique soit uniforme dans la région où se situe le substrat, est à l'origine des excellentes performances de notre réacteur en termes de gravure.

CONCLUSION

Nous avons mis au point une nouvelle source de plasma dont les caractéristiques sont bien adaptées à la reproduction de motifs sous-micrométriques. Le travail que nous avons effectué s'est situé non seulement du point de vue des applications, mais également sur le plan de la physique plus fondamentale, grâce à des études approfondies des propriétés de la décharge. Clairement, beaucoup reste à faire, particulièrement en termes de modélisation du plasma et de l'interaction plasma-surface que nous n'avons pour l'instant qu'ébauchées. Au cours des prochaines années, il nous restera à mieux maîtriser ces deux aspects en menant des études expérimentales et théoriques de front. Bien sûr, ce défi est de taille, mais nous sommes convaincus que cette approche est la seule qui soit valable pour améliorer notablement les procédés assistés par plasma.

REMERCIEMENTS

L'auteur tient à exprimer sa reconnaissance à toutes les personnes, collaborateurs, stagiaires, étudiants et techniciens, ayant été impliquées à divers titres dans les travaux résumés ci-dessus. En particulier, les contributions de MM. M. Chaker (INRS-Énergie et Matériaux) et M. Moisan (Université de Montréal) sont vivement remerciées ainsi que celles de Mmes C. Barbeau et I. Pérès et de M. E. Gat (stagiaires postdoctoraux). L'auteur tient également à exprimer sa gratitude à Mme A. Dallaire et M. M. Fortin (étudiants de 2e cycle) et MM. F. Bounasri et L. St-Onge (étudiants de 3e cycle). Enfin, une reconnaissance particulière est accordée à R. Grenier, R. Lemay, R. Martel et F. Roy pour leur exceptionnel soutien technique.

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EVALUATION OF THE ACID DEPOSITION AND OXIDANT MODEL WITH OZONE AND SULPHUR DIOXIDE DATA FROM HIGH ELEVATION SITES

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ABSTRACT

Mixing ratios of O_3, measured continuously at two high elevation (850 m-msl) sites and one valley (250 m-msl) site in southern Quebec, Canada, during the summer of 1988 and spring of 1990, and mixing ratios of SO_2 measured during the spring of 1990 at one high elevation site are compared with the predictions of the Acid Deposition and Oxidant Model (ADOM). These sites are representative of rural areas downwind of major anthropogenic source regions. This is the first evaluation of a regional-scale Eulerian transport and chemistry model using data from Canadian high elevation sites.

The observations show higher average O_3 mixing ratios in the spring than the summer at both the more northerly high elevation site and at the valley site. The model results for comparable elevations show a different seasonal tendency, with higher average O_3 seen in the summer. In the summer the average modelled ozone mixing ratio is about 14 ppbv higher than the average measured ozone mixing ratio for the more northerly high elevation site, and 8 ppbv higher for the more southerly. In contrast, the average modelled ozone mixing ratio for the spring is 4 to 6 ppbv lower than the average measured ozone mixing ratio for all three sites. In both seasons the range of the hourly ozone mixing ratios observed at the high elevation sites is greater than that predicted by the model. The measured and modelled sulphur dioxide hourly mixing ratios, averaged over a five week period, are both near 1.29 ppbv. In the spring, the diurnal variations in O_3 and SO_2 are well represented by the model.

The ability of the model to predict days with the upper or lower quartile of O_3 mixing ratios is assessed using the True Skill Statistic (TSS), with the highest skill (TSS = .77) shown for low O_3 events in the summer at the high elevation sites and the lowest skill (TSS = .27) shown for the valley site for both high and low O_3 episodes in the spring. The upper quartile O_3 events at both high elevation sites are predicted with a TSS of 0.56 or greater for both seasons. The model shows poor skill at predicting the daily trends in SO_2.

It is recommended that the sensitivity of the model output to the choice of boundary conditions for O_3, the mixing processes in the lower 1 km of the atmosphere during the summer season, and the loss of O_3 in the nocturnal inversion in summer be further investigated since these processes appear to significantly influence the ADOM predictions of ozone mixing ratio.

INTRODUCTION

One current problem in atmospheric science is understanding the complex linkage between emissions of specific pollutant species and the resultant impact of the reaction products of these species on vegetation, animals, humans and climate. To a large extent man's influence on the environment is under the control of policy makers, and changes are possible with the appropriate trade-off in economics and lifestyle. Two gas-phase species of current concern in the lower troposhere are ozone (O_3 - an oxidant and greenhouse gas) and sulphur dioxide (SO_2 - the precursor to sulphate which is one of the primary causes of the acidity in precipitation and fog).

Mathematical air-quality models which incorporate complex chemistry and meteorology have been developed to provide guidance in formulating the most appropriate control strategies for air pollutants with regional impacts. The Acid Deposition and Oxidant Model (ADOM), a regional-scale Eulerian atmospheric transport and chemistry model, was developed in a cooperative effort funded by the Canadian federal government, the Province of Ontario, the Electric Power Research Institute, and the Federal Republic of Germany to aid in the understanding of the impact of emission controls on acid deposition and ground-level oxidant concentrations (Venkatram et al., 1988; Karamchandani and Venkatram, 1992). Models such as ADOM must be carefully evaluated with field data so that their performance can be assessed before the predictions can be used with confidence. The Eulerian Model Evalation Field Study (EMEFS) was carried out from June 1988 to May 1990 at surface sites in eastern North America to gather data for the evaluation of ADOM and the Regional Acid Deposition Model, which was developed for use in the U.S.A. (e.g., Byun and Dennis, 1995). From July 15 through August 31, 1988 and March 15 through April 30, 1990, enhanced observations, including aircraft measurements of O_3 and SO_2 mixing ratios at altitudes from 0.5 to 5 km, were made in central Ontario to support the model evaluation. Evaluations of the performance of ADOM during the summer period have been made with aircraft data (Macdonald et al., 1993) and with O_3 profiles to 15 km obtained with ozonesondes and differential absorption lidar (Hoff et al., 1995).

Observations of meteorological parameters and ozone mixing ratios have been made at high elevation rural sites in forested areas of Quebec since 1986 as part of the Chemistry of High Elevation Fog (CHEF) program (Schemenauer, 1986), with sulphur dioxide monitored at one site from Sept. 1989 through July 1990. In this paper, data from these sites, located 300 to 500 km east of the aircraft study, are compared with the results of ADOM for the two EMEFS enhanced observation periods. Whereas the aircraft observations consist of a combination of horizontal transects up to 250 km for times of about 1 hour and vertical profiles over specific surface sites taken once or twice per day, the CHEF data provide continuous hourly measurements which permit sensitive testing of the model at an altitude equivalent to an elevated layer of the model throughout the long time periods for which the model is expected to have good predictive skill (e.g. seasonal means, etc.). The CHEF high elevation surface sites are exposed to higher wind speeds (Bridgman et al., 1994) and have generally higher mixing ratios and smaller diurnal variations in O_3 than low elevation surface sites. The CHEF mountain sites have long records of ozone and meteorological parameters, as well as fog and precipitation data (Schemenauer et al., 1995), which can be very complementary to data from standard surface networks, aircraft and remote sensing in further model evaluation.

METHOD

The Measurements

The O_3 mixing ratios were measured at Roundtop Mountain (RTR, 45°05'17"N, 72°33'09" W, 845 m-msl), a nearby valley site (RTV, 45°04'32"N, 72°40'33"W, 250 m-msl) and Mont Tremblant (MT, 46°12'50" N, 74°33'20" W, 860 m-MSL). The SO_2 measurements were made at RTR. These sites are northeast of widespread sources of anthropogenic pollution in North America (Benkovitz et al., 1994). Minimal anthropogenic activity is seen to the north of MT, and this site is considered to be representative of background conditions when under the influence of northerly air.

Ozone was detected with TECO 49 u.v. photometric analyzers equipped with automatic pressure and temperature compensation, and calibrated with sources traceable to NIST transfer standards. Sulphur dioxide was monitored with a TECO 43A pulsed fluorescence analyzer which was calibrated with a permeation tube dilution system. The sample inlets were located 3 m above ground level. The signals from the O_3 and SO_2 analyzers were sampled every 5 seconds and recorded on a data logger as 15-minute averages. For this analysis, hourly averages were derived for both species. Due to routine zeroing of the SO_2 analyzer for 30 minutes within each even hour (UTC) hourly averages are available for odd hours only. The detection limit for SO_2 is estimated at 0.1 parts per billion by volume (ppbv) and the hourly O_3 mixing ratio is known to 1 ppbv. For the time periods considered, the CHEF data recovery is 100% for O_3 and SO_2, except for the summer of 1988 when O_3 measurements are available only 90% of the time at RTR and 98% of the time at RTV. In this evaluation, model results are not included for periods of missing observations. The effect of the exclusion of one-half the modelled results for SO_2 was investigated. The daily averages of SO_2 mixing ratio were calculated with results for all hours and then again with the odd hours only. The two sets of values were correlated with an r^2 exceeding 0.999 and with mean, median and maximum differences of 0.02, 0.01 and 0.1 ppbv, respectively.

The locations of the high elevation sites were chosen to provide exposure to the prevailing wind directions, and to be relatively elevated and isolated compared with the surrounding terrain. These sites are regularly impacted by low level stratus and cumulus, and it is clear from the motion of these cloud fields that the sites are under the influence of air driven by synoptic winds characteristic of elevated altitudes. Upslope and downslope winds are important only under the condition of very low synoptic winds. The amount of orographic lift is small compared with the mixing in the boundary layer, and the high elevation sites will be located within the mixed boundary layer during most afternoon periods.

The Model and Data Analysis

The model domain consists of 33x33 grid squares, each approximately 127x127 km^2, covering eastern Canada and the United States, with 12 layers in the vertical spanning 1 to 10,000 m-agl. A grid cell refers to the volume occupied by one layer in one grid square. The output consists of hourly averages of a wide variety of chemical species, including O_3 and SO_2, which represent the volume average for the grid cell. The version of the model under evaluation is ADOM 2Bi (Macdonald et al., 1993), which was run for both EMEFS intensive time periods using the observed meteorology. Model results for July 15 to August 31, 1988 and March 25 to April 30, 1990 are used for the comparison.

The model uses a single ground height representative of the average topography in the grid square. For the grid squares considered here the ground height used for the model is 416 m-msl near MT and approximately 470 m-msl near RTR and RTV. In southern Quebec the actual topography within a grid square is complex, (e.g. the sites RTR and RTV are separated by about 10 km in the horizontal, and 600 m in the vertical) and the correct application of the observations to model evaluation is open to some interpretation. Two scenarios are considered here. A comparison is made considering RTV to be representative of the lowest layer of the model and RTR and MT to be representative of conditions near 600 m-agl. This approach is favoured by the authors.

The CHEF data from the mountaintop sites were compared with layers five and six of the model (hereafter M5 and M6), which span 416 to 646 and 646 to 1000 m-agl respectively. Data from the valley site were compared with layer one of the model (M1), which represents 1 to 56.2 m-agl. MT is located near the centre of grid square 19,20. Approximately 200 km to the southeast, the RTR and RTV sites are centrally located on the north-south border of grid squares 20,19 and 21,19. Data from MT were compared with model predictions for grid square 19,20 (MT-M5, MT-M6) and model results for grid squares 20,19 and 21,19 were averaged (RT-M1, RT-M5, RT-M6) to be compared with the data from the Roundtop sites. It will be shown that the model predictions for layers 5 and 6 are similar, and in general will not be distinguished from each other in the figures.

A second approach to the evaluation of the model, which considers both RTV and RTR to be surface sites in the layer M1, will be discussed. In this case these two sites represent the topographic extremes for sites located within the grid square, and the observations are bounds for conditions in this layer.

The hourly-averaged observations were compared with the model predictions both as frequency distributions and as scatter-plots. Diurnal variability was established by averaging the observations or model results for each of the 24 hours in the day over the entire summer or spring study period.

The ability of the model to predict days with high or low O_3 mixing ratios was assessed with the True Skill Statistic (TSS) (Flueck, 1987) as follows. To allow the time trends to be evaluated independently of the absolute mixing ratios seen, daily-averaged predictions for each of MT-M5, RT-M5 and RT-M1, and data from MT, RTR and RTV were ranked and tagged as in the upper or lower quartile for each set (i.e. the two ranking schemes: top 25% or remaining 75%; bottom 25% or remaining 75%). Since, as will be seen, model layers 5 and 6 see the same time series of events, the observations and model predictions were related as MT with MT-M5, RTR with RT-M5 and RTV with RT-M1. In addition, to directly compare the skill of the model with the regionality of the ozone events, observations of O_3 mixing ratio from RTR were used to "predict" conditions at MTR and RTV. The linkage between the model predictions for the grid squares of interest was investigated by applying the TSS to results from MT-M5 and RT-M5. The TSS is based both on correct predictions (hits -e.g. both the model predicts and the observations show a day in the top 25%) and false predictions (misses - e.g. the model predicts an upper quartile day but the observations do not show this to be true). Values of the TSS of 1, 0, and -1 indicate perfect predictive capability, no predictive skill, and the wrong forecast every time, respectively. Incorrectly predicting 10%, 40% and 50% of the time can give TSS values near 0.8, 0.2 and 0, respectively.

RESULTS AND DISCUSSION

Ozone

There is a marked difference in the frequency distributions of the measured O_3 hourly mixing ratios seen in the summer (Figure 1) and spring (Figure 2) intensive periods. Whereas in the spring period the measured O_3 mixing ratios approach a normal distribution at all sites, with a well-defined peak at 45 to 50 ppbv for the high elevation sites and at 35 to 40 ppbv for RTV, the distributions for the summer period are substantially broadened and skewed to lower O_3 mixing ratios, peaking at 20 to 25 ppbv at MT, 30 to 35 ppbv at RTR, and 10 to 25 ppbv at RTV. The number of hours in which the mixing ratio of ozone exceeded the 1 hour Canadian Ambient Air Quality Objective of 82 ppbv is small for all sites. The highest O_3 mixing ratios are seen at MT in the summer with 4 hours of data reaching 90 to 128 ppbv. Contrary to the observations, the model results, also shown in Figures 1 and 2, are skewed toward higher O_3 mixing ratios in the summer period, and do not reproduce the lower O_3 mixing ratios seen at that time. For both periods, the modelled distributions for the high elevation sites appear to be composites of two distributions, one tending to follow the observations, and the second providing a peak at low O_3 mixing ratios in the spring and at high O_3 mixing ratios in the summer. The closest agreement for the distributions is seen between RTV and RT-M1 for the spring season, with the model results close to normal, but slightly skewed to lower mixing ratios. The model predictions are more narrowly distributed than the observations in the summer for all sites, and do not reproduce the tail at higher O_3 mixing ratios seen at the high elevation sites in the spring.

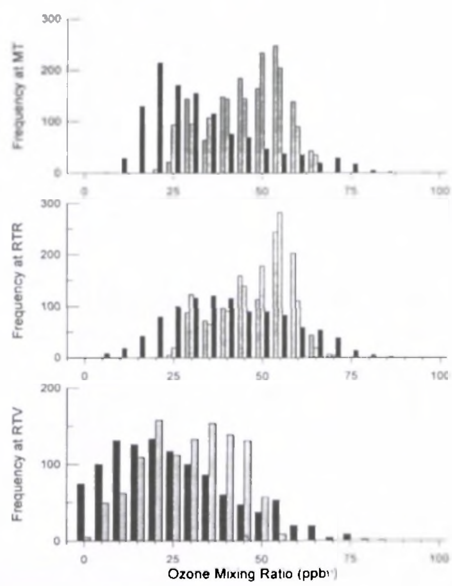

Fig. 1 **Frequency distributions for the hourly ozone mixing ratios which were measured (solid bars) and modelled (hatched bars) for July 15 to August 31, 1988. Values for M5 and M6 are shown for MT and RTR.**

Since ADOM gives an average over a grid cell it can be expected to be less variable than measurements made at a particular site. This may explain the inability of the model to capture tails of the distributions adequately. However it is clear that the model has consistent difficulty, over distance scales of 200 km and a range of altitudes, in predicting O_3 mixing ratios greater than 70 ppbv for both seasons.

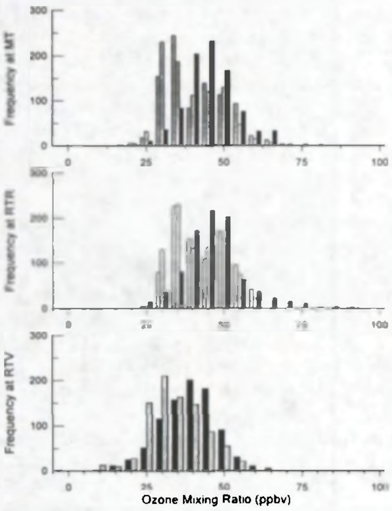

Fig. 2 **Frequency distributions for the hourly ozone mixing ratios which were measured (solid bars) and modelled (hatched bars) for March 25 to April 30, 1990. Values for M5 and M6 are shown for MT and RTR.**

Scatter plots relating the hourly observations at RTR with model predictions for RT-M5 are shown in Figure 3. Similar trends (not shown) are seen for M6 predictions for RTR and for M5 and M6 at MT. In the summer the points are generally clustered above the 1:1 line, showing model overprediction. In the spring the points fall generally below the 1:1 line, showing model underprediction. The relationships are not linear, but curve at higher O_3 mixing ratios, with the model predicting lower hourly mixing ratios than observed for both time periods.

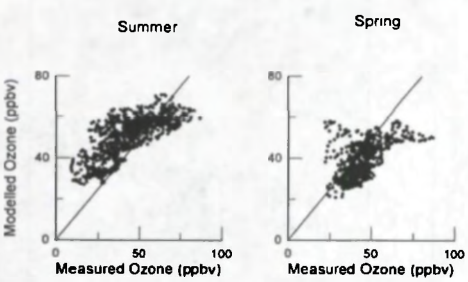

Fig. 3 **Measured and modelled hourly O_3 mixing ratios for RTR and RT-M5 for the summer and spring intensive periods. The 1:1 line is shown for each plot.**

The measured and modelled average hourly O_3 mixing ratios for the summer and spring intensive periods for the three sites are given in Table 1. Values calculated in the same manner as standard deviations are shown for each average, even though some of the distributions are far from normal (Figures 1 and 2). The large range seen in the data does not indicate an inability to determine the average precisely due to some random error, but rather shows the wide range of mixing ratios actually seen due to the effects of different meteorology on the chemical processing and transport of the pollutant species. If the MT measurements in the spring (shown in Figure 2a) are assumed to be normally distributed, then the estimated error in that average is 0.3 ppbv.

TABLE 1
Average O_3 mixing ratios (ppbv) for the summer 1988 and spring 1990 periods. The standard deviation is shown in brackets.

	number of hours	observed zone	——modelled zone—— M5	M6	M1
summer					
MT	1147	35 (16)	48 (11)	50 (10)	
RTR	1032	43 (16)	50 (10)	52 (10)	
RTV	1124	28 (17)			32 (12)
spring					
MT	888	43 (9)	37 (9)	39 (9)	
RTR	888	44 (10)	39 (8)	41 (9)	
RTV	888	36 (9)			32 (9)

The data in Table 1 show that the largest measured seasonal difference in average O_3 mixing ratio was seen at RTV and MT, with 8 ppbv more O_3 seen in the spring period; a small difference of 1 ppbv was seen at RTR. Consistent with earlier observations (Schemenauer and Anlauf, 1987) a positive gradient is seen with elevation, and the more northerly MT site tends to have lower summertime O_3 mixing ratios on average than the RTR site. The model overpredicts the average ozone mixing ratio seen in the summer in M5 and M6 by about 14 ppbv at MT, 8 ppbv at RTR and 4 ppbv at RTV. For the spring season the model underpredicts the average ozone mixing ratio by about 5 ppbv at MT and 4 ppbv at RTR and RTV. No seasonal difference is predicted for the average O_3 mixing ratio for RTV. The model does show a positive gradient with elevation, and lower mixing ratios at MT.

The mean diurnal variation in O_3 mixing ratio for the measurements and model results is shown in Figure 4. The model overprediction in the summer period and underprediction in the spring period can be seen to be quite uniform throughout the day at the high elevation sites. The summer data at RTV show good agreement with the model predictions in the late afternoon. The observed ozone mixing ratios for the high altitude sites show the maxima for the diurnal cycle occurring near 2 UTC and 21 to 23 UTC for the summer and spring periods, respectively, and the minima occurring near 14 UTC and 15 to 19 UTC in the summer and spring periods, respectively. The amplitude of the diurnal variation at MT is 9.7 and 4.8 ppbv in the summer and spring periods, respectively. The amplitudes seen at RTR are about half a ppbv smaller. The predicted M5 and M6 ozone mixing ratios for the high altitude sites show the diurnal cycle occurring with approximately the same timing, but with smaller amplitude in the summer (approximately 2 ppbv) and at MT in the spring (2.4 ppbv). The timing of the observed and predicted diurnal variation at RTV agrees well, with the maxima near 18 UTC and 21 UTC in the summer and spring periods, respectively, and the minima near 10 UTC. The amplitude of the signal at RTV is measured to be 21.6 ppbv in the summer period, compared with a predicted value of 16.4 ppbv. The agreement is better in the spring period, with a measured amplitude of 11.8 ppbv compared with a predicted 10.6 ppbv. Since the minima at the high elevation sites do not occur at night it is clear that these sites are not under the influence of the nocturnal inversion in the same way as RTV, but instead are under the influence of tropospheric air continually transported to the site. It is possible that the diurnal minimum observed at MT and RTR is due to O_3-depleted air from below the nocturnal inversion mixing up from the surface in response to surface heating. This mechanism would lead to a larger amplitude in the summer, as observed at all sites, because deposition to the vegetation at the surface is stronger during the nocturnal inversion in the summer than to the snow covered surface in the spring. This is consistent with RTV, which shows the strongest afternoon peak and the sharpest decline at night, being below the nocturnal inversion while RTR and MT are above. This diurnal behavior of the high elevation sites supports the use of data from these sites to evaluate the model in elevated layers.

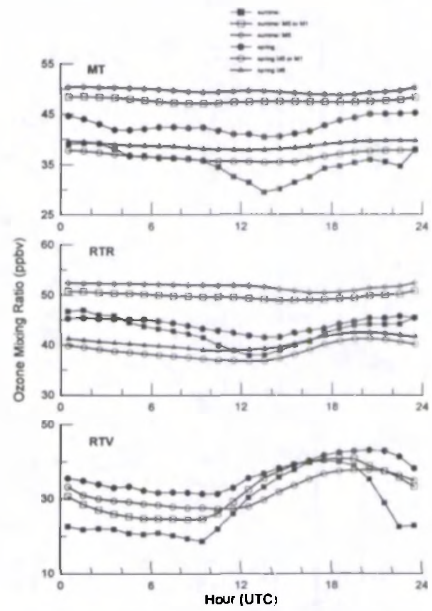

Fig. 4 **Diurnally averaged O3 mixing ratio for MT (top panel), RTR (middle panel) and RTV (lower panel). Local Eastern Standard time is given by UTC - 5 hours.**

The lateral boundary conditions for the model (Michael Moran, personal communication) for the summer period for O_3 were mixing ratios of 41.9, 60.2 and 61.9 ppbv for layers 1, 5 and 6, respectively, along the western grid boundary and 31.2, 32.8 and 33.7 ppbv for layers 1, 5 and 6, respectively, for the northern and eastern boundaries, and most of the southern boundary. Three grid squares in the southern boundary, those over Florida, were given the same conditions as the western boundary. The lateral boundary conditions for the spring period were O_3 mixing ratios of 44.9, 44.1 and 45.3 ppbv for layers 1, 5 and 6, respectively, along the boundaries in the southwestern corner and 30.1, 31.6 and 32.5 ppbv for layers 1, 5 and 6, respectively, for the northwestern, northern, eastern and southeastern boundaries. Figures 1 and 2 show that the predicted model mixing ratios in layers 5 and 6 have a peak within the range defined by the boundary conditions for each season. This comparison suggests that for much of the time the ozone modelled for M5 and M6 at these locations simply reflects transport and mixing of the ozone which was input as a boundary condition at that layer. If this is indeed the case then the observations indicate that lower input concentrations should be specified in the summer season, and higher in the spring than currently in use, and the sensitivity of the model results to the choice of boundary conditions should be investigated.

Another factor which could contribute to the overprediction of O_3 mixing ratios in the summer period is model underestimation of the O_3 destruction at night at low elevations. Unfortunately it is not clear if the difference seen at night between the average measured and modelled mixing ratios in the summer in layer 1 is due to the model underestimating the losses in the nocturnal boundary layer or to the limited vertical resolution of the model (Byun and Dennis, 1995). In addition, the weak mixing in the lower layers of the model as suggested by comparison of the diurnal variation at higher layers, would contribute to the transport of O_3 mixing ratios characteristic of the initial boundary conditions.

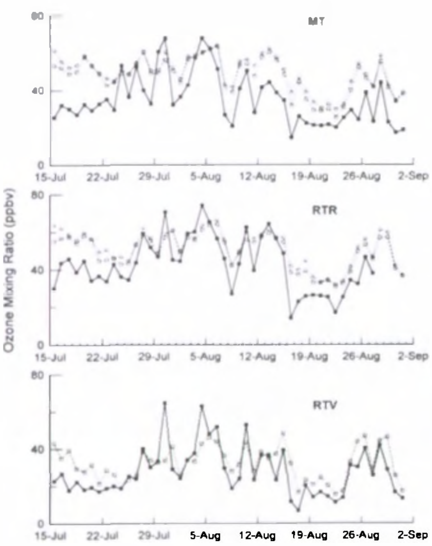

Fig. 5 Ozone data for the summer intensive period showing measured (solid symbol, solid line) and modelled (open symbol, dashed line) daily averages. Both M5 and M6 are shown for for MT and RTR.

Time series of the measured and modelled daily averages of O_3 mixing ratio are shown in Figure 5 for the summer intensive period. The regional nature of the ozone events can be seen by comparing the measured curves from the different sites. The trends with time for the measured and predicted daily-averaged ozone mixing ratios for the spring period (not shown) are similar to those shown in Figure 5 with the exception that the predicted values lie at lower mixing ratios than the observations. Higher variability, on a daily averaged basis, is seen for O_3 in the summer period than in the spring period. The TSS test of time trends of measured values and model predictions for all sites is shown in Table 2. The model shows its highest success (TSS approximately 0.77) in predicting periods with low ozone mixing ratio at both RTR and MT in the summer, with the next highest success (TSS of 0.67) for low ozone periods at RTV in the summer. The upper quartile days are predicted with a TSS of at least 0.56 for MT and RTR over both periods. The poorest performance is seen for RTV in the spring.

The TSS indicates that the model demonstrates a strong regionality in ozone episodes in layer 5, with a TSS > 0.8 for both seasons for low ozone and a TSS near 0.7 for high ozone with results for RT-M5 used to predict MT-M5. The TSS supports the use of data from MT and RTR as representative of regional scale ozone episodes since RTR can "predict" the conditions at MT on a large fraction of days (TSS range between 0.56 and 0.76). These applications of the TSS give a standard by which to judge the performance of the model for the high elevation sites. In general the model can predict the timing of periods with high and low ozone as observed at the high elevation sites over distances of 200 km. The interpretation of the TSS for daily averages at RTR and RTV is complicated by the fact that the valley site is subject to the stronger diurnal variation.

TABLE 2
True Skill Statistic calculated on 48 days of data for MT and RTV, and 44 days of data for RTR in the summer and 37 days of data for all sites in the spring for the lower (L) and upper (H) quartiles of data.

	Summer L	Summer H	Spring L	Spring H
RT-M5 to predict RTR	0.76	0.64	0.56	0.56
MT-M5 to predict MT	0.78	0.56	0.41	0.56
RT-M1 to predict RTV	0.67	0.44	0.27	0.27
RTR to predict MT	0.76	0.64	0.56	0.71
RTR to predict RTV	0.52	0.76	0.56	0.27
RT-M5 to predict MT-M5	0.89	0.67	0.85	0.71

If RTR and RTV are both considered as sites in M1 the following conclusions reached above will still be valid. Any combination of the distributions observed during the summer period at RTR and RTV will lead to a distribution that indicates more hours with O_3 mixing ratio above 60 ppbv than does the predicted distribution RT-M1. Any combination of the distributions observed at these sites in the spring will lead to a distribution which peaks at higher O_3 mixing ratios than the predicted distribution for the first layer. The summer average mixing ratio in the lowest layer could be reproduced by a suitable averaging of the RTV and RTR data, but any such averaging for the spring season would still lead to an underprediction.

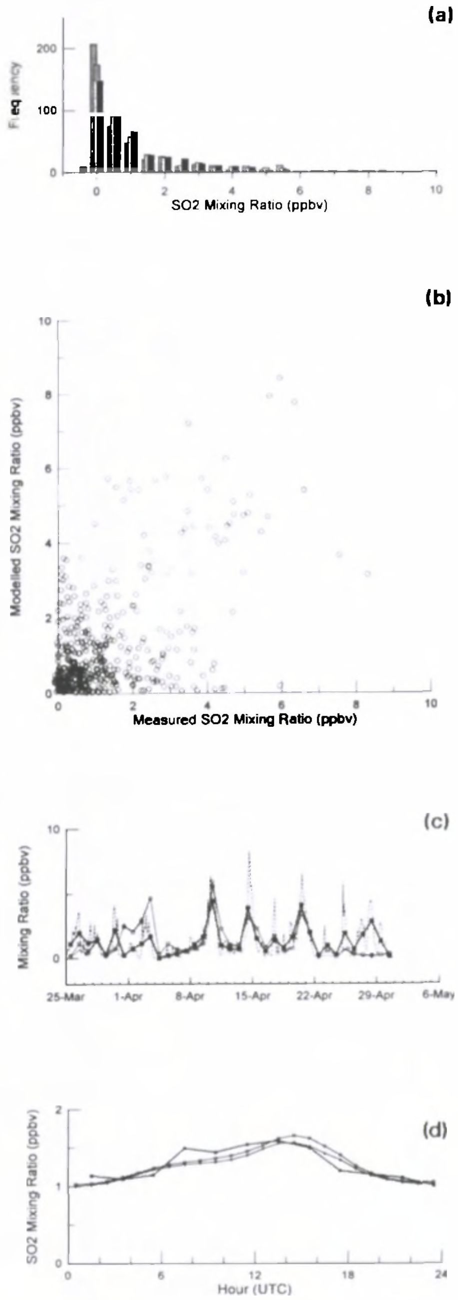

Fig. 6 Observations and model results for SO_2 mixing ratios at RTR during the spring period: a) frequency distribution of measured (solid) and modelled (hatched) hourly data, b) scatter plot of hourly data with RT-M5 results, c) time series of measured hourly averages (dashed line), measured daily averages (solid symbol/line), and modelled daily averages (open symbol/line) and d) diurnally averaged measurements (solid symbols) and model results (open symbols). The results for both RT-M5 and RT-M6 are shown for all plots except b) which shows RT-M5 only.

Sulphur Dioxide

The distribution of measured SO_2 mixing ratios in the spring period is skewed, with the mode in the range 0 to 0.5 ppbv, over half the data within 1 ppbv of zero, and maximum values reaching 8 ppbv (Figure 6a). The small negative values are due to variability in the zero correction. The distribution for the ADOM predictions, also shown in Figure 6a, is a good representation of the measurements. However, an hour by hour comparison of the observations and M5 results (Figure 6b) shows considerable scatter. Results for M6 are similar.

The time series of daily averages of measured and modelled SO_2 mixing ratio (Figure 6c) shows periods with very good agreement, as well as periods with overprediction and underprediction. The TSS indicates poor predictive capability for the model with values of 0.27 for the upper quartile days and 0.12 for the lower quartile days.

The average SO_2 mixing ratios over the five week period were 1.29, 1.29 and 1.25 ppbv for the measured, M5 and M6 values respectively, showing excellent agreement. The diurnal variation in SO_2 mixing ratio (Figure 6d) has an amplitude of 0.5 ppbv, and a maximum near 14 UTC in both the model results and measurments, indicating that on average in the spring season SO_2, as O_3, is appropriately mixed through the lower troposphere.

The above observations indicate that the emission of the primary pollutant SO_2 and its subsequent transport to southern Quebec are well represented by ADOM over the full spring period. However, the predicted timing of episodes of high SO_2 is poor both on an hourly and daily basis. This is not surprising since, unlike O_3 which is gradually produced from a complex mix of pollutants in the lower troposphere, SO_2 is introduced into the atmosphere at elevated levels from a variety of point sources to the south and west of the sites. Small shifts in wind direction or changes in vertical stability of the atmosphere relative to the model resolution can cause the plumes to hit or miss the grid cells being evaluated. There is no observational evidence presented here to indicate that the SO_2 episodes seen at RTR on an hourly or daily basis are routinely representative, on these time scales, of conditions over the entire grid cell.

Additional High Elevation Ozone Measurements

The results from the CHEF sites can be compared with results of ozone measurements at high elevation sites in the eastern U.S. Aneja and Li (1992) show diurnal variations at Whiteface Mountain, N.Y. (1483 m-msl) and Mt. Moosilauke, N.H. (1000 m-msl). In the summer of 1988 (May to October) both sites show minima from about 0900 to 1200 local time and broad maxima extending from about 1800 to 2400. This is very similar to the diurnal patterns shown in Figure 4 for the two CHEF mountain sites during the ADOM period. These diurnal patterns are consistent with what other authors have reported for high elevation sites, e.g., Lefohn et al. (1990) for Whiteface Mountain and Aneja et al. (1994) for two elevations (2006 and 1760 m-msl) in North Carolina. Aneja and Li (1992) report the August 1988 Whiteface Mountain mean ozone concentration to be 50.3 ppbv. This is similar to, but higher than, the value given for the ADOM period for the CHEF RTR site in Table 1 (43 ppbv). Whiteface Mountain is 140 km southwest of RTR and at an elevation 630 m higher. In general, where comparisons can be made, and considering the general south to north decrease in ozone concentrations in eastern North America, the measured ozone concentrations at the two CHEF mountain sites seem representative of values to be expected at 850 m-msl and should provide a good basis for comparison with the ADOM model.

Comparison of Model Evaluations

The results for the summer period given above agree well with conclusions drawn for model intercomparisons for the same time period for southern Ontario. Macdonald et al. (1993) concluded that the model can predict the timing of episodes in the lower troposphere (250 to 2200 m-agl), that the full range of observed O_3 mixing ratios was not seen by the model, and that the observed vertical mixing of pollutants was underpredicted by the model. Hoff et al. (1995) concluded that ADOM treats the temporal behaviour of O_3 fairly well in the lower troposphere but not near the surface, that the model performs best during simple synoptic conditions with a relatively clean atmosphere, and that local chemistry appears to be secondary to larger-scale dynamic motions through the free troposphere in controlling the average ozone concentration. The data and method used for the evaluation given in this paper permit more sensitive and quantitative testing of the model in layers 5 and 6, and will be appropriate for evaluating the effect of proposed changes to the model.

CONCLUSIONS

The application of the True Skill Statistic to the ozone measurements at the high elevation sites confirms that periods of high and low ozone mixing ratio occur over distance scales of 200 km in southern Quebec. Comparison of the ozone data from the Canadian sites with results from other mountain observations in eastern North America show decreasing ozone concentrations with increasing latitude. These long term measurement programs can supply valuable continuous measurements for the evaluation of air chemistry models.

The distributions of O_3 mixing ratios observed for the summer 1988 and spring 1990 EMEFS intensive periods are different, with a smaller range of values seen in the spring than in the summer and with higher average O_3 mixing ratio seen in the spring than in the summer. The ADOM predicts distributions of O_3 mixing ratios which span a smaller range than the observed values in both seasons, and which give higher mixing ratios on average in the summer than in the spring. Thus the seasonal dependence of the O_3 mixing ratio is different for the model and the observations. This difference may be related to the choice of boundary conditions, and to underestimation of the depletion of O_3 near the surface at night in the summer.

The ADOM mixing ratios for both the summer and spring time periods very rarely exceed 60 ppbv and are never greater than 70 ppbv whereas the measurements reach and exceed 90 ppbv at times. Thus the model cannot reproduce the magnitude of events with high O_3 mixing ratio.

The prediction of the timing of events is often evaluated simply by visual inspection, which tends to fix the eye on the major peaks in the time series, especially if agreement is found between the observations and predictions for these peaks. The application of an objective numerical measure of agreement, such as the True Skill Statistic, is recommended. For the times investigated here, it is shown that the model has the greatest skill in predicting the timing of low ozone periods at the high elevation sites.

The measured and modelled diurnal variations in O_3 are similar in the timing of the maxima and minima, indicating that the mixing in the boundary layer is occurring at the right time of day, and depletion of ozone is occurring in the nocturnal inversion. However the difference between the maxima and minima in the predicted values are lower than in the observed values for the summer period for both high elevation sites and in the spring at MT, indicating that the model treatment of boundary layer mixing may not be strong enough. This would be especially evident in summer when increased surface losses are seen in the nocturnal boundary layer. Mixing to higher layers is important since it affects not only the concentrations at that layer, but the long range transport of species due to the higher wind speeds aloft.

The mixing ratios of SO_2 at RTR during the spring period range from near zero to approximately 10 ppbv in well-defined events. The distribution of hourly SO_2 mixing ratios for the model results and measurements agree well, but the model shows poor skill in predicting the timing of episodes. The diurnal variation in SO_2 is well represented by the model, consistent with the good agreement seen for O_3 at RTR for this time period.

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(continued on page **80**)

CONTRÔLE DES MODES LATÉRAUX DE LASERS À SEMI-CONDUCTEURS: EXPÉRIENCES ET SIMULATIONS

par Nathalie McCarthy, Sylvain Mailhot, Damien Stryckman, Yves Champagne* et Guy Rousseau
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Résumé

Les lasers à semi-conducteurs de puissance élevée, à large fenêtre d'émission, sont devenus des sources cohérentes très compétitives pour plusieurs applications. Cependant, ces lasers émettent simultanément sur plusieurs modes latéraux, ce qui augmente la divergence du faisceau et en diminue la cohérence spatiale. Notre but consiste à réduire le nombre de modes latéraux contenus dans le faisceau émis par ce type de lasers disponibles commercialement. Quelques techniques de contrôle de modes latéraux ont été proposées et testées avec des lasers de 100 mW: cavités externes terminées par différents composants optiques et couches à réflectivité profilée déposées directement sur la face de sortie des lasers. Nous présentons aussi les résultats de simulations numériques reliées aux expériences réalisées.

Abstract

High power broad-area (BA) semiconductor lasers are now considered as interesting sources of coherent radiation for various applications. However these lasers emit simultaneously on several lateral modes, which contribute to increase the beam divergence and to decrease the spatial coherence of the emitted laser beam. Our goal consists in reducing the number of lateral modes contained in the beam emitted by commercially available BA lasers. Some techniques of lateral mode control have been proposed and tested with a 100 mW BA laser: external cavities terminated by various optical components and profiled reflectivity coatings deposited directly on the output facet of the lasers. Numerical simulations of the lateral mode discrimination of these configurations are also reported.

INTRODUCTION

Les lasers à semi-conducteurs (ou diodes laser) de puissance élevée ont atteint des niveaux de performance qui en font des sources cohérentes compétitives pour une vaste gamme d'applications: mémoires optiques, génération d'harmoniques, systèmes de communication optique et pompage optique de lasers à l'état solide. On divise habituellement les diodes laser de puissance en deux grandes catégories, soient les réseaux monolithiques de diodes laser et les lasers à large ruban d'injection ("broad-area" ou BA). De façon générale, les réseaux de diodes laser présentent une bonne discrimination envers les modes latéraux (suivant l'axe x, dans le plan de la jonction) d'ordre supérieur, mais leur mode fondamental se caractérise par un déphasage de 180° entre les émetteurs adjacents, ce qui produit une distribution angulaire d'intensité à deux lobes dans le champ lointain. D'autre part, les lasers BA ont une faible discrimination entre les modes latéraux et tendent à émettre simultanément sur plusieurs modes. La présence de ces modes d'ordre supérieur est à l'origine d'une forte dégradation de la cohérence spatiale du faisceau et d'une distribution d'intensité en champ lointain qui s'élargit rapidement lorsque le courant d'injection augmente. Ces comportements sont très néfastes lorsqu'on veut, par exemple, utiliser le faisceau pour pomper optiquement un autre laser; le faisceau doit plutôt être focalisable sur une petite tache tout en restant étroit sur une grande distance le long de l'axe de propagation z, cette distance étant optimale lorsque le faisceau ne contient que le mode latéral gaussien.

Dans cet article, nous présentons différentes méthodes que nous avons utilisées pour réduire le nombre de modes latéraux dans les diodes laser BA tout en conservant une puissance relativement élevée: les cavités externes anamorphiques, les cavités à symétrie cylindrique terminées par différents composants optiques (miroir uniforme, miroir à réflectivité profilée...) et les couches à réflectivité profilée déposées directement sur la face de sortie (face d'émission) des diodes laser. Les techniques de déposition sont brièvement décrites. Les résultats de simulations numériques reliées aux travaux expérimentaux sont aussi présentés.

CAVITÉS EXTERNES

Les cavités externes (ou cavités étendues) ont déjà fait leurs preuves pour le contrôle des modes latéraux.[1-3] Les cavités externes offrent plusieurs degrés de liberté puisqu'on peut varier le nombre et le type de composants intracavités, de même que le type de coupleur externe. La figure 1 montre le schéma du montage que nous avons utilisé pour mesurer les principales caractéristiques d'émission de la diode laser en cavité externe.

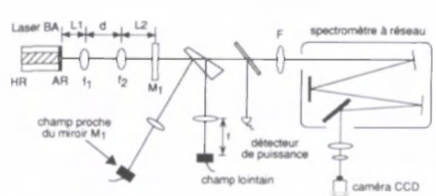

Figure 1. Schéma du montage expérimental de la diode laser en cavité externe et de l'arrangement utilisé pour l'analyse de son faisceau.

La face arrière du laser a une réflectivité élevée ($R \sim 100\%$). L'autre face (face avant) a été recouverte d'une couche anti-réfléchissante (AR) afin que l'oscillation laser puisse s'établir entre la face arrière et le miroir externe M1 qui termine la cavité. La fabrication de ces couches anti-réfléchissantes est décrite plus loin dans cette section. La lentille f_1 collimate le faisceau qui est ensuite focalisé par la lentille F sur la fente d'entrée d'un spectromètre à réseau (Jarrell-Ash, résolution = 0.01 nm) à la sortie duquel une caméra CCD monochrome (Spiricon) enregistre l'image du champ proche du faisceau résolu en longueur d'onde. Le laser a été positionné de façon à ce que la jonction (et par conséquent l'axe latéral) soit perpendiculaire au plan de la figure 1. Pour travailler dans des conditions de cavité externe anamorphique, nous ajoutons une lentille cylindrique f_2 (de 25 mm de focale) entre f_1 et M_1; cette nouvelle lentille n'ayant un effet que le long de l'axe latéral x.

Afin d'alléger l'écriture, nous désignerons par la lettre A la configuration pour laquelle la lentille f_2 et le miroir M_1 sont absents du montage. Dans ce cas, nous avons fait les mesures avant de déposer une couche AR sur la face de sortie du laser. La configuration B sera celle qui comporte une cavité externe anamorphique[4]. Dans ce cas, M_1 est un miroir plan à réflectivité uniforme ($R = 30$ %), la distance L_1 entre le laser et la lentille f_1 est de 8 mm et f_1 possède une focale de 8 mm. La distance L_2 entre M_1 et la lentille cylindrique f_2 peut être variée alors que la distance d entre f_1 et f_2 est gardée fixe à 30 mm. Le grand intérêt de cette configuration réside dans le fait que la taille de la distribution transverse d'intensité (dans la direction y) du faisceau à la face de sortie du laser est la même après son trajet dans la cavité externe. Ceci permet d'optimiser le couplage transverse entre le faisceau et le guide d'onde du laser. Dans la direction latérale (direction x), on recherche exactement le comportement inverse: le faisceau qui revient dans le laser s'est élargi pendant son trajet dans la cavité externe et c'est le milieu de gain lui-même qui agit comme filtre spatial profilé, favorisant ainsi la présence des modes latéraux les plus étroits. Finalement, la configuration C ne comprend que la lentille de collimation f_1 et un miroir M_1 dont la réflectivité varie de façon gaussienne avec le rayon[5] La forme exacte du profil de réflectivité est donnée par

$$R(\rho) = 0.62 \exp[-(\rho / w_m)^2] ,$$

où ρ est la position radiale et w_m (la demi-largeur à 1/e) est égale à 700 μm. Le profil de réflectivité est obtenu en déposant des couches profilées de diélectriques sur un substrat de verre. Il a été réalisé par l'Institut national d'optique (Québec).

Dans toutes les configurations, les lasers à semi-conducteurs utilisés sont des lasers

EG&G de GaAs/GaAlAs (modèle C86090E), à double hétérostructure, avec une largeur de ruban de 75 μm et une longueur de 370 μm. Ils émettent un faisceau de puissance maximale de l'ordre de 100 mW, à une longueur d'onde de 840 nm et leur courant de seuil se situe entre 220 et 250 mA avant le traitement anti-réfléchissant. Le faible confinement latéral du faisceau lumineux se propageant dans le matériau semi-conducteur est assuré uniquement par un mécanisme de "guidage par le gain". L'émission de telles diodes laser contient habituellement plusieurs modes latéraux, même à des puissances très faibles (de l'ordre du milliwatt). Par exemple, nous avons détecté, avec un de nos lasers, la présence de 3 modes latéraux à 2.5 mW et de 11 modes latéraux à 80 mW de puissance émise. Sur les lasers destinés à être utilisés en cavité externe, nous déposons une couche anti-réfléchissante sur la face de sortie par évaporation thermique. Dans le système à vide, le faisceau émis par la diode laser est détecté pendant que le dépôt de SiO s'effectue; l'évaporation est arrêtée lorsque le signal détecté atteint un minimum. Nous pouvons estimer que la réflectivité résiduelle de la face est inférieure à 10^{4} après le traitement anti-réfléchissant.

Les figures 2a, 2b et 2c montrent les images du faisceau en champ proche résolu en longueur d'onde obtenues avec la diode laser dans les configurations A, B et C respectivement.

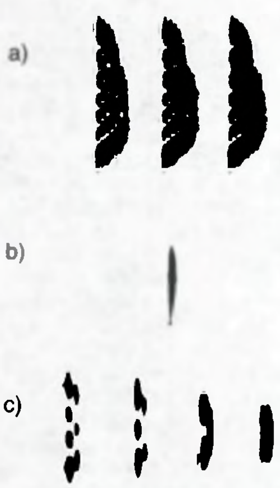

Figure 2. Images du faisceau en champ proche résolu en longueur d'onde pour les configurations A, B et C, pour des puissances lumineuses semblables. L'axe horizontal représente la longueur d'onde et l'axe vertical est la direction latérale x.

Ces spectres d'émission présentent une information très complète. L'axe horizontal représente la longueur d'onde, augmentant de gauche à droite. L'axe vertical représente la position latérale (direction x) sur la face de sortie de la diode laser. Trois groupes de modes (chaque groupe correspondant à un mode longitudinal) sont montrés dans la figure 2a; ces groupes sont distants en longueur d'onde de 0.2 nm. Dans chaque groupe, les modes latéraux d'ordre supérieur peuvent être identifiés par leur longueur d'onde plus courte et leur distribution spatiale d'intensité à plusieurs lobes. On peut constater aussi que le mode latéral fondamental (à un seul lobe) est beaucoup plus étroit sur la face de sortie que les modes latéraux supérieurs. La figure 2a a été enregistrée à une puissance de 32 mW. Pour ce laser, on constate que sept modes latéraux étaient présents à cette puissance. La figure 2b a été obtenue avec la cavité externe anamorphique pour laquelle L_2 était de 100 mm. On constate que l'émission est à la fois monomode latérale et monomode longitudinale (résultat confirmé par d'autres mesures: aucun battement de mode n'a été observé) à une puissance de 40 mW. Ceci représente notre meilleur résultat jusqu'à présent. La figure 2c montre le spectre obtenu avec un miroir gaussien externe pour une puissance de 47 mW. L'écart entre les groupes de modes longitudinaux est encore de 0.2 nm. Dans ce cas, on observe un phénomène particulier: le contenu en modes latéraux à l'intérieur des groupes associés à des modes longitudinaux différents n'est pas le même d'un groupe à l'autre. D'une part, il aurait été préférable que le profil de réflectivité ait été plus étroit afin d'augmenter encore plus les pertes des modes latéraux supérieurs. D'autre part, la réflectivité résiduelle du revêtement AR pourrait être à l'origine d'un effet de cavités couplées.

La configuration qui nous a donné les meilleurs résultats est la cavité externe anamorphique; dans ce cas, le paramètre que nous avons fait varier est la distance L_2 entre la lentille f_2 et le miroir externe M_1. Les cercles de la figure 3 montrent le courant de seuil mesuré expérimentalement de l'émission laser (ceci correspond au seuil d'oscillation du mode latéral fondamental, d'ordre 0), alors que les carrés montrent le seuil mesuré du mode d'ordre 1 (ceci correspond donc à la fin du régime monomode latéral).

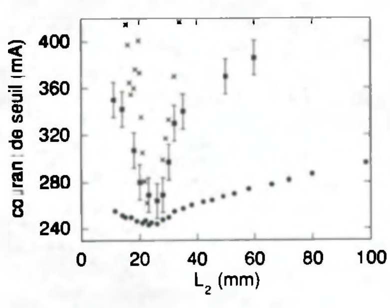

Figure 3. Courants de seuil mesurés des modes latéraux d'ordres 0 (cercles) et 1 (carrés) en fonction de L2 pour la configuration B. Les croix correspondent aux courants de seuil calculés pour le mode 1.

Les résultats suggèrent que des puissances possibles, en régime monomode latéral, puissent être de plus en plus élevées à mesure que la valeur de L_2 s'éloigne d'une plage d'environ 10 mm centrée à 23 mm. Par exemple, pour L_2 = 14 mm, 20 mm et 60 mm, nous avons mesuré des puissances monomodes maximales de 21 mW, 10 mW et 40 mW, respectivement. Ces résultats sont en excellent accord avec les simulations numériques; les croix sur la figure 3 correspondent aux courants de seuil calculés pour le mode 1.

DÉPÔTS PROFILÉS

Les configurations B et C augmentent la discrimination envers les modes latéraux d'ordre supérieur parce qu'elles limitent latéralement le faisceau lumineux. Le même phénomène peut se produire si on élimine la cavité externe et si le profil de réflectivité est réalisé directement sur la face de sortie de la diode laser[6]. Cette approche a déjà été testée avec succès avec d'autres types de lasers[7-9]. Nous avons proposé et testé dans notre laboratoire une technique simple pour réaliser une couche diélectrique mince profilée sur nos diodes laser. La couche a une épaisseur qui varie dans la direction latérale (parallèle à la jonction) et une épaisseur constante dans la direction transverse (perpendiculaire à la jonction); elle produit donc une réflectivité profilée dans la direction latérale. Le diélectrique utilisé est du SiO dont l'indice de réfraction s'élève à 1.9.

Les couches minces profilées peuvent être obtenues par deux méthodes similaires. La première méthode consiste à placer un filament très mince à quelques dizaines de microns du substrat (voir la fig. 4a).

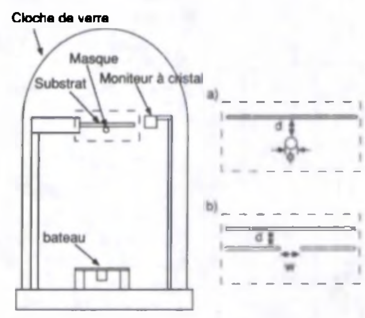

Figure 4. Schéma du système à vide contenant le substrat (ou la face d'émission du laser) qui est masqué a) par un filament de diamètre ϕ ou b) par une fente étroite de largeur w.

Le filament crée un "effet d'ombre" sur le substrat, produisant ainsi un dépôt d'épaisseur variable. Le temps de déposition est ajusté de façon à obtenir une épaisseur égale à $\lambda/4$ sur les bords du substrat (λ étant la longueur d'onde du faisceau dans le SiO) et une épaisseur nulle au centre. La pente du profil d'épaisseur est variée en changeant la distance d entre le filament et le substrat. Les profils de réflectivité les plus étroits que nous avons obtenus (largeur totale à mi-hauteur) ont été réalisés avec un filament de tungstène de 25 μm de diamètre placé à environ 120 μm du substrat. Cependant, les simulations numériques ont montré qu'un profil aussi large n'aurait que peu d'effet sur la discrimination des modes latéraux de nos lasers.

Nous avons plutôt opté pour la seconde méthode, qui exploite le même "effet d'ombre", mais où le filament est remplacé par une fente étroite (faite de deux lames de rasoir). Dans ce cas, nous n'avons plus de limite inférieure sur la largeur du profil de réflectivité. Cependant, le dépôt doit être réalisé en deux étapes: d'abord une couche profilée d'épaisseur $\lambda/4$ au centre et zéro sur le bord, suivie d'une seconde couche d'épaisseur constante ($\lambda/4$) du même matériau diélectrique. Ceci résulte en une couche d'épaisseur $\lambda/2$ au centre et $\lambda/4$ sur les bords. La figure 5 montre un exemple de profil d'épaisseur (5a), mesuré avec un profilomètre mécanique, et le profil de réflectivité calculé correspondant (5b).

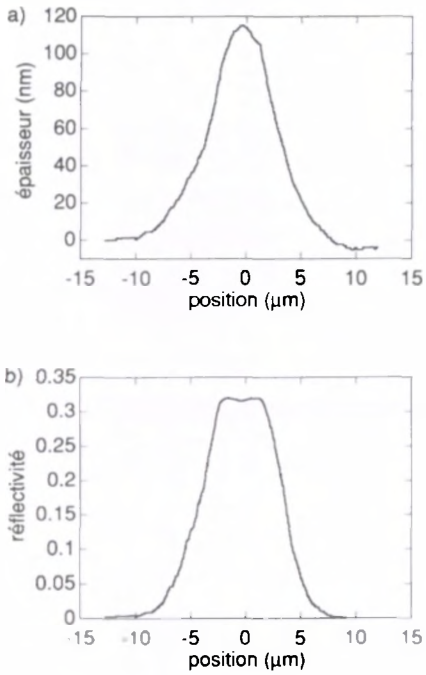

Figure 5. a) Profil de l'épaisseur du dépôt obtenu avec une fente de 20 μm placée à 90 μm du substrat de verre et b) profil de réflectivité correspondant calculé en considérant un substrat de GaAs.

Ce profil quasi-gaussien a été obtenu en plaçant une fente de 20 μm de largeur à 90 μm du substrat. On constate que la largeur totale à mi-hauteur du profil de réflectivité est d'environ 15 μm, ce qui devrait être suffisamment étroit pour réduire le contenu en modes latéraux de nos lasers. Le principal défi consistait à centrer latéralement la fente sur la fenêtre émettrice qui n'est pas nécessairement centrée sur la diode laser. Ce problème a été résolu en maximisant la puissance lumineuse transmise par la fente lorsque le laser fonctionne sous le seuil.

Le courant de seuil est passé de 220 mA (sans dépôt) à 280 mA avec le dépôt profilé. Ce comportement était tout à fait prévisible puisque la couche profilée diminue la réflectivité globale de la face de sortie. Toutefois, l'efficacité quantique différentielle a été légèrement améliorée, passant de 0.54 W/A à 0.64 W/A.

La figure 6 montre l'image du faisceau en champ proche résolu en longueur d'onde obtenue avec la diode laser ayant un dépôt profilé sur la face de sortie.

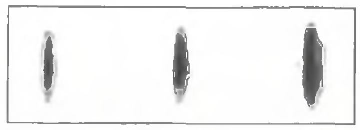

Figure 6. Image du faisceau en champ proche résolu en longueur d'onde émis par la diode laser avec le dépôt profilé sur la face de sortie. Axe horizontal: λ et axe vertical: x.

Le spectre a été enregistré à une puissance d'environ 30 mW. On constate que le laser avec le dépôt profilé émet seulement dans le mode latéral fondamental à cette puissance. La puissance maximale qui pouvait être atteinte en régime d'émission monomode latérale était inférieure à 1 mW sans le dépôt profilé.

SIMULATIONS NUMÉRIQUES

Les logiciels de simulation que nous avons développés ont été utilisés pour le calcul des caractéristiques d'émission des diodes laser opérées dans les diverses configurations présentées dans les paragraphes précédents. Ces programmes utilisent la méthode de propagation de faisceaux[10] pour simuler la propagation du champ optique dans le laser, un algorithme de transformation d'échelle[11] pour la propagation dans la cavité externe (s'il y a lieu) et l'algorithme de Prony[12] pour extraire les différents modes latéraux (et leur valeur propre associée) pour toutes les configurations. Les logiciels tiennent compte des variations latérales du gain, de l'absorption, des effets thermiques, des variations latérales de l'indice de réfraction induites par la distribution des porteurs de charge et de la déplétion de la concentration des porteurs par le champ optique due à l'émission stimulée. Nous nous sommes intéressés aux effets de l'utilisation de cavités externes et de dépôts profilés sur la discrimination modale, les caractéristiques du mode latéral fondamental intracavité et celles du faisceau transmis dans l'air en champ proche et en champ lointain. Nous avons aussi calculé les caractéristiques telles le courant de seuil requis pour atteindre le régime d'émission stimulée et l'efficacité quantique différentielle.

Les valeurs des paramètres optiques, électriques et thermiques utilisées dans les simulations numériques ont été ajustées à celles des lasers EG&G de modèle C86090E; celles-ci peuvent être retrouvées dans les tableaux I et II de la référence 13. Nous avons calculé une très faible discrimination envers les modes latéraux d'ordre supérieur pour la diode laser sans dépôt sur la face de sortie et sans miroir externe. En effet, le rapport $|\gamma o|/|\gamma 1|$ entre les valeurs propres des deux modes qui ont les plus faibles pertes vaut 1.016, dans ce cas. Ceci est cohérent avec nos résultats expérimentaux qui montrent que la puissance maximale pour laquelle le laser sans dépôt émet sur un seul mode latéral est inférieure au milliwatt.

Pour la configuration B, la discrimination $|\gamma o|/|\gamma 1|$ a été calculée pour différentes valeurs de L_2. Cette étude a révélé que la discrimination reste inférieure à 1.1 seulement pour les valeurs de L_2 comprises entre 15 et 29 mm. Dans cet intervalle, le faisceau qui revient dans la diode laser après son trajet dans la cavité externe est tellement étroit qu'il ne subit pas de filtrage spatial dû à la largeur finie du milieu de gain. À mesure qu'on s'éloigne de cet intervalle, le faisceau de retour s'élargit et la discrimination augmente. La figure 2b a été obtenue avec une valeur de L_2 égale à 100 mm et une bonne discrimination a effectivement été observée. D'autre part, les croix de la figure 3 montre le courant de seuil calculé pour le mode latéral d'ordre 1 en fonction de la longueur L_2 pour la diode laser opérée dans la configuration B. Ces points montrent un bon accord avec les résultats expérimentaux obtenus.

Pour la diode laser avec un dépôt profilé (sans cavité externe), nous avons supposé que la réflectivité de la face de sortie était décrite par la fonction $0.3\ \exp(-x^2/wm^2)$, où x est la direction latérale et wm la demi-largeur à 1/e du maximum. La figure 7 montre la discrimination $|\gamma o|/|\gamma 1|$ en fonction de la largeur du profil de réflectivité, telle que calculée au seuil de l'émission laser.

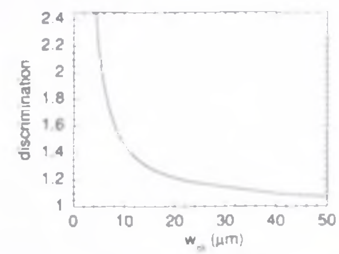

Figure 7. Discrimination $|\gamma o|/|\gamma 1|$ en fonction de la largeur wm du profil de réflectivité.

L'amélioration de la discrimination s'accompagne d'une légère hausse du courant de seuil. L'évolution du courant de seuil en fonction de wm est montrée à la figure 8. Par exemple, avec 2wm = 15 μm (largeur du dépôt profilé sur la diode laser de la section précédente), le courant de seuil est 1.25 fois plus élevé que sans dépôt (passant de 226 à 280 mA), ce qui correspond très bien aux résultats expérimentaux obtenus (le seuil passant alors de 220 à 280 mA).

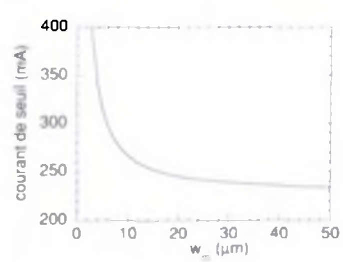

Figure 8. Courant de seuil de l'émission laser en fonction de la largeur du profil de réflectivité pour une réflectivité centrale de 0.3.

PERSPECTIVES

Les techniques décrites dans cet article offrent plusieurs degrés de liberté pour le contrôle des modes latéraux dans les lasers à semi-conducteurs à guidage par le gain et elles requièrent un équipement généralement accessible dans tous les laboratoires d'optique. Les méthodes décrites pour réduire l'oscillation des modes latéraux d'ordre supérieur peuvent être appliquées à des lasers à large ruban encore plus puissants que ceux dont nous disposions. Les simulations numériques effectuées se sont avérées en bon accord avec les résultats expérimentaux.

À moyen terme, nous prévoyons utiliser un réseau à réflectivité profilée en cavité externe pour restreindre le spectre d'émission à un seul mode longitudinal et latéral et à en accorder la fréquence. Nous avons mis au point un procédé de fabrication de tels réseaux par interférence de faisceaux gaussiens sur une photorésine. Une telle source serait une alternative compacte et peu coûteuse aux lasers présentement utilisés en spectroscopie.

REMERCIEMENTS

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SYMMETRY-VIOLATING NN POTENTIALS IN THE NUCLEUS

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ABSTRACT

The parity-violating and time reversal noninvariant nucleon-nucleon interactions are reviewed, and their manifestation in the nucleus discussed.

INTRODUCTION

Major advances in our understanding of the weak interaction have come from low energy nuclear studies. The best examples come from nuclear β-decay measurements which established the existence of the neutrino and the fact that the interaction does not conserve parity. The very high precision β-decay measurements that are possible today provide stringent tests of the weak currents in the Standard Model. Test of the weak interaction from semi-leptonic processes have been reviewed recently by Towner and Hardy [1]. In this article I will concentrate on another aspect of the weak interaction, namely, the non-leptonic part. In particular, I will discuss the weak parity-violating and time-reversal-violating nucleon-nucleon interactions, and studies of these in low-energy nuclear experiments.

The weak interaction is responsible for pure leptonic processes such as μ-decay ($\mu^- \rightarrow e^- + \nu_e + \nu\mu$), semi-leptonic processes such as β-decay (e.g., $n \rightarrow p + e^- + \bar{\nu}_e$), and non-leptonic processes such as $\Lambda^0 \rightarrow p + \pi^-$ decay. The three classes of the weak interactions can be split further into two parts depending on whether strangeness is conserved or not. In the case of the non-leptonic weak interaction information on the strangeness changing ($\Delta S = \pm 1$) part of the Hamiltonian is obtained by studying the weak decays of elementary particles, for example, the decays $\Lambda \rightarrow N\pi$, $K \rightarrow 2\pi$, 3π, $\Sigma \rightarrow N\pi$. However, for the strangeness conserving part of the Hamiltonian, the allowed strong interaction processes will generally render unobservable any expected manifestation of the weak interaction. Thus, it is not feasible to study the $\Delta S = 0$ non-leptonic part of the weak interactions using elementary particle processes. However, the weak Hamiltonian gives rise to a weak nucleon-nucleon potential and part of this potential does not conserve parity. Manifestations of the parity nonconserving (PNC) weak NN potential are seen in the low energy nuclear physics processes. These processes, though difficult to measure and to calculate, provide the only source of information on the $\Delta S = 0$ non-leptonic weak interaction.

The goal of studies of parity non-conservation in the nucleus is to determine the strength of the coupling consttants for the weak NN interaction, and to determine the interplay between the strong and weak interactions in the nuclear many-body system. Extracting information on the coupling constants for the parity violating NN potential from such measurements requires knowledge of both the weak interaction and of the effects of nuclear structure on its manifestation in these rare nuclear processes. The nonleptonic weak interaction is an interaction between the quarks and is mediated by the W and Z bosons. However, in the low-energy regime of the nucleous it is more efficient to describe the weak interaction in terms of an effective potential between nucleons mediated by mesons. The physics of the weak nucleon-meson amplitudes $\langle N\,M \mid \mathcal{H}_w \mid N\rangle$ then appears as an effective weak $N \rightarrow NM$ coupling constant. These effective coupling constants are calculated within quark models for the nucleons and mesons starting with the fundamental weak interaction between quarks. Reliable values of the effective

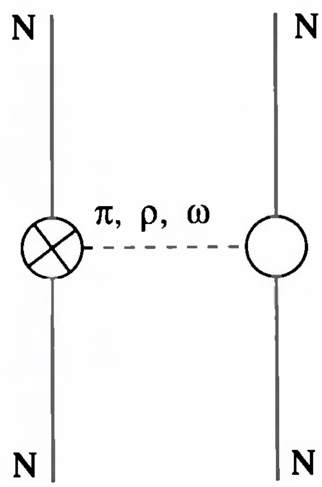

Fig. 1. The one-meson-exchange contribution to the weak parity-violating NN interaction. Here one nucleon emits a meson via the weak interaction (depicted by the crossed-circle vertex and a second nucleon absorbs the meson via the strong interaction (depected by the open-circle vertex).

coupling constants for the weak NN potential would provide very useful tools for verifying the quark model caclulations.

THE PARITY VIOLATING NN POTENTIAL

The strong NN potential is well described in terms of the exchange of mesons (π, ρ, ω, ...) between the nucleons. A natural extension of these models for the weak NN potential is a meson exchange model in which one nucleon emits a mesons through the weak interaction and a second nucleon absorbs the meson via the strong interaction (Fig. 1). The studies of parity violaiton in the nucleus are carried out in the low-energy regime. This, taken with the fact that the NN potential is strongly repulsive at short distances, means that only the lightest mesons are important for the PNC potential. Thus, we might expect the one-pion exchange diagrams to dominate. However, it turns out that CP invariance severely restricts the one-pion exchange contributions to the PNC potential. The limitation arising from CP invariance, which applies equally to any neutral pseudoscalar (e.g., π^0, η^0, etc.) meson, is called Barton's Theorem. Barton [2] and later Henley [3] showed that for these mesons the P-violating meson-nucleon vertex function is not invariant under CP and must vanish for CP-invariant weak interactions. For the charged pions ($\pi^\pm$) a CP invariant coupling can be constructed, but it is restricted to an isovector ($\Delta T = 1$) interaction. For this reason contributions to the weak PNC potential arising from the exchange of vector mesons, particularly isoscalar ($\Delta T = 0$) ρ-exchange, are important. Significant contributions to the PNC potential are then expected from π, ρ, and ω-exchange.

The expressions for the weak PNC potentials are obtained by combining one strong and one weak NM-vertex Lagrangian with the meson progator, and taking the non-relativistic limit of the vertex functions.

The full expressions for the weak and strong vertex Lagrangians and for the resulting six PNC potentials for $\pi(\Delta T = 1)$, $\rho(\Delta T = 0, 1, 2)$, and $\omega(\Delta T = 0, 1)$ exchange are given in refs. [4,6]. Both quark model analyses [4] for the weak matrix elements $\langle N\,M \mid \mathcal{H}_w \mid N\rangle$ and theoretical nuclear structure analyses [6] of experimental data indicate that of the corresponding six coupling constants, F_π, F_0, F_1, F_2, and G_0 and G_1, only the isoscalar F_0, coefficient of the ρ-potential and the isovector F_π, coefficient of the π-meson potential contribute importantly. The expressions for these two PNC potentials are:

$$-iV_\pi^{PNC} = i\frac{F_\pi}{M}\frac{m_\pi^2}{2\pi}(\tau_1 \times \tau_2)^z\,(\sigma_1 + \sigma_2)\cdot \hat{r}\;Y_1(x_\pi)$$

$$-iV_\rho^{PNC} = i\frac{F_0}{M}\frac{m_\rho^2}{2\pi}\tau_1 \cdot \tau_2 (1+\mu_v)(\sigma_1+\sigma_2)$$

$$\cdot\hat{r}\;Y_1(x_\rho) \tag{1}$$

where m_π (m_ρ) is the pion (rho) mass, M the nucleon mass, and μ_v is the nucleon vector magnetic moment, μ_v=3.7. Here the z-symbol on the isospin vector $\tau_1 \times \tau_2$ indicates the third component of the vector. Also, $r = r_1 - r_2$, $x_\pi = m_\pi r$ and $Y_1(x) = (1 + 1/x)Y_0(x)$ with $Y_0(x) = e^{-x}/x$. The coupling constants F_π and F_0 involve the product of one weak and one strong vertex coupling constant and their strengths remains a central issue in PNC studies.

The different isospin structure of the two potentials means that different linear combinations of F_0 and F_π are involved in PNC effects in different nuclei. For example, a parity mixing between two states that differ by one unit of isospin is determined solely by F_π, while a mixing between two states that differ by a proton (neutron) excitation involve a constructive (destructive) linear combination of F_0 and F_π. Thus in principle, measurements of PNC effects in three or so nuclei could determine reliable values for the weak coupling constants.

Evaluating matrix elements of the PNC potentials between two-nucleon states requires a transformation of the wave functions from a single particle coordinate system to a relative and centre of mass coordinate system. The required coefficients (Moshinsky brackets [5]) for this transformation are known for harmonic oscillator wavefunctions. However, the eigenfunctions of the harmonic oscillator potential are not the eigenfunctions of the nucleon-nucleon interaction. The most serious shortcoming of the harmonic oscillator wave functions is their inability to describe the short-range repulsion of the NN interaction. This strong repulsion means that as $r \rightarrow 0$ the relative wave functions go more rapidly to zero than given by uncorrelated oscillator functions. However, the physics of the short-range repulsion can be incorporated phenomenologically by multiplying the two-body potentials by a short-range correlation function. Thus we write

$$\hat{V}_{PNC}(r) = V_{PNC}(r)\hat{g}(r), \tag{2}$$

where $\hat{g}(r)$ is some function that tends to zero as $r \rightarrow 0$ and tends to unity for large r. The standard choice is that made by Adelberger and Haxton [6] who used $g(r) = [1 - exp(-ar^2)(1 - br^2)]^2$ with $a = 1.1 fm^{-2}$ and $b = 0.68 fm^{-2}$ obtained from the work of Miller and Spencer [7]. Typically, the short range correlations reduce the π-exchange matrix elements by a factor of ~ 1.4 and the ρ-exchange by ~ 3.6 [6].

DETECTION OF PARITY VIOLATION IN THE NUCLEUS

The parity-violating potential is a very small part ($10^{-7} - 10^{-6}$) of the total Hamiltonian for a nuclear system, $H = H_0 + V_{PNC}$. Thus, it can be treated in perturbation theory, and the eigenfunctions of H can be written

$$\Psi_{J+} = \phi_{J+} + \sum_{J-} \frac{\langle \phi_{J-} | V_{PNC} | \phi_{J+} \rangle}{E_+ - E_-} \phi_{J-} = \phi_{J+} + \mathfrak{F}\, \phi_{J-} \quad (3)$$

The matrix elements $\langle \phi_{J-} | V_{PNC} | \phi_{J+} \rangle$ are ~ 1 eV. In a light spherical nucleus a typical nuclear splitting between states of the same J but opposite parity is $E_+ - E_- \sim 1$ MeV, so that the odd parity amplitude is $\mathfrak{F} \sim 10^{-6}$. However, in complex nuclei one finds situations where the energy splitting between states J^+ and J^- are considerably smaller that 1 MeV, and in these cases there is an amplification of the PNC signal. Indeed, many of the PNC searches focus on parity-doublets, i.e., closely spaced J^+, J^- pairs. Exploiting this enhancement can have its disadvantages when it comes to interpreting the measurements. This is because very precise knowledge of the nuclear wave functions is needed to extract information on the weak interaction — considerably more precise than is needed in most analyses of parity-conserving observables. The largest PNC signals are seen in heavy nuclei where nuclear levels are very closed spaced, but the nuclear structure problems become enormously harder as the complexity of the nucleus increases. For this reason, the approach to analyses in light versus heavy nuclei have followed very different paths.

Parity inversion refers to the spatial transformation $r \rightarrow -r$, which implies a momentum transformation $k \rightarrow -k$. The angular momentum vector ($L = r \times k$) and the spin vector (σ) are unchanged under parity. Thus, measurements usually involve searches for parity-odd observables such as ($\sigma.k$), which can arise from an interference between a parity-conserving and a parity-violating amplitude. These parity-odd correlations are first order in $\mathfrak{F}$. Alternatively, one can search for violation of parity-forbidden selection rules, such as a parity-forbidden α-decay, and these are proportional to $\mathfrak{F}^2$.

In the case of parity-odd observables arising from an interference between a parity-conserving and parity-nonconserving amplitude a second enhancement of the signal is possible. The PNC effect is proportional to $2\mathfrak{F}\frac{\langle O(PNC)\rangle}{\langle O(PC)\rangle}$, where $\langle O(PNC)\rangle$ is the matrix element of an observable which is now non-zero because of the P-violation and $\langle O(PC)\rangle$ is the matrix element of the parity-conserving observable. Thus, by choosing cases where nuclear structure effects render $\langle O(PC)\rangle$ to be very hindered, the PNC signal can be amplified significantly.

Most of our knowledge on the PNC potentials have come from measurements of parity-violating asymmetries seen in γ-decay, or in the scattering of polarized nucleons from nuclei. In the case of the photon decay of an excited parity-mixed state of the nucleus (eq. (3)) to a final state of definite parity, both magnetic and electric radiation of the same multipolarity (and necessarily of opposite parity) are emitted. A parity-violating asymmetry can be detected by searching for circularly polarized photons resulting from the interference between the two types of radiation. Alternatively, if the nuclear level has been polarized, a search can be made for an asymmetry of the emitted photon relative to the direction of polarization.

Several such experiments have been performed [8]. These are three very favourable cases were both sources of amplification of the PNC signal play a role. These occur in ^{18}F, ^{19}F and ^{21}Ne where parity doublets are found in the low-lying bound states of the nucleus. Most of the theoretical work has concentrated on these three doublets and detailed analyses have been carried out within the shell model framework. [6]. In the case of ^{18}F there is a 0^-, 0^+ doublet lying at 1081 keV and 1042 keV, respectively. All searches for circular polarization in the γ-decay of the 0^- 1081 MeV state yield a zero result, and theoretical analyses of this result indicate an upper bound on the value of $F\pi$ that is consistent with zero. While this bound is allowed by quark model calculations of the effective weak coupling constants, it requires considerable cancellation amongst different model contributions. The unexpectedly small value of F_π has in part motivated the more recent searches for parity-violating effects in different nuclear mass regions.

The largest parity-violating effects have been seen in measurements of the (helicity dependent) longitudinal analyzing powers for polarized neutron scattering. In neutron transmission experiments on heavy nuclei, the parity-violating asymmetries, which are defined as the fractional difference of the resonance cross section for neutrons polarized parallel and antiparallel to their momentum,

$$P = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \quad (4)$$

can be as large as 10% [10]. These measurements are made on p-wave resonances in compound nuclear systems such as ^{238}U and ^{232}Th [11]. In these systems the energy separation between opposite parity s-wave and p-wave resonances range from 0.1-100 eV. The mixing of one s-wave state in a p-wave state leads to a longitudinal asymmetry

$$P = 2\mathfrak{F}\frac{\gamma_s^n}{\gamma_p^n} \quad (5)$$

Here γ_s^n and γ_p^n are the neutron reduced-widths evaluated at the p-wave resonance energy. The actual asymmetries involve a summation over many s-wave resonances since it is unlikely that P is dominated by the nearest-neighbour opposite-parity resonance. The large size of the PNC asymmetries in compound systems arises because of (1) the small energy denominators in $\mathfrak{F}$ and (2) the favourable ratio of s-wave to p-wave neutron widths.

The close spacing between the resonances reflects their complexity and they correspond to highly excited compound states of the nucleus. The wave functions of these resonances involve 10^5–10^6 single particle components, and their structure can only be described statistically. In the statistical model the neutron reduced widths γ_s^n and γ_p^n and the PNC mixing matrix elements $\langle V_{PNC}\rangle$ are treated as independent Gaussian-distributed random variables with zero mean. Using the known values of the resonance energies and reduced widths, the root-mean-squared PNC mixing matrix element M can be determined directly from a set of experimental values of P. A maximum likelihood analysis [11] yields a value

$$M = [Av\langle \psi_p | V_{PNC} | \psi_s \rangle^2]^{1/2} = 0.58^{+0.50}_{-0.25}\ meV \quad (6)$$

where ψ_s and ψ_p are the s- and p-wave resonance wave functions.

The observed magnitude of M is about as expected since the density of states in compound systems is about a thousand times larger than in light nuclei and the average PNC matrix element there is ~ 1 eV. French *et al.* [12] have developed a microscopic framework for a statistical treatment of nuclear properties. The formalism has been applied successfully to studies of strength functions of positive parity operators, such as the quadrupole operator, in compound nuclei. Tomsovic [13] has proposed an extension of the theory for studies of PNC matrix elements. The first step in this direction has been taken by Johnson *et al.* [14] who examined the PNC strength function in large shell model spaces and compared this to the measured value of M to extract a range of values for $F\pi$ and F_o.

An example of a violation of a parity-forbidden selection rule is the α-decay of the excited 2^-(8.87 MeV) state of ^{16}O to the 0^+ ground state of ^{12}C; $^{16}O(2^-) \rightarrow {}^{12}C + \alpha$. The α-particle has spin/parity $J = 0^+$, and it can carry away L units of angular momentum. Thus, in the absence of parity violation, only states in ^{12}C with $J = 2+L$ and parity $\Pi = (-)^{1+L}$ can be populated by the decay of a 2^- state. A parity-violating α-width of $\Gamma_\alpha = (1.03 \pm 0.28) \times 10^{-10}$ eV has been measured [15] for this state. This width arises from a 2^+ amplitude $\mathfrak{F}$ admixed into the 2^- state, and the magnitude of the PNC width is proportional to $\mathfrak{F}^2$. Unfortunately, the uncertainties in the calculation [16] of this admixture have proved too large to extract information on the weak potential from this measurement.

THE ONE-BODY PNC POTENTIAL

The PNC potentials are two-body potentials, and the largest uncertainties in evaluating their matrix elements between many-body nuclear states arise from the uncertainties in nuclear wave functions themselves. Disentangling the nuclear structure from the underlying weak PNC matrix elements is the most challenging aspect of any theoretical analysis of nuclear parity violation. Insight into the complexities involved and into any pertinent shortcomings with the model wave functions can be obtained by starting with an analysis of the problem within a one-body approximation. Michel [17] derived an effective one-body PNC potential, which allowed him to evaluate PNC asymmetries using Nilsson model wave functions for a variety of spherical and deformed nuclei.

Typical many-body nuclear calculations assume an inert core set of nucleons (interacting only via the average nuclear potential) and a valence set of interacting nucleons. The one-body PNC interaction U_{PNC} between two nucleons in valence states $|a\rangle$ and $|b\rangle$ can be derived from matrix elements of the two-body interaction V_{PNC} by summing over all configurations in the core,

$$\langle b | U_{PNC} | a \rangle = \sum_c \langle b,c | V_{PNC}(1,2) | a, c\rangle \quad (7)$$

Here the two-body matrix element is antisymmetric, i.e., it includes both the direct and exchange terms. The matrix elements of the one-body ineteraction can be expressed in terms of an analytic one-body operator. The chosen operator acts as a meaningful, well-defined approximation to the two-body PNC potential if the associated effective coupling constants are not dependent on the core states involved in the sum (7). The simplest and most appealing one-body operators that violate parity, but not time-reversal invariance, are the isoscalar and isovector axial operators $\vec{\sigma}\cdot\vec{p}$ and $\vec{\sigma}\cdot\vec{p}r$. The appropriate effective coupling constants are defined as

$$\epsilon^0 = \frac{\langle b \,\|\, U_{PNC}^{\lambda\tau=0} \,\|\, a\rangle}{\langle b \,\|\, \vec{\sigma}\cdot\vec{p} \,\|\, a\rangle} \tag{8}$$

$$\epsilon^1 = \frac{\langle b \,\|\, U_{PNC}^{\lambda\tau=1} \,\|\, a\rangle}{\langle b \,\|\, \vec{\sigma}\cdot\vec{p}r \,\|\, a\rangle}$$

The contribution of each of the six terms in V_{PNC} to the one-body coupling constants ϵ^0 and ϵ^1 has been calculated by Hayes and Towner [18] assuming a single nucleon outside a closed-shell configuration. The results are summarized in Table 1.

Most striking is the lack of any strong shell or mass dependence in the coupling constants ϵ^0 or ϵ^1. The total isoscalar and isovector PNC strengths remain almost constant with A (the mass of the nucleus). Furthermore, the large neutron excess in heavy nuclei has little effect on the values of the effective coupling constants. There are two competing factors determining the mass dependence of ϵ. First there is the dependence on the size of the nucleus, which increases linearly with the harmonic oscillator length parameter, $b \propto A^{1/6}$. Matrix elements of $\vec{\sigma}\cdot\vec{p}$ scale with $1/b$, while matrix elements of V_{PNC} scale roughly with $1/b^2$. Thus, if the number of core orbitals which are summed remained fixed, ϵ would scale like $1/b$ approximately, and thus decrease roughly as $A^{-1/6}$. However, this scaling with the oscillator parameter is strongly offset by the increase in the number orbitals being summed as A increases. In general, the two effects compensate, resulting in an approximately mass independent effective coupling constant.

To examine the expected distribution of the PNC strength in the nucleus we can examine the strength functions of the effective one-body operators. The axial operators $\vec{\sigma}\cdot\vec{p}$ and $\vec{\sigma}\cdot\vec{p}r$ are exactly analogous to the electric spin dipole operators $\vec{\sigma}\cdot\vec{r}$ and $\vec{\sigma}\cdot\vec{r}\tau$. They differ in their helicity properties, but if we confine ourselves to a $0\hbar\omega \rightarrow 1\hbar\omega$ calculation, (i.e., a calculation where the positive and negative parity states differ only by the excitation of a nucleon through one oscillator shell), the distribution of the matrix elements of $\vec{\sigma}\cdot\vec{r}$ and $\vec{\sigma}\cdot\vec{p}$ are identical. The operators σ,τ, and $\sigma\cdot\tau$ generate the group SU(4), and the irreducible representations of this group form the Wigner Supermultiplets. If the nuclear force were independent of spin and isospin, i.e. invariant under the Wigner SU(4) symmetry, the distribution of matrix elements of any set of operators $O(r)$, $O(r)\sigma$, $O(r)\tau$, and $O(r)\sigma\tau$ would be the same. The nuclear Hamiltonian does contain SU(4) noninvariant terms, such as the Heisenberg $(\tau_1\cdot\tau_2)$ interaction and the spin-orbit interaction. Nonetheless, the distribution of operators differing only by an SU(4) rotation remains similar, particularly in light nuclei. The operator $\vec{r}\tau$ is the electric dipole operator and its strength distribution in the nucleus is determined by the giant dipole resonance which lies at about $1.5\hbar\omega$, ($\hbar\omega \simeq \frac{41}{A^{1/3}}$ MeV) of excitation, and is a few MeV wide. Thus, from SU(4) symmetry arguments, we expect that the strength distributions for $\vec{\sigma}\cdot\vec{p}$ and $\vec{\sigma}\cdot\vec{p}\tau$ also exhibit resonance-like structure.

To demonstrate this in a realistic calculation we consider the nucleus ^{19}F which has a $1/2^+$ ground state. The parity mixing between the ground state and the first excited $1/2^-$ state has been deduced from the γ decay of the $1/2^-$ state. The total (isoscalar and isovector) one-body PNC strength built on the ground state of ^{19}F is shown in detail in Fig. 2. The states of ^{19}F were calculated in a full $(0+1)\hbar\omega$ shell model calculation, in which spurious centre-of-mass excitations were removed exactly. There are then over three hundred $1/2^-$ states in the nonspurious model space. From Fig. 2 it can be seen that most of the strength of the parity-violating interaction is concentrated at high energies, and that the first excited state involves only a very small fraction of the total strength. This points to the need for a very detailed calculation of the structure of this state before a meaningful analysis of the PNC matrix element can be extracted from the γ-decay measurements. The upper panel of the figure shows the PNC strength obtained using the full form of the PNC potential via eq. (7), the bottom panel shows the results obtained using the operators $\vec{\sigma}\cdot\vec{p}$ and $\vec{\sigma}\cdot\vec{p}r$. The two distributions are very similar over the entire excitation spectrum. However, for some individual states large differences occur. This suggests that whilst the operator $\vec{\sigma}\cdot\vec{p}$ provides an excellent approximation to the overall PNC strength function in the nucleus, it should not be used for the extraction of PNC coupling constants from measurements on isolated parity doublets.

TABLE I. Contribution from each component ($F_\pi, F_0, \ldots G_1$) of the two-body V_{PNC} to ϵ for closed-shell-plus-one configurations for five choices of the closed-shell core.

	^{16}O N=8 Z=8		^{40}Ca N=20 Z=20		^{90}Zr N=50 Z=40		^{208}Pb N=126 Z=82		^{232}Th N=142 Z=90	
	ϵ^0	ϵ^1	ϵ^0	ϵ^1	ϵ^0	ϵ^1	ϵ^0	ϵ^1	ϵ^0	ϵ^1
	0p-0s		1p-1s		2p-2s		3p-3s		3p-3s	
F_π		-.205		-.157		-.126		-.119		-.132
F_0	-.156		-.143		-.136		-.140		-.144	
F_1		-.001		-.001		-.001		-.001		-.001
F_2		.000		.000		.000		.005		.005
G_0	-.014		-.014		-.014		-.015		-.016	
G_1		-.007		-.008		-.008		-.009		-.009
Total	-.170	-.213	-.157	-.166	-.150	-.135	-.155	-.129	-.160	-.128
$\epsilon(\vec{\sigma}\cdot\vec{p})$ eV	2.4	3.0	2.5	2.7	2.5	2.3	2.6	2.2	2.7	2.1

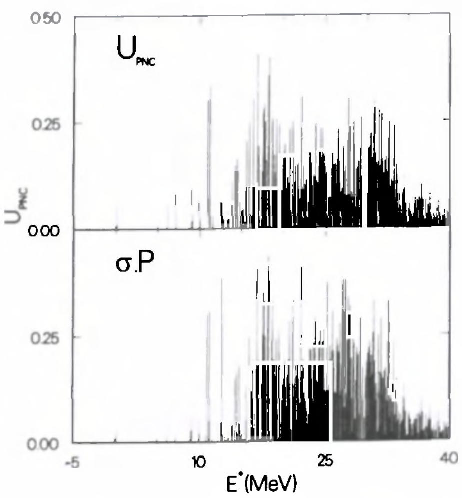

Fig. 2 The distribution of one-body PNC strength built on the $J = 1/2^+$ ground state of ^{19}F. In this figure the height of each line represents the magnitude of the PNC matrix element (in arbitrary units) and the energy position of the line is the excitation energy of the corresponding $T=1/2$ or $T=3/2$ $J=1/2^-$ excited state. The PNC matrix elements were obtained from a $1\hbar\omega$ shell model calculation. The upper panel of the figure shows the one-body strength derived from the two-body PNC interaction using eq (7). The lower panel shows the strength obtained using the operators $\epsilon^0\vec{\sigma}\cdot p$ and $\epsilon^1\vec{\sigma}\cdot pr$, where the coupling constants ϵ^0 and ϵ^1 are taken to be orbital independent. We note the very small fraction of the total strength to the first $1/2^-$(100 keV) state. This is the state that is relevant to the parity-violating γ-decay in ^{19}F.

T-VIOLATION IN THE NN INTERACTION

Since the discovery of CP-violation in kaon decay over thirty years ago, the origin of the effect has still not been identified. There have been many searches for other CP-and T-violating effects, but nothing has been seen in systems other than the neutral kaons. A number of models have been proposed for the interaction responsible for the observed CP-violation. The observed effect can be accounted for within the minimal standard model through a CP-violating phase in the Cabibbo-Kobayashi-Maskawa quark mixing matrix. Alternatively, new interactions requiring an extension of the standard electroweak model may be responsible, and the predictions of some of the proposed models are quite different in systems other than the neutral kaons. T-violation in the NN interaction can occur simultaneously with P-violation, or as a P-conserving T-violating, interaction. However, in contrast to the PT-violating interactions, interactions that violate T but conserve P do not arise in the standard model. In this section we discuss attempts via low-energy measurements to put limits on the strengths of either form of T-violation in the NN interaction.

The time-reversal noninvariant low-energy NN potentials can be described in terms of a single meson exchange in which one of the $N \rightarrow NM$ vertices involves a P,T-violating or T-violating P-conserving non-leptonic Hamiltonian. Measurements of T-violation in the nucleus require polarized nuclear targets, and are generally more difficult than searches for P-violating T-conserving asymmetries. The magnitude of a T-violating amplitude in the nuclear wave functions is expected to be very small, especially in the case of a T-violating P-conserving amplitude.

The issues involved in the PT-violating and the T-violating P-conserving interactions are different and we consider them separately. The most stringent tests on the limits of time-reversal noninvariant interactions come from searches for electric dipole moments in the neutron or in neutral atoms. However, investigations of the role of T-violation in the NN interaction have concentrated on searches in the nucleus. We first consider the simultaneous violation of time reversal invariance and parity conservation. P,T-violation in the NN interaction may be studied in γ-decay and in neutron transmission on polarized nuclei. PT-violation is always accompanied by P-violation alone, and the ratio of the two asymmetries is the relevant observable. A symmetry-violating potential $V^P + V^{P,T}$ has the effect of changing a nuclear state $|a\rangle$ to a state $|A\rangle$, given by

$$|A\rangle = |a\rangle + \Sigma \frac{|a'\rangle}{E_a - E_a'} \times$$

$$(\langle a'|V^P|a\rangle + \langle a'|V^{P,T}|a\rangle) \tag{9}$$

where the state $|a'\rangle$ is of the same angular momentum as $|a\rangle$ but of opposite parity.

We recall that for P-violation alone, CP-invariance excluded T=0 and T=2 π-exchange. For the P,T-violating potentials this restriction no longer holds, and T=0,1 and 2 π-exchange are allowed. The isotensor potential is not generally expected to play a dominant role. The expressions for the T=0 and 1 π-exchange P,T-violating potentials are [19,20]

$$V_{P,T}^{(T=0)} = -\bar{g}^{(0)\prime}_{\pi NN} g_{\pi NN} \frac{m_\pi^2}{8\pi M} \sigma_- \cdot \hat{r} \tau_1 \cdot \tau_2 Y_1(x_\pi),$$

$$V_{P,T}^{(T=1)} = \bar{g}(1)'_{\pi NN} g_{\pi NN} \frac{m_\pi^2}{16\pi M} \sigma_+ \cdot \hat{r} \tau_-^z +$$

$$\sigma_- \cdot \hat{r} \tau_+^z] Y_1(x_\pi) \tag{10}$$

where $\sigma_+ = \sigma_1 + \sigma_2$, $\sigma_- = \sigma_1 - \sigma_2$ and similarly for τ_+ and τ_-.

In the case of P-violation alone, ρ-exchange is known to be as important as π-exchange. The T=0 and 1 ρ-exchange P,T-violating potentials are [21]

$$V_{P,T}^{(T=0)} = \bar{g}^{(0)\prime}_{\rho NN} g_{\rho NN} \frac{m_\rho^2}{8\pi M} \sigma_- \cdot \hat{r} \tau_1 \cdot \tau_2 Y_1(x_\rho),$$

$$V_{P,T}^{(T=1)} = \bar{g}(1)'_{\rho NN} g_{\rho NN} \frac{m_\rho^2}{16\pi M} \sigma_+ \cdot \hat{r} \tau_-^2$$

$$-\sigma_- \cdot \hat{r} \tau_+^2] Y_1(x_\rho) \tag{11}$$

The coupling constants $\bar{g}^{(T)\prime}_{MNN}$ characterize the *P,T*-violating $N \rightarrow NM$ vertices and the coupling constants g_{MNN} the strong vertices. (We are following the standard notation in which a 'bar' over the coupling constant indicates T-violation and a 'prime' P-violation. A 'bar' and a 'prime' together indicates PT-violation). The overall form of the ρ-exchange P,T-violating potentials is the same as for π-exchange except for one key difference in the isovector potential. There the relative sign between the two terms is negative for ρ-exchange and positive for π-exchange.

To obtain insight into the properties of the P,T-potentials and to estimate the relative importance of the different components we turn to the effective one-body potentials. These are derived in exactly same way as the one-body PNC potentials using eq. (7). For charge-symmetric cores, i.e., cores with an equal number of neutrons and protons, the matrix elements of $\sigma_- \tau_1 \cdot \tau_2$ are zero, and matrix elements of $\sigma_- \tau_+^z$ and $\sigma + \tau_-^z$ are equal after summation. Thus, when N=Z there is no T=0 contribution to P,T-violation. Futhermore, ρ-exchange interaction gives no contribution for any isospin channel. For charge-nonsymmetric cores ($N \neq Z$) these terms give a finite contribution, but generally small. The vector meson exchange contributions to P,T-violation are about two orders of magnitude smaller that the T=1 π-exchange matrix elements. This is in sharp contrast to the situation seen in P-violation, where ρ-exchange plays a dominant role.

As noted above, the ratio of the P,T-violating to P-violating asymmetries is the significant observable and this is proportional to the ratio of the matrix elements of V^P and $V^{P,T}$. Herczeg [19] has pointed out that if a reliable calculation of $\langle a'|V^{P,T}|a\rangle$ is not available, an estimate of the ratio $A_{P,T}/A_P$ combined with a measured value of the P-violating effect may give a more reliable estimate of $\langle a'|V^{P,T}|a\rangle$ than would an unreliable calculation of it. To this end, Herczeg defines the ratio κ,

$$-i\frac{\langle a'|V^{P,T}|a\rangle}{\langle a'|V^P|a\rangle} = \kappa \frac{\bar{g}^{(1)\prime}_{MNN}}{g^{(0)\prime}_{\rho NN}}. \tag{12}$$

Here it is assumed that P-violation occurs primarily through isoscalar ($I = 0$) ρ-exchange characterized by the coupling constant $g^{(0)\prime}_{\rho NN}$ which is related to the coupling constant F_0, used in eq (1) by, $F_0, = -g^{(0)}_{\rho NN} g_{\rho NN}/2$.

The ratio κ has been evaluated [21] as a function of nuclear mass assuming a single nucleon in a closed-shell-plus-one configuration. The magnitude of κ is found to be about 5, and to display very little mass dependence. Griffiths and Vogel [22] have also calculated κ for specific rare-earth nuclei, using the quasiparticle random phase approximation. They find a very similar range of values. These results are significant because they suggest that the ratio of the P,T-violating to P-violating amplitudes is approximately independent of nuclear structure. Thus, knowledge of the magnitude of κ allows an estimate of $\langle V^{P,T}\rangle$ from a measurement of $\langle V^P\rangle$.

There has been only one experimental result on P,T-violation in γ-decay. This is from a study of the decay of the (polarized) 8^-(1.142 MeV) metastable state of ^{180}Hf to the 6^+(0.641 MeV) state. The transition exhibits an unusually large P-violating effect through a forward-backward asymmetry (1.7%) and circular polarization (0.2%) of the emitted γ-rays. The effect is an E2-E3 interference. If $|A\rangle$ is a P-mixed and P,T-mixed state (eq. (9)), the γ-ray transition $|A\rangle \rightarrow |B\rangle$, exhibits a P,T-violating effect proportional to

$$a_{P,T} = Im\frac{\langle B\|\pi' L'\|A\rangle}{\langle B\|\pi L\|A\rangle}, \tag{13}$$

where $\pi' L'$ is the irregular multipole available due to P,T-violation while πL is the multipole present in the absence of $V^P + V^{P,T}$. The P-violating effect in the same transition is proportional to

$$Ap = Re\frac{\langle B\|\pi' L'\|A\rangle}{\langle B\|\pi L\|A\rangle}, \tag{14}$$

The measurement in ^{180}Hf yielded

$$\frac{Im\langle f|E2|i\rangle}{Re\langle f|E2|i\rangle} = -0.7 \pm 0.6 \tag{15}$$

This implies a limit on the PT-coupling constant $|\bar{g}'_{\pi NN}| \langle 3.8 \times 10^{-6}/\kappa$. However, the sensitivity of the experiment would have to be improved by four orders of magnitude in order to improve the limit on $\bar{g}_{\pi NN}$ set by the dipole moment of ^{199}Hg.

P,T-violation can also be probed by study of the transmission of polarized neutrons through polarized nuclear targets [23]. These experiments are an extension of the neutron transmission measurements on unpolarized targets. In the case of polarized targets, the fractional difference of the resonance cross sections for neutrons polarized parallel and antiparellel to their momentum, $P_{P,T} = \sigma\uparrow - \sigma\downarrow/\sigma\uparrow + \sigma\downarrow$, implies simultaneous P- and T-violation. The P,T-violating asymmetry arises through a term in the scattering amplitude proportional to $\sigma \cdot (k \times J)$. Here $\sigma\uparrow$ and $\sigma\downarrow$ are the total scattering cross-sections for neutrons polarized parallel and antiparellel to $(k \times J)$, σ and k are the neutron spin and momentum and J is the target spin.

In a two-state mixing approximation, the ratio of the P,T-violating to P-violating asymmetries in the neutron measurements is given by

$$\lambda = \frac{P_{P,T}}{P_P} \simeq -i\frac{\langle\psi_s|V^{P,T}|\psi_p\rangle}{\langle\psi_s|V^P|\psi_p\rangle} \simeq \kappa \frac{\bar{g}^{(1)\prime}_{\pi NN}}{g_{\rho NN}} \cdot \tag{16}$$

where ψ_s and ψ_p are compound nuclear *s*- and *p*-wave resonance wave functions. The neutron transmission experiments are most sensitive to the isovector coupling P,T-violating interaction, since it is probed by all the nucleons. Combining the present limit on $\bar{g}^{(1)\prime}_{\pi NN}$ with the calculated value of κ implies that the required accuracy is about $P_{P,T}/P_P \sim 10^{-5}$.

Finally, we consider the T-violating P-conserving (TVPC) NN potential. In the case of the TVPC interaction, the form of the meson-exchange potential has been shown by Simonious [24] to be severely constrained. No π-exchange or ρ^0-exchange is allowed; Only $\rho^\pm$ and A_1 (or heavier) mesons can contribute. The A_1 meson is considerably heavier than the ρ, and so its contributions are strongly damped by the short-range NN correlations. The ρ-exchange T-violating potential, which generates only an isovector potential, is given by [24]

$$V_\rho^{TV\,PC} = \frac{m_\rho^3 g_\rho^2 \bar{g}_\rho \mu_v}{4\pi M^2} \frac{1}{x_\rho} Y_1(x_\rho) \sigma_- . l$$

$$[\tau_1 \times \tau_2]^2 \tag{17}$$

Here $l = r_{12} \times \frac{1}{2}(p_1 - p_2)$, g_ρ is the normal strong ρNN coupling, and $\bar{g}_\rho$ is a dimensionless ratio of the TVPC coupling to g_ρ. The form of TVPC potential implies that neutrons only interact with protons. Futhermore, in the case of charge symmetric cores (N=Z), there is no contribution to the one-body potential form the core nucleons. Thus, only a few valence nucleons can contribute to a TVPC observable.

The most stringent limits on $\bar{g}_\rho$ come from an analysis [25] of the experimental limits on the electric dipole moment of ^{199}Hg and of the neutron. These implies $|\bar{g}_{\rho NN}| \leq 9.4 \times 10^{-2}$.

French *et al.* [12] studied the sensitivity of spectral fluctuations and strength functions in the compound nuclear regime to a time-reversal noninvariant term in the nuclear Hamiltonian. The sensitivity to spectral fluctuations arises because a TVPC Hamiltonian leads to stronger level repulsion than a symmetry-conserving Hamiltonian. In the case of strength functions, one can search for deviations from the Porter-Thomas distribution generated by a time-reversal invariant Hamiltonian. The data set studied included 1702 levels in 32 nuclei. Since the analysis of compound nuclear resonances require enormous model spaces, French *et al.* used their spectral averaging formalism for this analysis. The results were expressed in terms of a coefficient α_T, which is the ratio of typical TVPC NN matrix elements to those of the symmetry-conserving shell model

TABLE II. Isovector π-exchange, $V_{P,T}$, and isoscalar ρ-exchange, V_P, matrix elements evaluated for a closed-shell-plus-one configuration for six choices of the closed-shell core. The weak interaction coupling constants are $g^{(1)}_{\pi NN} = 1.0 \times 10^{-11}$ and [illegible] $= -11.4 \times 10^{-7}$.

	^{16}O N=8 Z=8	^{40}Ca N=20 Z=20	^{90}Zr N=50 Z=40	^{138}Ba N=82 Z=56	^{208}Pb N=126 Z=82	^{232}Th N=142 Z=90
	$0p - 0s$	$1p - 1s$	$2p - 2s$	$2p - 2s$	$3p - 3s$	$3p - 3s$
$< V_{P,T} >$ in eV $\times 10^{-4}$	1.084	0.875	0.708	0.779	0.608	0.633
$< V_P >$ in eV	1.513	1.550	1.535	1.576	1.581	1.600
[illegible]	−8.2	−6.4	−5.3	−5.6	−4.4	−4.[illegible]

TABLE III. Weak PNC coupling constants. The theoretical values and range are from the quark model calculations of Deplanques *et al.* [4] and the experimental values are from the analyses of Adelberger and Haxton [6]

Coefficient	Best value(10^{-6}) Theory	Reasonable range (10^{-6}) Theory	Best value(10^{-6}) Fit to Expt
F_π	1.08	0:2.71	< 0.4
F_0	1.59	-1.59:4.29	0.8

involves mixing between several states, have yet to achieve the required accuracy to extract reliable coupling constants.

In heavy nuclei, where the parity violation between compound resonances is analyzed within the statistical shell model, the present indications are that the models need to be extended. To date statistical calculations have been confined mainly to studies of positive parity operators. For most of these, the strength function of the operator is determined by the same model space that determines the level density. In the case of negative parity states, the level density is determined by the so-called intruder state. The intruder state is the state of maximum J from the next highet shell which is pulled down one shell by the very strong spin-orbit interaction in heavy nuclei. The angular momentum difference between the opposite-parity intruder orbital and all other orbitals in the shell means that the intruder cannot contribute to the one-body PNC matrix elements. Thus, if the calculations are carried out in the model space that determines the spectral level density, the PNC matrix elements will arise solely from the valence two-body part of PNC interaction and matrix elements of the one-body potential (eq. 7) will be identically zero. This suggests the need for extensions of the standard model space and it remains to be seen whether the statistical model will be able to reproduce the giant resonance structure of the one-body operators.

interaction. The limit at the 99% confidence level is $|\alpha_T| < 2 \times 10^{-3}$. Haxton *et al.* [25] have related α_T to the coupling constant $g_{\rho NN}$ in ^{199}Hg by comparing matrix elements of V_ρ^{TVPC} with matrix elements of the residual strong interaction in a shell model calculation. They find that the limit on α_T implies $|g_{\rho NN}| \leq 2.5$.

There has been one published measurement of a T-violating P-conserving correlation in the scattering of polarized neutrons on aligned ^{165}Ho targets. These measurements searched for a dependence of the forward elastic-scattering amplitude on the T-violating P-conserving correlation term $(\sigma \cdot J \times k)$ $(J \cdot k)$. Here, J and σ are unit vectors along the axes of the target alignment and neutron polarization, and k is the direction of the incident neutron beam.

The neutron scattering experiment was analyzed in terms of the T-violating potential by Engel *et al.* [26] who derived a TVPC optical potential for the neutron-nucleus potential, starting from the ρ-exchange two-body potential. In this way they obtained limits on $g_{\rho NN}$. This result indicates the need for an order of magnitude better accuracy in the measurements in order to improve on the limits set by the electric dipole searches. It is anticipated that an improvement of ~150 can be achieved.

FUTURE DIRECTIONS

While much progress has been made in our attempts to understand nuclear parity violation, a number of open questions remain. The original motivation of the program was to extract information on the fundamental weak interaction between the quarks from the PNC meson-nucleon coupling constants. However, this hope has been blighted by theoretical difficulties at the particle physics level. In principle, the weak meson-nucleon amplitudes, and hence the corresponding coupling constants, can be calculated starting with the standard electroweak interaction between quarks. However, the elementary W and Z exchange occuring inside the weak meson-nucleon vertex are dressed by hadronic effects in a sufficiently complicated way that the estimated [4] values for the coupling constants are assigned large uncertainties. The "best values" and "reasonable range" for the two PNC coupling constants F_π and F_0, resulting from the quark model calculations, along with the values obtained [6] from the best fit to experiment, are tiven in Table III. The allowed range on the theoretical values for the coupling constants means that even very precise experimental determinations of F_π and F_0 will not provide constraints on the fundamental weak interaction between quarks. The calculations require the evaluation of three-hadron matrix element of a four quark-operator, $\langle MN | \mathcal{H}_w | N \rangle$. An improvement in the calculations to the level that would allow a direct connection between the meson-nucleon potentials and the quark-quark weak interaction is unlikely to be achieved in the near future.

On the nuclear physics side, the outlooks is much more optimistic. Studies of parity violation have pushed models of the nucleus to new limits and, indeed, have become the primary motivation for extensions of statistical treatments of chaotic spectra in nuclei. In the lighter nuclei, around mass 18, state-of-the-art shell model calculations have been carried out to analyze the PNC effects. As shown in Fig. 2, the PNC matrix element between a state $|J^+\rangle$ and a closely lying state $|J^-\rangle$ is only a very small fraction of the total PNC strength to all states$|J^{-1}\rangle$. Thus, very detailed knowledge of the nuclear wave functions is needed to obtain a reliable prediction of the matrix elements. In particular, at least $2\hbar\omega$ of excitation must be included in the model space and spurious center of mass excitations must be eliminated exactly. Structure theorists have taken advantage of the rapid advances in computer technology and modern shell model codes can now handle very large model spaces. Recently, these advances provided the first multi-$\hbar\omega$ calculation of ^{21}Ne, which in turn provided the first set of consistent values for F_π and F_0 for the PNC measurements in the three parity-doublet cases. Calculations in light nuclei, where the parity mixing is not confined to a doublet but instead

New experiments are planned to measure parity-violating asymmetries in polarized-neutron scattering over a wider range of nuclear masses. In contrast to heavy nuclei, analyses of the PNC matrix elements in light nuclei show that the one-body part of the interaction dominates there. A current topic of interest is the issue of how the role of the one-body versus two-body parts of the PNC interaction vary as the intruder orbital is lowered in energy. Ideally, one would like to measure the effects in a common nucleus that can be calculated both within the regular shell model and the statistical shell model.

Studies of P-odd T-odd correlations in the nucleus have proved less sensitive than searches for electric dipole moments. To data gamma ray correlations are simply too insensitive to provide meaningful limits on the PT-voilating coupling constants. However, there may exist transitions where enhancements arising from special nuclear structure effects result in a large asymmetry. The most likely candidates would be expected in deformed nuclei and further theoretical work is needed here. Estimates for the required sensitivity in the neutron transmission experiments suggest a need for an accuracy of 10^{-5} -10^{-6} for the P_{PT}/P_P ratio. It remains to be seen whether this accuracy can be achieved. Significant improvements on the T-odd P-even correlations in neutron scattering experiments are anticipated in the near future. These are expected to provide improved limits on the corresponding coupling constant.

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OUTFLOWS FROM SPIRAL GALAXIES

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SPIRAL GALAXIES --- A VIEW THROUGH THE TELESCOPE EYEPIECE

When most of us envision a "galaxy", we tend to think of giant spirals, both structured and beautiful, often displayed with prominence on the covers of astronomy texts (Fig. 1). The image is at optical wavelengths, as if peering through a very powerful telescope on a clear, moonless night. We see a bright flattened disk consisting of $\approx 10^{11}$ stars too crowded over the field of view to be resolved individually. Prominent spiral arms wind through the disk emerging from a glowing central bulge, and around the disk is a roughly spherical halo region sparsely populated with globular star clusters, each one containing perhaps half a million stars. With careful observation, we can discern numerous details, bifurcated spiral arms, subtle colour differences, dark dust lanes threading along the arms or reddish ionized hydrogen (HII) regions associated with the brightest, hottest stars. The view is breathtaking, and not at all incorrect. Indeed, some might argue that this picture is quite adequate, given that most of the *observable* mass of the galaxy is locked up in stars which emit black body radiation at predominantly optical wavelengths. But there's more going on here than meets the eye.

Fig. 1 The nearby galaxy, M 31 (The Andromeda Galaxy) and its two small companions. The image is at optical wavelengths in which the emission is predominantly from stars. Image available through the home page of "Students for the Exploration and Development of Space" (http://seds.lpl.arizona.edu/).

Decades of study of our home Galaxy, the Milky Way, have provided us with a view which is very similar to the description above, the sun and its planets near an outer spiral arm orbiting the center of the Galaxy with a period (a few x 10^8 yr) dictated by the Galactic mass distribution. An optical 3-D map of the Milky Way, however, becomes sketchier with increasing distance from the sun, due to obscuration by interstellar dust. Indeed, if we look along the plane of the Milky Way (seen as the faint band of light stretching across the sky), the stars that are visible are only the relatively nearby ones, out to distances of a few kpc (1 kpc = 3.1 x 10^{19} m) compared to the 8 kpc distance to the Galactic Center[1]. Starlight is scattered and reddened by dust by the same processes which dim and redden light from the setting sun. Since interstellar grain radii tend to be in the range, $\lesssim$ a few hundredths to a few tenths of a μm, however, wavelengths sufficiently longer than this particle size will propagate over scales of Galactic proportion, essentially without interaction. Consequently, observations at mm, cm, and some infrared wavelengths provide us with useful probes of the large scale structure of the Galaxy.

THE INTERSTELLAR "VACUUM" --- A BROADENING PERSPECTIVE

When a radio telescope is pointed at the Milky Way, the resulting view is quite different from the optical picture described above. Stars, being weak emitters at radio wavelengths, disappear from view and instead, depending on the tuned frequency, the sky is filled with emission from the "vacuum" between the stars. Interstellar space is filled with numerous components (including dust), collectively known as the interstellar medium (ISM). The ISM is not uniform, rather its constituents occupy volumes of space of various size and cover many orders of magnitude in density and temperature --- from hot "coronal" gas with densities as low as 0.001 particles cm^{-3} and temperatures as high as $\approx 10^6$ K to molecular cloud cores with densities as high as 10^{7-8} particles cm^{-3} and temperatures as low as ≈ 10 K. Although the densest of clouds is still orders of magnitude rarer than the best vacuum attainable in earth-based laboratories, when integrated over the extremely large distances of interstellar space, column densities can be considerable (e.g. 10^{22} particles cm^{-2} for neutral atomic hydrogen) and the emission is often easily detectable.

Much of the *volume* of the ISM is taken up by hot, low density ionized hydrogen (called coronal gas) and by low density cosmic rays which were accelerated in high energy regions like supernova shock waves. The ionized hydrogen is detectable from its Bremsstrahlung emission in the soft X-ray regime, which requires satellite observations. Ultra-relativistic (e.g. $\gamma \approx 1000$) cosmic ray electrons spiral around Galactic magnetic field lines and can be detected by the subsequent synchrotron emission which is radiated as a continuous spectrum in the cm-wavelength radio regime. These two components contribute a negligible amount of mass to the ISM, but occupy large filling factors and cover most of the observable sky, though with decreasing intensity as a function of distance from the Milky Way plane. They are also tracers of energetic phenomena and the cosmic ray component allows us to map out the structure and direction of the Galactic magnetic field from observations of synchrotron polarization.

The total ISM *mass* constitutes approximately 10% of the galaxy's total observable mass. Most of this mass is split roughly equally between two neutral components. One is neutral atomic hydrogen (HI), which is ubiquitous throughout the Galaxy and detectable through observations of the ground state hyperfine transition at υ = 1420.406 MHz. HI (T $\approx$ 100 K) is seen in cloud structures, in wispy filaments, arcs and plumes, and as smooth warmer intercloud gas. It is extremely useful for mapping out the large-scale rotation of the Galaxy from Doppler shifts of this spectral line. The second component is molecular hydrogen (H_2) which congregates in denser clouds and is more concentrated towards the galaxy's plane than the HI. There does not appear to be any intercloud H_2, since the radiation field in low density regions between clouds is capable of dissociating the hydrogen molecule. Interstellar dust is correlated spatially with dense molecular clouds and it is believed that molecules form most efficiently on the surfaces of these grains. Unfortunately, H_2 has no dipole moment and is therefore undetectable under normal interstellar conditions[2]. Therefore, the quantity of molecular hydrogen is normally inferred (with some controversy as to the conversion factor) from observations of the next most abundant molecule, carbon monoxide, which is collisionally excited by the H_2. CO has several accessible rotational transitions in the mm and sub-mm regimes (e.g. $J = 1 \rightarrow 0$ corresponds to υ = 115.271 GHz).

So far as we know, this description of the ISM in our own Galaxy is applicable to most other spirals, though it is difficult to discern the detailed structure of the various components in other galaxies due to lack of sufficient spatial resolution at the greater distances. There are also differences between galaxies, however, especially in the relative quantities of the various components, and in the agitation they are experiencing from internal energetic events.

THE VIOLENT INTERSTELLAR MEDIUM

Recently, our understanding of the interstellar medium (ISM) in our own and other spiral galaxies has undergone a dramatic change. Twenty-five years ago,

[1]Interstellar absorption varies strongly with position in the Galactic plane.

[2]Under some conditions, e.g. in regions close to stars, molecular hydrogen can attain temperatures of several thousand K in which case some vibrational transitions are observable in the infra-red.

the ISM was thought to consist only of quiescent neutral hydrogen in two phases (cool cloud and warm intercloud gas) which were in pressure equilibrium (Field, Goldsmith and Habing 1969). As satellite-based telescopes were launched, this view had to be modified to include the hot X-ray emitting component, presumably supplied through supernova explosions (Cox and Smith 1974, McKee and Ostriker 1977). With continually improving observations, especially at non-optical wavelengths, we now see the ISM as complex and multi-phased as described above. However, far from quiescent, it is now understood to be frothy and seething, undergoing violent activity, and possibly experiencing outflows as gas is driven away from the disk into the halo region around it (e.g. Norman and Ikeuchi 1989, or papers in Bloemen 1991).

The realization that there is a dynamic disk-halo relationship in our own Galaxy crystallized with the discovery of expanding HI shells and supershells of kpc scale extending over the disk-haloboundary ("Heiles Shells"; Heiles 1979, 1984). Since this early work, other evidence for disk-to-halo outflows has accumulated, including expanding molecular (i.e. CO) shells in the Galactic Center region (Oka et al. 1995), and features over the disk in various wavebands which spatially correlate with the Heiles Shells (e.g. Koo et al. 1991; Waller and Boulanger 1993; Reach et al. 1993). The input energies implied by the HI shell masses (obtained from the luminosity of the spectral line) and expansion velocities (obtained by the Doppler shift of the spectral line) can be considerable --- energies up to ≈ 10^{55} erg are not out of the ordinary.

GALAXY OUTFLOWS

It has been known since the early days of radio astronomy that some galaxies experience outflows, but these outflows are in the form of narrow jets originating from "active galactic nuclei" or AGNs, most likely associated with a supermassive black hole at the galaxy's center. Although spectacular, such outflows were only seen in distant elliptical galaxies and were not observed in relatively nearby spirals. Since the 1980s, however, there have also been discoveries of (wider opening angle) bipolar outflows from the nuclei of spiral galaxies. Some of these nuclear outflows fall into the lower luminosity end of the AGN category, but not all. It appears that galaxies without AGN but which are experiencing strong nuclear "starbursts" can also produce a bipolar outflow.

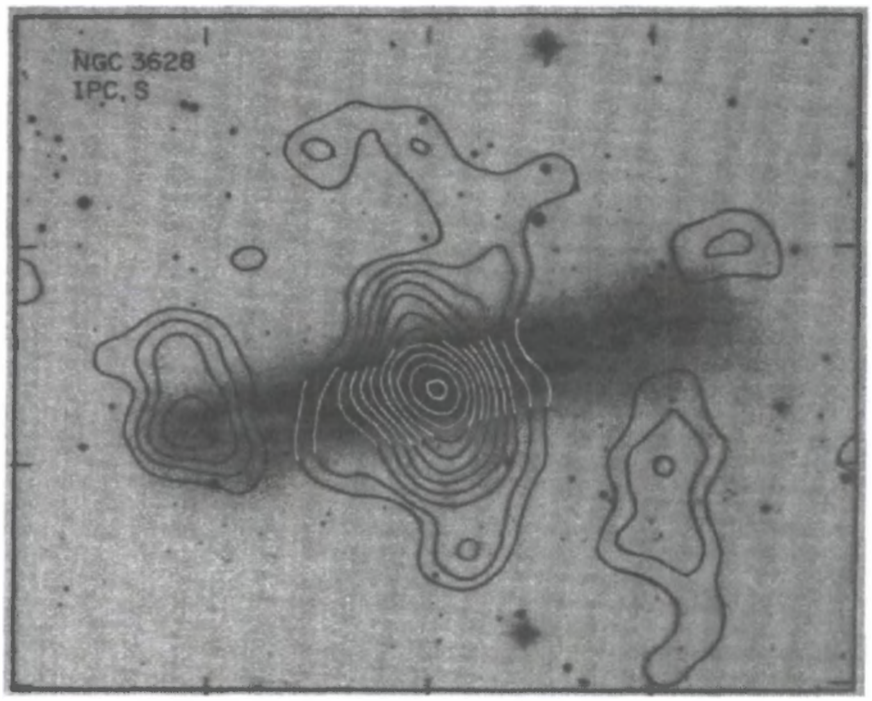

Fig. 2 **The edge-on nuclear starburst galaxy, NGC 3628, with optical emission shown in greyscale and overlaid contours depicting X-ray emission due to hot ionized gas. Adapted from Fabbiano et al. (1990), copyright American Astronomical Society, reproduced with permission.**

A starburst occurs wherever there is an unusually high massive (e.g. ≳ 5 → 8 $M_\odot$) star formation rate. Massive stars live for a relatively short (e.g. ≲ 10^7 years) time and end their lives in supernova explosions. Since the star formation process itself can occur over timescales longer than this, star births and star deaths can proceed at the same time. Star formation activity (and therefore supernova activity) can be enhanced in the nucleus if, for example, a passing companion galaxy perturbs the gas distribution, resulting in gas transfer towards the center. The build up of gas invokes accelerated star formation and a resulting "burst" of activity from the collective contributions of many individual supernova explosions. Given that initial outflow velocities from supernovae are of order 10,000 km s^{-1}, the consequences can be significant. In some cases, the result is bipolar nuclear outflow along the rotation axis of the galaxy as the hot ejecta takes the path of steepest decreasing pressure gradient away from the nucleus. A good example of bipolar outflow from a nuclear starburst is the galaxy, NGC 3628 (Fig. 2) in which the outflowing hot gas is visible as soft X-ray emission far from the plane. Starburst galaxies are more numerous than AGN in the nearby universe and potentially present us with a clearer view of the physical processes which are involved in driving such outflows.

The first clear evidence for outflows from the *disks* of spirals other than the Milky Way came from observations of NGC 3079 in which HI shells and supershells similar to the "Heiles Shells" of our own Galaxy were detected (Irwin and Seaquist 1990). There are now a number of other galaxies for which there is good evidence for disk-to-halo outflow. Of those displaying HI shells, the complete (but growing) list is still probably less than a dozen (see examples in Irwin 1995). This number increases if we also include galaxies which display radio continuum (from synchrotron emission) thick disks or halos (e.g. Hummel, Beck, and Dettmar 1991). A good example of a galaxy which displays both HI disk-halo arcs as well as a dramatic radio continuum halo is NGC 5775 (Fig. 3). The halo around this galaxy is so large (≈ 16 kpc radius in projection) that the galaxy resembles an elliptical in this waveband. At the same time, considerable structure is observed in the outflow features, potentially providing clues as to the mechanism(s) that formed them. These observations suggest that gas (both non-relativistic and relativistic) can be expelled from spiral galaxy disks where the star formation rates are considerably more modest than in the nuclei. The question arises, then, are the disk outflows also a result of processes related to massive star formation?

There is good evidence to suggest that the disk outflows are indeed related to starbursting, but starbursting alone does not appear to be sufficient to account for the observed features. In the Milky Way, some of the Heiles Shells do appear to be correlated with active sites of star formation and most of the theoretical work pursued to date has focused on modelling the structures expected from a rapid input of supernova kinetic energy (e.g. Tomisaka 1991). However, a difficulty arises when the largest HI shells are considered. Obviously, the input energy must be at least as high as the expansion energy of the shell (up to 10^{55} erg). When converted to the required number of input supernovae, the result can be more than 10^4. This stretches the starbursting scenario severely, since most associations of hot, supernova-producing stars in our own Galaxy are thought to contain < 10^2 stars, though some may be more populous. Moreover, even if the energy is available, large scale HI features can only be formed if the scale height of the disk is also unrealistically large (e.g. Heiles 1990). This "energy problem" has led some researchers to seek other explanations for the HI supershells.

In the Milky Way, there appear to be connections between a few outflow features and "high velocity clouds". These clouds form part of a cloud stream which stretches between the Milky Way and its nearby companion galaxies, the Magellanic Clouds, as a result of a tidal interaction. These connections, as well as the energy problem described above have led to the Cloud Impact model for the formation of HI shells in the Milky Way (see review by Tenorio-Tagle and Bodemheimer 1988), and now in other galaxies as well (e.g. NGC 4631, Rand and Stone 1995). As the name suggests, the HI supershells are formed from the impact of clouds onto the Galactic disk, in which case the shell energy is dictated by the infalling cloud mass and the infall velocity. This allows for much larger input energies since the infalling cloud can be a tidal shred from the interacting galaxy with an (almost) arbitrarily large mass. Of course, appealing to cloud impacts as the source of disk-halo supershells requires that the galaxy either be undergoing an interaction or at least have companions nearby as a potential source of external clouds.

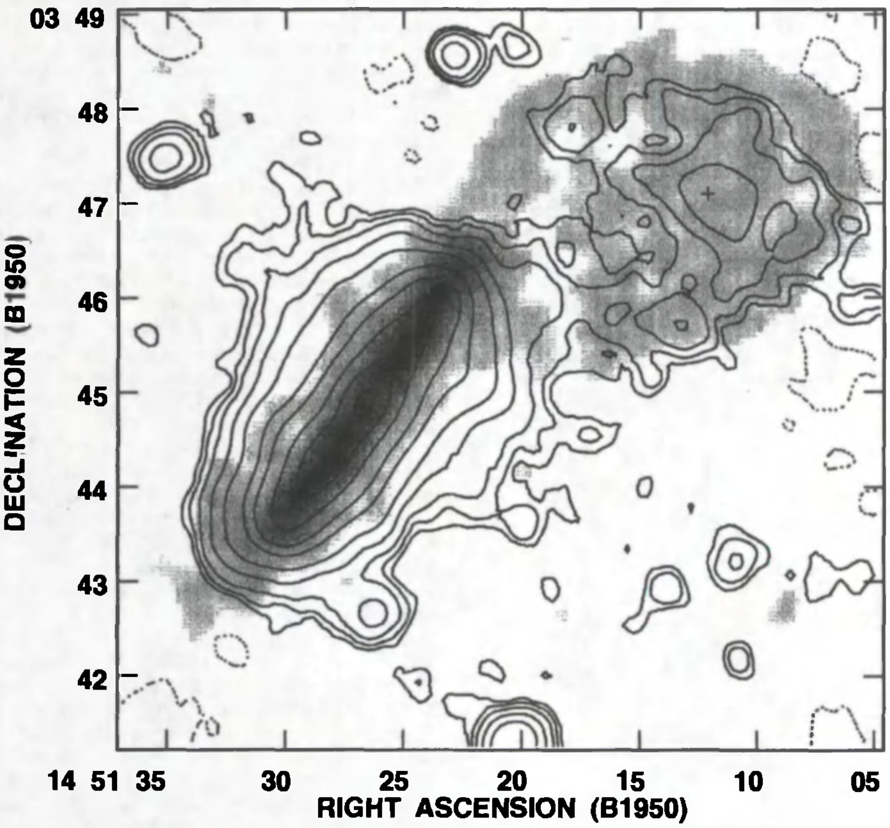

Fig. 3 The edge-on galaxy, NGC 5775, and its interacting face-on companion, NGC 5774, to the north-west (i.e. upper right). The centers of both galaxies are marked with crosses. Greyscale denotes the neutral hydrogen emission which is strongest in NGC 5775 along a narrow south-east to north-west path and corresponds roughly to the stellar disk of this edge-on galaxy. Fainter neutral hydrogen emission can be seen extending away from this disk in the form of arcs, plumes and extensions. Contours represent radio continuum emission from the synchrotron process, forming an extended flattened halo with considerable substructure.

Recent observations of HI supershells in two undisturbed, isolated spiral galaxies (Lee and Irwin, in preparation; Giguere and Irwin, in preparation) now indicate that the cloud impact model is an unlikely one for these galaxies. The star formation rates in these galaxies exceed that in our own, and it is therefore possible though not observationally proven that very large numbers of supernovae may also congregate in individual clusters. However, the difficulty in producing HI supershell structures remains. For example, in one case, the size of the HI shell is fully half the radius of the galaxy, far in excess of any reasonable scale height. It is therefore worthwhile to search for some additional source of energy, besides supernovae, to explain the observations. Perhaps the disk and halo are coupled in such a way that rotational shear can be converted into vertical motion. Further theoretical work, possibly in the realm of non-linear magneto-hydrodynamics (e.g. Parker instabilities), appears to be required.

THE SIGNIFICANCE AND CONSEQUENCES OF OUTFLOWS

While only a "handful" of galaxies showing evidence for outflows have so far been identified, I would contend that this is largely because of selection effects. It is important to observe galaxies which are highly enough inclined that the disk can in fact be separated spatially from the halo region around it. So far, few studies have systematically concentrated on galaxies with this orientation. Because the features tend to be faint, it is also necessary to integrate long enough to obtain good signal-to-noise. The radio continuum halo observed around NGC 5775 (Fig. 3), for example, was only detected by combining data from three separate observing sessions, for a total of 6 hours of on-source time using the Very Large Array (VLA) radio telescope near Socorro, New Mexico. Neutral hydrogen observations also tend to be time consuming, both in the collection and analysis of the data. A single galaxy requires an integration time of approximately 12 hours using the VLA and processing and analysis must proceed on "cubes" of data since a map is generated for every spectral channel. The rewards, however, are well worth the time investment. In a survey of 17 edge-on galaxies in the radio continuum, it was found that virtually *every* galaxy showed radio continuum extensions beyond the optical boundaries of the disk (Sorathia and Irwin 1995, in preparation; Sorathia 1994). It is entirely possible then, that at some level, outflows are a common characteristic of all spiral galaxies which are actively undergoing star formation.

What is the ultimate fate of the expelled gas? Does the gas cool and fall back to the disk again like a "Galactic Fountain" as first suggested some 20 years ago (Shapiro and Field 1976) or does it leave the galaxy altogether, flowing into intergalactic space? For galaxies like NGC 5775 (Fig. 3) the radio continuum emission extends so far from the plane (i.e. $\approx$ 16 kpc) that the halo resembles an oblate spheroid in projection. The existence of halo substructure far from the plane implies that dynamical processes are still at work at very large scale heights, suggesting that at least some mass loss is likely occurring. On the other hand, observations of X-ray emission from the hot halo of the galaxy, NGC 891, suggest that this thermal gas is bound to the galaxy (Bregman and Pildis 1994). Some galactic circulation models suggest that either scenario is possible, depending on the density of the ISM and the level of energy input (e.g. Norman and Ikeuchi 1989).

As yet, we have no direct observational measure either of mass loss or mass circulation rates from a galaxy disk. Some theoretical estimates place a mass loss rate for our own Galaxy of order $\approx 1\ M_\odot\ yr^{-1}$ (Völk 1991). Other galaxies are clearly experiencing higher star formation rates than the Milky Way, suggesting an upwards increase in the mass loss rate for them. If these estimates are correct, then over the course of a single galaxy rotation (a few x 10^8 years) the ISM, which contains a few times $10^9\ M_\odot$ could be significantly (i.e. at levels $\gtrsim$ 10%) depleted. After a dozen rotations, a naive extrapolation would have the ISM totally depleted. With less gas available to form stars, this alters our view of the star formation history of the galaxy and the global progression of star formation in various models. Indeed, our telescopic view of the galaxy, being dictated by the available starlight, is a product of these processes.

Apart from mass loss due to outflows, there is already a gas consumption "problem" in galaxies simply from the conversion of gas into stars (Larson, Tinsley, and Caldwell 1980). That is, if current star formation rates (as estimated from observations of star forming activity in galaxies) are assumed to be constant with time, then the same conclusion --- that the ISM will be depleted over timescales shorter than the age of the galaxy --- is reached. Additional mass loss from outflows only exacerbates this problem. While it is now more widely believed that star formation rates are not constant and may even undergo cycles of bursts, some researchers have suggested that the ISM must be continually supplied by some (as yet hypothetical) source of external accretion, for example primordial material left over from the epoch of galaxy formation (Pfenniger and Combes 1994; Pfenniger, Combes and Martinet 1994). Thus, a better understanding of the long-term effects of gas consumption and mass loss are required in order to address concerns of a cosmological nature.

If gas is being driven into intergalactic space, it is also of interest to consider what effects such outflows will have on the galaxian environment. Will these outflows dynamically affect their nearby neighbours, as suggested by observations of a companion to the galaxy, NGC 3079 (Irwin et al. 1987)? To what extent do these outflows enrich the intergalactic medium with heavy elements from supernova ejecta? Is this a source of hot intergalactic gas which is observed in some clusters of galaxies? Does this gas contribute to the intergalactic absorption lines (mostly Lyα) seen against background quasars (and closer objects)? The implications of such activity are only now being explored. It seems likely, however, that our view of spiral galaxies as the isolated stellar systems which grace the covers of textbooks may require substantial modification.

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III-V SEMICONDUCTOR CHARACTERIZATION FOR OPTOELECTRONICS

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ABSTRACT

Three of the specialized non-destructive characterization tools developed to monitor the advanced materials used in the fabrication of high speed optoelectronics are described, namely, scanning reflectance spectroscopy (sRS), scanning photoluminescence (sPL) and double crystal x-ray diffraction mapping (DCDM). Applications of these tools to the non-destructive assessment of III-V semiconductor composition, layer thickness and defect density are illustrated.

INTRODUCTION

While silicon, an elemental semiconductor from the fourth column of the periodic table, is the building block of today's electronics industry, semiconductor alloys with equal numbers of atoms from the third and fifth columns are playing a small but increasing role. Unlike silicon, these so-called III-V compound semiconductors readily emit light under electrical stimulation and so find use in a range of optoelectronic applications from high efficiency solar cells to the LED panel lights found on most pieces of high tech gear to the laser that reads your compact discs. They also typically have a higher intrinsic resistance and a higher electron velocity than silicon and so are favoured for the high frequency analog and high speed digital electronics in such items as satellite broadcast receivers, cellular phones and supercomputers. Device designers tailor the properties of the semiconductor compound for each application by using more than one group III or group V element in carefully controlled ratios, while maintaining the overall stoichiometry. To take advantage of the alloy's unique properties, it is frequently necessary to use a series of thin layers of different composition grown on top of a single crystal substrate. The thinnest of these layers can be only a small number of atomic layers thick. This article describes some of the challenges inherent in using III-V compound semiconductors in device fabrication and some of the methods that have been developed to monitor and help control their properties.

Consider the set of quaternary III-V alloys: $In_xGa_{1-x}As_yP_{1-y}$. These alloys are essential to today's fiber optic telecommunications systems, being used to make the necessary lasers, detectors and high speed signal processing circuits. By changing the ratio of indium to gallium and arsenic to phosphorous, an alloy can be selected with a specific combination of properties. The first challenge is to get the right ratios. If the systems design calls for a laser that emits at 1557 ± 5 nm, one of the preferred wavelengths for silica based fiber optics, the composition of the light emitting active layer, as described by the indium and arsenic mole fractions, x and y, must controlled to within ± 0.003. Unfortunately, most of the traditional assay tools, such as energy dispersive x-ray analysis, have accuracy quoted to the nearest 0.005. Even the most accurate methods have difficulty with the small sampling volumes (spot size a few millimeter in diameter, layers less than 5 micrometers thick). Therefore, knowledge of the absolute composition is given up in favour of more precise relative composition indicators. For this quaternary alloy, a convenient compromise is to measure the bandgap energy and the lattice constant of the material, which both vary in predictable ways with x and y. Only one composition will have a specific combination of both bandgap energy and lattice constant.

The bandgap energy is the separation between the highest ground state and the lowest excited state of the valence electrons in the semiconductor. Stimulated de-excitation of electrons across the bandgap creates the lasing photons the device designer is aiming for. Since the bandgap energy defines the laser wavelength and similar properties critical to other devices, knowledge of the bandgap is more important to optoelectronics design than knowledge of the composition which controls it. Luckily, bandgap energy is much easier to measure precisely using the optical methods described in the following sections.

In an analogous fashion, the lattice constant is also a more critical property for optoelectronic applications than the composition it depends upon. The lattice constant is the fundamental repeat distance of the crystal lattice, typically 0.5 to 0.6 nm. In the first step in the fabrication of a working device, semiconductors layers are grown on a single crystal substrate epitaxially, i.e. in such a way that the atoms in the layers line up with those in the substrate. If the lattice constant of the alloy is intrinsically larger or smaller than that of the substrate, then the crystal must distort tetragonally in order to match up in the plane of the growth interface. The distortion builds in strain. If the strain becomes too high, dislocations and other crystal defects are formed which ultimately degrade device performance. Some of the more advanced designs deliberately build in small amounts of strain to modify the electronic band structure of the material in advantageous ways. The thickness of the strained material must be kept low so that the total strain energy is insufficient to induce defect formation. For high performance devices with good reliability it is necessary to control the relaxed lattice constant of the layer relative to that of the substrate to better than one part in 10^3. The x-ray diffraction methods that are described in this article are used to detect minute differences between the lattice constant of the epitaxial layer and the substrate.

The second challenge inherent in using III-V compound semiconductors in device fabrication is to get the layer thicknesses right. For example, the multiplication layer of an avalanche photodiode is several microns thick. To control the breakdown voltage of such a device the thickness of this layer must be known to better than 2%. The waveguide layers of a laser are more difficult still, in that they are only a couple of hundred nanometers thick. The relative thickness tolerances are the same, plus the index of refraction must also be tightly controlled. The extreme case occurs in those devices where the active layer is a series of quantum wells, each only a handful of atomic layers thick. While thickness control is made somewhat easier since quantum wells only come in integer number of atomic layers (monolayers) thick, measuring the thickness of these thin layers requires innovative solutions. Optical methods have been developed that fill most of these needs.

The third major property that needs to be measured and controlled for successful device fabrication is concentration of the impurities added deliberately to change the conductivity of the layers. The concentrations of these dopants that make the difference between acceptable and unusable material can be on the order of 10^{15} cm^{-3} or a ppb. At present, few non-destructive methods exist for measuring the dopant concentration quantitatively, particularly in complex device structures. Those that partially fill the need are beyond the scope of this review[1].

The final item to be found on the list of critical properties for optoelectronic device manufacture is defect density. Defects, at the most basic level, are misplaced atoms: departures from the expected translation symmetry of the lattice or the incorporation of an unintended impurity atom. The more serious crystal defects must be avoided because they make the wafer more likely to break during handling. They can be detected by x-ray diffraction methods as described later. Both crystal defects and impurities are important because they are often associated with electronic states which change the concentration of free carriers and thereby alter the operating characteristics of the device. Techniques that probe the recombination of injected carriers are very effective monitors of the electrically active defect density as will be shown.

Over the past seven years, a number of scanning techniques have been developed in the Advanced Technology Laboratory at Bell Northern Research to meet the demand for rapid, non-destructive assessment of the substrates and epitaxial layers used in the optoelectronic and high speed electronic device manufacturing of its parent company, Nortel. Three of the techniques will be discussed: scanning reflectance spectroscopy (sRS), scanning photo-luminescence (sPL) and double crystal x-ray diffraction mapping (DCDM). The measurements are currently being performed by instruments designed and built for us by Waterloo Scientific, of Waterloo, Ontario.

THICKNESS BY SCANNING REFLECTANCE SPECTROSCOPY:

Scanning reflectance spectroscopy[2] makes use of optical interference to infer the thickness of an epitaxial layer and map its distribution across the wafer. In sRS, the relative intensity of infrared light reflected at normal incidence from the sample is measured as a function of wavelength *and* position. If the index of refraction of the top layer is sufficiently different from that of the material beneath it, then the total reflected light will be modified by constructive and destructive interference between light reflected at the top and bottom surfaces of the layer. The reflectance spectrum for a 3.0 μm thick layer of InP grown on a marker layer of $In_{.53}Ga_{.47}As$ is shown in Figure 1. The amplitude of the modulation is determined by the difference in the indices of refraction of the layer and the material below it; in this example the difference is 0.36 (~ 10%). The spacing of the extrema is related to the product of the thickness and index of refraction of the top layer. Thinner layers have more widely spaced extrema. Since the indices of refraction of the $In_xGa_{1-x}As_yP_{1-y}$ alloys are known to better than 1 part in 300 and the extrema positions can be determined from such a spectrum to an accuracy of 1 part in 1000, the thickness of the layer can be readily determined with an overall accuracy of better than 0.3%.

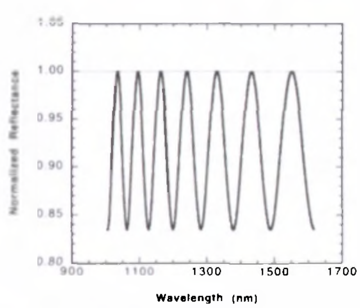

Fig. 1 Normalized reflectance plotted as a function of wavelength for a 3 μm thick layer of InP on a 3.5 μm thick layer of $In_{.53}Ga_{.47}As$. The reflected light spectrum of a bare InP substrate is used to normalize the data and thereby reduce system artifacts.

The thinnest layer that can be practically measured by reflectance spectroscopy has only one complete period in the spectral range covered by a single light source - detector pair. For the range shown in Figure 1, which corresponds to an InGaAs detector and a tungsten lamp, the thinnest measurable InP layer is ~ 300 nm thick. For thinner layers, measurements based on the polarization dependence of reflection, such as ellipsometry[3], are more appropriate. Multi-layer structures have more complex spectra, which may be thought of as the superposition of the reflectance spectra of each individual layer. They can be analyzed by iterative fitting to theoretical curves or by using a modified Fourier approach[4].

The spectra tell us the thickness of the layers at fixed points. To map the thickness variation by taking spectra at many points on the wafer is time consuming and, luckily, unnecessary. If the monitoring wavelength is fixed and the wafer scanned under the beam, then any variation in the product of index and thickness will appear as a change in reflectance. An example of such a reflectance map is shown in Figure 2a. Since the change in index of refraction across the wafer due to variation in composition or other factors is usually a hundred times or more smaller than the variation in epitaxial layer thickness, contours of equal reflectance correspond very well to lines of equal layer thicknesses. To convert the reflectance map into a thickness map, it is necessary to identify the thickness associated with each contour. The problem is not quite as daunting as it may seem. If one calculates the thickness of the layer for one point on each adjacent extrema on the map, it is possible to accurately interpolate the thicknesses for the contours between them. Figure 2b shows the resultant inferred thickness map. The pattern seen in Figure 2 is a result of gas flow patterns in the metal organic chemical vapour deposition (MOCVD) system used to deposit the layers. There are 41,000 valid data points on this map. Data acquisition and analysis took only 45 minutes. Very few other analytical methods provide this speed, resolution and accuracy non-destructively.

Fig. 2a The reflectance at a wavelength of 1000 nm is displayed for an InP layer grown on an $In_{.53}Ga_{.47}As$ marker layer. The red and blue fringes correspond to thicknesses of InP with reflectance extrema at the map wavelength. The InP substrate diameter is 50 mm.

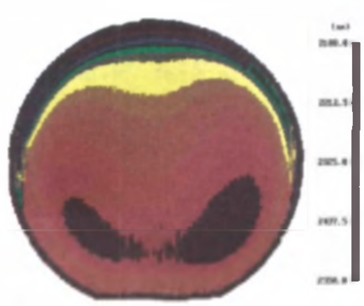

Fig. b: With the additional information inferred from at least one reflectance spectrum for each fringe, the sRS map can be translated to this thickness map. The characteristic pattern is due to the flow of reactants in the deposition chamber which enter at the top of this image.

BANDGAP ENERGY AND DEFECT MAPPING BY SCANNING PHOTOLUMINESCENCE

A convenient method for measuring the bandgap energy of a semiconductor is photoluminescence spectroscopy[5]. In photoluminescence, a low power laser is used to excite a ground state electron into the band of excited states. The electron rapidly loses energy to lattice vibrations until it reaches the lowest unoccupied excited state. It then drops back to the uppermost empty level in the band of ground states, giving up the excess energy in the form of a photon with energy roughly equal to the bandgap energy. The difference between the energy of the emitted photon and the true bandgap is very nearly kT, being simply related to how many of the states are already occupied by thermally excited carriers. The spectra at room temperature are broad in comparison to those familiar to atomic fluorescence spectroscopists, but are more than adequate to allow detailed maps of bandgap variation to be constructed.

Figure 3 is a scanning photoluminescence map of the bandgap energy distribution for a $In_xGa_{1-x}As_yP_{1-y}$ layer grown on InP. The 7,000 point map took 16 hours to acquire. The total range of the data is 40 meV, corresponding to a standard deviation in peak wavelength of 9 nm for the central 90% of the wafer. For a laser with a wavelength tolerance only 10 nm wide, this implies that only a maximum of 45% of the devices made from this wafer will be within specification. Notice that the pattern in Figure 3 is reminiscent to the thickness distribution seen in Figure 2. The gas vortices in the MOCVD chamber that lead to enhanced growth rate in the kidney shaped central region also lead to composition variation and thus bandgap energy shifts. This is confirmed when the sPL data is analyzed in conjunction with the x-ray diffraction data discussed in a later section.

Fig. 3: The peak energy of the photoluminescence emission is mapped for a $In_xGa_{1-x}As_yP_{1-y}$ layer deposited by MOCVD. As in Figure 2, the gas flow direction is top to bottom. The InP wafer diameter is 50 mm.

A novel application of bandgap energy mapping by sPL allows the measurement of the thickness of quantum wells[6]. One of the most dramatic effect of reducing the thickness of an epitaxial layer to below the quantum limit (20-30 nm) is a rapid increase in bandgap energy. As can be shown with simple particle-in-a-box models, which are surprisingly good approximations to the observed data, the increase is inversely proportional to the well thickness squared. Therefore if the composition of the well doesn't vary, maps of quantum well sPL energy can be directly interpreted in terms of variations in well thickness. When ternary or quaternary alloys are used as the well material, sPL energy data can still be used to map the well thickness as long as the structure includes a reference layer of the same nominal composition and of a thickness in excess of the quantum limit. Then the energy shifts due to composition variation (which show up in both maps) can be separated from those due to growth rate variation (which only show up in the quantum well map). An example of a nominally 14 monolayer (8.2 nm) thick $In_{.53}Ga_{.47}As$ quantum well grown by MOCVD is shown in Figure 4. Clearly defined regions appear with distinct energy shifts. The assignment of the bands to a specific number of monolayers is made on the basis of comparison to theory or a one time calibration with a destructive analysis method such as transmission electron microscopy. The quantum well thickness pattern is similar to that found by sRS for thicker layers.

Fig. 4 The quantum energy shift is mapped by subtracting the observed photoluminescence peak energy of a $In_{.53}Ga_{.47}As$ quantum well from that of a thick $In_{.53}Ga_{.47}As$ reference layer grown beneath it. Each band of distinct energy is assigned to a specific number of monolayers based on a separate calibration. The layers were grown by MOCVD on a 76 mm diameter InP wafer .

The intensity of the emitted photoluminescence is a function of the excitation rate and the rate at which the electron de-excite through alternative paths that do not involve the emission of a near bandgap photon. Surface states or mid-bandgap defect states frequently act as non-radiative de-excitation paths. If the excitation power is not so high that the density of photo-excited electrons exceeds the density of non-radiative centers, than any decrease in sPL intensity is directly related to the density of defects. Figure 5 shows an interesting example of a sPL intensity map measured under low excitation conditions. The wavelength was fixed to be near the peak of the sPL spectrum and the wafer was stepped 200 μm on center to build up a high spatial resolution map. The 48,000 point map took 35 minutes to acquire. At the cores of the conspicuous low sPL intensity regions were tiny specks of dust which had not been properly cleaned from the wafer prior to epitaxial layer growth. It is not uncommon to find with sPL that contamination spreads many millimeters away from its point of origin. Other sources of epitaxial layer defects have been found by this sensitive method, including: substrate defects, residues of cleaning chemicals and impurities in the gases used for growth. In many instances, the concentration of the impurities which have a dramatic effect on sPL intensity and aspects of device performance[7] was found to be at or below the detection limit of traditional impurity analysis methods (i.e. below 10^{16} cm^{-3}).

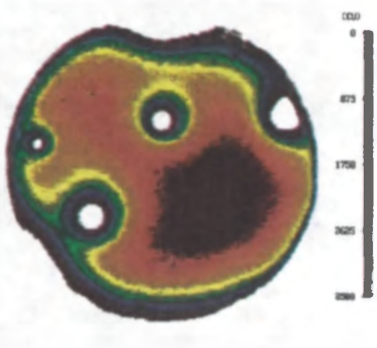

Fig. 5 The photoluminescence intensity at a fixed wavelength is mapped for a MOCVD grown $In_xGa_{1-x}As_yP_{1-y}$ layer. The sPL intensity is strongly reduced in the vicinity of particulates which were inadvertently introduced prior to growth. The InP wafer diameter is 50 mm.

DEFECT AND LATTICE CONSTANT MAPPING BY DOUBLE CRYSTAL X-RAY DIFFRACTION

The crystal perfection of the sample is most easily assessed by x-ray diffraction. If the interatomic plane spacing, the wavelength of the x-rays and the angle of incidence with respect to the crystal planes satisfy the well known Bragg diffraction condition, the x-rays diffract strongly from a single crystal sample. If there is any local deviation in the sample crystal plane orientation or spacing, the diffraction condition will not be satisfied and the detected x-ray intensity falls. Double crystal diffraction[8] is a variant of the classical method in which diffraction from a first crystal is used to reduce the divergence of the x-ray beam before it is diffracted from the test wafer. The measurement consists of monitoring the diffracted x-ray intensity as the sample is rocked through the optimal angle. The peak angle, intensity and the full width half maximum of the rocking curve are recorded. Although the actual angle corresponding to the peak intensity has limited meaning due to uncertainty in the instrument's true zero position, relative angle changes can be mapped with arc second precision and are used to quantify long range lattice curvature and the angular deviation across low angle grain boundaries[9]. This method is complementary to the higher spatial resolution topography methods where the wafer is imaged for a fixed rock angle[10].

In Figure 6 the peak full width at half maximum (fwhm) map of an average quality 76 mm diameter GaAs substrate is displayed. It was obtained by measuring rocking curves in a matrix of x-y points on a 750 μm grid over a 8 hour period. There are many high fwhm features, predominantly at the wafer periphery, but also running diagonally across the wafer. From the peak angle maps acquired at the same time, one can identify these elongated features as low angle grain boundaries where the lattice planes tilt by 10 to 30" with respect to one another. At those positions the rocking curves broaden or even split since the x-ray beam straddles the boundary. When the misorientation across these features is very large (> 50"), the mechanical strength of the wafer is compromised. Batches of substrates can be screened this way to eliminate those most likely to break.

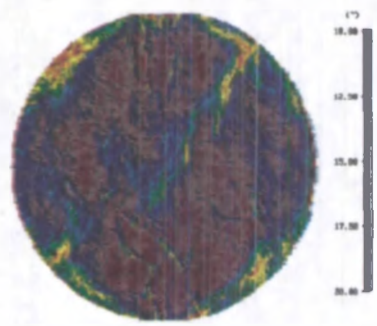

Fig. 6 The DCD fwhm is mapped for a commercial grade semi-insulating GaAs wafer grown by liquid encapsulated Czochralski. The regions of higher than normal fwhm correspond to low angle grain boundaries or other crystal defects. The wafer diameter is 76 mm.

DCDM is an important tool for the evaluation of epitaxial layers. When there are two different crystal plane spacings within the x-ray sampling volume (e.g. a not too thick, slightly mismatched layer on a substrate), the diffraction condition is satisfied at two different angles. The DCD rocking curve then shows two distinct peaks, whose separation is linearly related to lattice strain. Device engineers can examine DCDM peak separation maps and decide whether the strain is within acceptable tolerances. Alternatively, DCDM peak separation maps can be used to determine ternary alloy composition. The peak separation observed for an $Al_xGa_{1-x}As$ layer grown by molecular beam epitaxy (MBE) on GaAs is shown in Figure 7. The uniformity is quite good: the inferred composition is x = .304 ± .005. However the DCD map shows an edge-to-center variation that goes counter to expectations based upon flux distributions observed in the growth chamber. The central portion of the wafer has a higher than expected peak separation, corresponding to ~ 1% more aluminum in the alloy. The root cause was traced down to interactions with the substrate holder in the growth chamber. Due to the placement of the substrate heater and the high thermal conductivity of the holder, the holder is generally cooler than the wafer. Depending on the degree of thermal contact between the wafer and the holder, the center of the wafer can be up to 15°C hotter than the edge. Unfortunately, at the temperatures preferred for the growth of high quality $Al_xGa_{1-x}As$, a significant proportion of the gallium atoms striking the wafer surface re-evaporate. In the hot central zone even more gallium evaporates, locally enhancing the aluminum mole fraction. By redesigning the holder, this effect can be minimized.

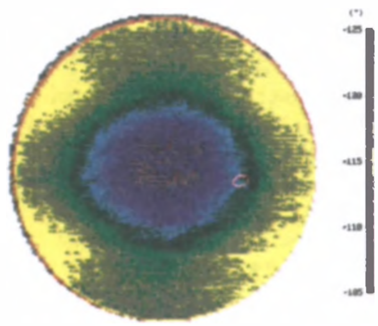

Fig. 7 The DCD peak separation is displayed for a $Al_{.3}Ga_{.7}As$ layer grown by MBE on GaAs. The central area of larger absolute peak separation was caused by enhanced gallium desorption during growth at a local hot spot. The wafer diameter is 76 mm.

For quaternary alloys, sPL peak energy data and DCDM must be combined to infer both the group III and group V mole fractions. With this data, for instance, it is possible to show that the downward energy shift shown in Figure 3 and the enhanced quantum well growth rate shown in Figure 4 are the consequence of enhanced arsenic incorporation (y increases by 0.015). The ratio of indium to gallium in the $In_xGa_{1-x}As_yP_{1-y}$ layers is largely unchanged across the wafer. Modifications to the growth chamber geometry and the use of substrate rotation reduce the non-uniformity by a factor of 2. In this way, the tight specifications on laser wavelength and lattice strain imposed by the application can be met.

SUMMARY

The techniques described here have proven to be essential to the development of the III-V compound semiconductors for a variety of optoelectronic applications. They have demonstrated the required accuracy and precision to monitor several of the key properties. They provide rapid feedback, so that it is possible to quickly adjust growth conditions to hit tight specifications. They are a definite improvement on the traditional approaches of growing calibration wafers for destructive analysis of a small number of selected points, or waiting until the devices are fabricated and tested (typically 3-6 weeks). These new techniques have been optimized for speed, to make high spatial resolution mapping practical. By studying the pattern of the properties measured on the wafer, it is frequently obvious why the variations have occurred and what measures should be taken to correct them. Because these tests are non-destructive, there is little reluctance on the part of manufacturing engineers to monitor frequently, a practice which has led to many unexpected discoveries about sources of non-reproducibility and non-uniformity. Without the insights that sRS, sPL and DCDM have provided, the job of developing advanced optoelectronics would have been much more difficult.

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THE EARLY HISTORY OF WOMEN IN UNIVERSITY PHYSICS: A TORONTO CASE STUDY

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One often finds, in discussions of women in the sciences, references to women's presence in "non-traditional" areas of study. The implication is usually that "traditionally" women were not to be found in the sciences generally, or in particular sciences such as physics. There is little truth in this idea.

That women have studied all of the sciences and have been involved in scientific work in all disciplines is increasingly demonstrated by a growing literature.[1] In Australia, as Marjorie Theobald has shown, science was part of the "women's studies" curriculum of women's schools and academies throughout the colonial period. A collection of essays dealing chiefly with modern Europe reveals women at work in the sciences, from the eighteenth century when much science was conducted in domestic or semi-domestic settings, to more recent times. A recent collection, edited by Marianne Gosztonyi Ainley, carries the story to Canada. While none of these studies suggests that it was easy for women to be scientists, the overall message of involvement is clear. Women have always been interested in science and studied it whenever and wherever they could manage to do so; and some women, in every period since the eighteenth century, have reached the highest levels of excellence in all areas of scientific endeavour. That science - even physics - is a "non-traditional" area for women is largely false.

How, then, did the idea develop? The story of women in physics at the University of Toronto is suggestive. Women appear to have studied physics at Toronto very soon after their admission to the university in 1884. By the early decades of the twentieth century, women were making their mark in graduate physics and earning doctorates as well as master's degrees in the field. In the 1940s, the Department of Physics even admitted several women into the professorial ranks and, shortly after the middle of the century, named its first woman full professor. The promise of the first half of the century was not fulfilled, however, in the second half.

The story of Elizabeth Rebecca Laird illustrates the early presence of women in undergraduate physics at Toronto. One of two sisters who gravitated to the study of science (Annie Laird moved from chemistry to household science and was the head of Toronto's household science department for 34 years) Elizabeth chose physics after her matriculation from London Central Collegiate and graduated from Toronto with honours in mathematics and physics in 1896. But the fact that she "had stood first for three years running" in her class did not win her the coveted fellowship that would have given her several years of graduate study abroad; this scholarship was designated, as the author of a newspaper obituary later described it, for a "he" not a "she."[2] Undaunted, Elizabeth Laird took a teaching post at the prestigious Ontario Ladies College at Whitby.[3] Within two years, a local newspaper was able to report that "Miss Lizzie R. Laird" was studying physics at Bryn Mawr College in Pennsylvania and had been granted a Mary Garrett European fellowship. This distinguished award, one of only two handed out annually, entitled its recipient to a year of study in Europe. Elizabeth's fellowship year must have been especially rewarding, for she worked with Max Planck in Berlin, just prior to his publication of "the papers that launched the quantum theory."[4] After the granting of her doctorate in 1901, Elizabeth Laird would teach physics at Mount Holyoke, a small New England college for women, heading the department there from 1903 until 1940. In that year she "retired" to more than a decade of further work, on a volunteer basis, at the University of Western Ontario, before her second retirement in 1953.[5]

That Elizabeth Laird was not alone as an early woman undergraduate in physics at Toronto we know from the story of Caroline Macdonald, a physics graduate who ultimately made her career as a missionary in Japan. Macdonald, the second woman to graduate in honours mathematics and physics at Toronto, earned her degree in 1901. Unlike Laird, Macdonald was offered a graduate fellowship. The efforts of J.C. McLennan to persuade her to accept the award were, however, unavailing. Perhaps, as Caroline Macdonald's biographer suggests, she foresaw that the path of a woman physicist in Canada would be difficult, but it is even more likely that "she was already committed in quite another direction." After a period working for the YWCA, this talented and dynamic woman moved to Japan where she became involved in settlement work and eventually in the Japanese labour movement.[6]

Nevertheless, women eventually did move into graduate study in physics at Toronto. An examination of the university calendars and directories reveals them,[7] as does Elizabeth J. Allin's brief history of the department, Physics at the University of Toronto, 1843-1980.[8] Vivian Ellsworth Pound was the first woman to earn a doctorate in physics at the university, receiving her degree in 1913. Pound lectured at Queen's from 1912 to 1917, when she evidently moved briefly into the world of business. But she returned to university science in 1922 when she found a position in mathematics at Buffalo. Like Elizabeth Laird, Vivian Pound may have been forced to leave Canada in order to pursue a career in university teaching and research. We know from American Men of Science [sic] (1961) that she remained at Buffalo and was promoted to full professor, retiring as Professor Emeritus in 1955.

In short order, other women followed Vivian Pound into doctoral studies in physics at Toronto. Their heyday came in the 1920s and early 30s. Between 1926 and 1933, six women were awarded Ph.Ds in physics: Mattie Levi Rotenberg, Elizabeth Cohen, Beatrice Reid Deacon, Elizabeth J. Allin, Florence M. Quinlan, and May Annetts Smith. Indeed, between 1900, when J.C. McLennan was granted U. of T.'s first Ph.D in physics, and 1933, when five physics doctorates were awarded, women constituted nearly one quarter of the 31 winners of this degree at Toronto. This percentage may have been considerably higher than the norm. As published statistics are by decade, rather than cumulative, comparisons cannot be exact. But we do know that, in 1930-31, when Canadian women's involvement in graduate study appears to have temporarily peaked, women earned slightly more than one-fifth of all master's degrees granted in all fields in Canada, but only seven percent of the doctorates.[9] For women to have been the recipients of over 20 percent of Toronto's first 31 Ph.Ds in physics must therefore be counted a singular achievement.

The success was shortlived. After 1933 women disappear from the lists of Toronto doctorates in physics, not to reappear for some time. Their disappearance cannot be attributed entirely to lack of mentorship, for the department, under J.C. McLennan and E.F. Burton, followed up its support of women students in physics with the granting of some teaching appointments. Even prior to 1920-21, a total of 25 women taught for the physics department at Toronto, although most were probably master's students and few taught for more than two or three years. One of these early assistants in physics, Annie Theresa Reed (B.A. 1897) was an exception to the rule. The calendars and directories list her as "Class Assistant in Physics" from as early as 1911 and into the 1930s, but by 1924-25 she also held the title "Secretary to the Physics Department," a role that she had evidently played for some time. Holding onto the latter position until 1946, Annie Reed became not just a fixture, but a force in the department, remembered fondly for her humour as well as her power.[10]

Towards the end of World War I, several women were promoted from assistantships to positions as demonstrators. One of the women who began teaching for the department at this time (earning her doctorate over a decade later) was Florence Quinlan. Quinlan was to carve out a special niche for herself teaching physics to household science and music students at the university and, like Reed, had a long career at Toronto. Nor was she alone, for she was soon joined in undergraduate teaching by another Toronto graduate, Kathleen Crossley (B.A. 1918). Crossley never obtained either a master's degree or the doctorate, but nevertheless taught at the university for more than three decades, to be "remembered by many generations of first year students" as the instructor who introduced them to physics.[11] The third woman who would spend her entire career teaching physics at the University of Toronto was Elizabeth Allin, who taught in various capacities from the mid-1920s, joining the staff as "Demonstrator and Research Assistant" in 1931, for a career that did not end until she retired in 1972.

Other women taught for the department, but none so continuously or for such long periods as Quinlan, Crossley and Allin, all of whom also received promotions into the professoriate in the early 1940s. The four women who perhaps came closest to having careers in physics at Toronto were May Annetts Smith, Beatrice Reid Deacon, Mattie Levi Rotenberg and Elizabeth Cohen, all women with Toronto Ph.Ds from the interwar years.

Continuing with her research and demonstrating work after her 1933 doctorate, May Annetts gave up any chance for a position at Toronto when she left for England to be married in 1936.[12] The stories of the other three women are more ambiguous. All three taught at Toronto for many years after their doctorates, but were never promoted beyond the rank of instructor.[13] Beatrice Deacon and Mattie Rotenberg may have experienced discrimination because they were married. During the first half of the twentieth century, elementary and secondary women teachers typically lost their positions on marriage; most women on university faculties were also expected - or asked - to leave when they tied the marital knot. Yet the University of Toronto was not consistent on this point. The biologist Norma Ford and the astronomer Helen Hogg were among several women scholars who managed to combine marriage and teaching at Toronto during this period, gaining both permanent positions and promotions.[14] Deacon and Rotenberg, it would appear, were not so fortunate. I have been able to discover next to nothing about Beatrice Deacon, except that she was active in teaching and research at Toronto until at least 1947-48 and was still a member of the Canadian Association of Physicists in 1952.[15] Mattie Rotenberg was perhaps a special case, as she eventually had many other irons in the fire. In addition to her ongoing physics teaching and her marriage, she gradually moved into broadcasting for the CBC and became deeply involved in Jewish education and philanthropy.[16]

It would be useful to know more about Elizabeth Cohen, the one single woman in this group of four women physicists who seems most likely to have wanted or needed a full-time career in science. Cohen's 1929 Toronto doctorate in physics was rewarded by a year of study in Britain (divided between the Universities of London and Bristol) and an instructorship, followed by an assistant professorship at Mount Holyoke during Elizabeth Laird's last decade as head of physics there. Financial problems forced a reduction in staff at the New England college, however, and Cohen returned to Toronto in 1935. There she worked for the department in various capacities, but without promotion, until the mid-1950s.[17] While I have discovered no evidence of anti-semitism working against Elizabeth Cohen or Mattie Rotenberg, it is not inconceivable that cultural and religious difference played some role in blocking their advancement, especially in the case of the unmarried Elizabeth Cohen.[18]

As we have seen, among the women who taught for the physics department, only Florence Quinlan, Kathleen Crossley, and Elizabeth Allin made it into the professorial ranks. Their promotion occurred in 1941-42, when the exigencies of war may finally have revealed the department's reliance on these women's work.[19] As Elizabeth Allin later recalled, all three felt "very lucky" to receive appointments as assistant professors - despite their several decades of service in the cases of Quinlan and Crossley, and the ten years or more that Allin herself had taught physics at Toronto.[20] In fact, the late 1930s had been trying years, especially for the women physicists. There were eleven men in the Toronto physics professoriate at Toronto by 1937, but no woman had yet joined them; indeed the Great Depression was used as an excuse to remove talented married women from the teaching ranks altogether.[21] And depression was followed by war. During the Second World War, several of Toronto's male physicists were seconded to various government and military jobs, leaving huge teaching loads for those who were left behind. Quinlan, Crossley, and Allin did receive their assistant professorships, but they certainly worked very hard for them. Elizabeth Allin, for example, taught classes as large as five hundred students, chiefly armed forces personnel who needed to learn the rudiments of radar.[22]

During the immediate post-war years, physicists at Toronto were anxious to get back to the research that had been laid aside in 1939 and very soon the graduate program doubled in size. But, of the women physicists, only Elizabeth Allin appears to have been involved in graduate teaching and research during this period. Part of a team that worked in the area of spectroscopy, she delivered papers at physics society meetings and was among those who were instrumental in founding the Canadian Association of Professional Physicists (later the Canadian Association of Physicists) in the late 1940s. As she recalled in interviews in 1991 and 1993, Elizabeth Allin wanted to talk to Canadians about her work. For all her interest in research that was done elsewhere - and she had studied at Cambridge with Ernest Rutherford, among other luminaries - Allin thought it wrong that Canadian physicists should meet each other chiefly at American conferences. As the secretary of the CAP, she worked hard to make the organization a success and was proud of the contribution she made to Canadian physics through this work.[23]

When Elizabeth Allin retired from teaching in 1972, she had earned the respect of her colleagues and been made a full professor. But, by then, she was the only woman remaining on faculty in an increasingly male department. In the two years, 1971 and '72, the university awarded 50 doctorates in physics. How many of these were women is unknown, but I suspect that, in general, the number of women doctoral candidates during the post-World War II years was not great.[24] More significant, perhaps, was the fact that no women were recruited to the professoriate during the years which Allin labelled "the years of affluence" between 1948 and 1969. As she noted in her history of physics at Toronto, by 1970 the department had a professorial staff "numbering between sixty and seventy" and the atmosphere had greatly changed.[25] The small department of less than a dozen professors that had made Elizabeth Allin and her colleagues feel so at home in the 1930s that "we felt as if we owned it,"[26] had expanded mightily. But it would appear that few women physicists had participated in this growth.

Recently, women have made a comeback as graduate students in physics at Toronto. There have been, moreover, struggles to hire and retain women faculty. The reasons that these struggles have proven so difficult and unproductive are complex and beyond the scope of the present account. What should be clear from this historical sketch of women in the physics department at Toronto, however, is that physics is far from a "non-traditional" subject for women in Canada. Indeed, during the early decades of Toronto's development as a research university, women were very much present, demonstrating their talents as both undergraduates and graduate students in the field. Some were even admitted to the teaching ranks although, with the possible exception of Elizabeth Allin, they appear not to have been given the same opportunities at Toronto as men. If physics came to be seen as "traditionally" not a women's subject, this was a development belonging more to the second, than the first half of the twentieth century. It appears to have been attitudes that developed, and changes in the culture and conduct of physics that occurred during the expansionist period after World War II, that gave rise to the false impression that, with rare exceptions, women were not at home in the subject.

We need to know more about women like Elizabeth Laird, Elizabeth Allin, and their less well-known female colleagues. What were the forces that made it possible for some women to succeed in physics, when others - especially in subsequent generations - would find it so difficult? We need, especially, to look carefully at how physics, at Toronto and elsewhere, changed during the decades following the Second World War, for it was in these decades that the cultures and structures that govern contemporary physics were largely created. Even this brief appraisal of the blocked careers of many of Toronto's early women physicists suggests that we should not focus on gender alone when making these explorations. Considerations of gender may well have been complicated by marital status, ethnicity, and religion - not to mention race, class and sexual preference. The records rarely speak directly to these issues; nor are we necessarily at ease with them. Thus answers to the question of why Elizabeth Allin's female colleagues did not manage to move up through the ranks, as she did, may always largely elude us. But it is important to ask this question nevertheless. For an examination of the lives of these women physicists alerts us to the kinds of constraints that may continue to block the advancement of women in university physics in our own time, as well as to the complexity of the prejudices and fears that prevent us from overcoming them.

We cannot change the past, but we can try to learn from it and, in the case of the early history of women in physics at the University of Toronto, there is some reason to be encouraged. That women earned nearly one quarter of the Ph.D's in physics that were awarded by Toronto in the first third of the 20th century is an important fact. Equally important is the fact that several of them, including at least one who did not have a doctorate, were able to work in physics at Toronto during the middle years of the century, although their jobs were sometimes insecure and almost invariably low-paying. Finally, there is the encouraging fact that one of them, Elizabeth Allin, had a well-recognized and successful career, despite the apparently less welcoming climate for women physicists at Toronto during the years that followed.

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3. At the time, a number of Ontario women's colleges offered courses equivalent to the first year of study at a university. OLC was one of several Methodist institutions for young women which had an affiliation with Victoria College and could prepare its students for advanced standing at the University of Toronto. See Johanna Selles-Roney, "'A Realm of Pure Delight': Methodists and Women's Education in Ontario, 1836-1925," (Ed.D Dissertation, University of Toronto, 1992).

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5. Newspaper clippings cited above. See also University of Toronto Archives, Clippings Collection, A73-0026/214(10) 'Noted Physicist Plans Her Second Retirement," The Globe and Mail June 26, 1953. Laird's research during the war was chiefly on radar; after the war she worked on "the effect of microwave radiation...on biological materials." Previously, she had worked in a variety of areas, publishing approximately 30 papers during the course of her career. One official listing, appearing to date from the mid-1930s, reveals that the majority of those published before 1935 were in the prestigious journal, Physical Review. The same account noted that Laird was a Fellow of both the American Physical Society and the American Association for the Advancement of Science. See clipping entitled "Physics" Mount Holyoke College Archives, Elizabeth R. Laird Papers.

6. Margaret Prang, A Heart at Leisure from Itself: Caroline Macdonald of Japan (Vancouver: University of Vancouver Press, 1995), especially chapter 1. Caroline Macdonald stayed in contact with her physicist friends, however, and later years would see her appealing to E.F. Burton, Toronto's head of physics from 1932 to 1948, for assistance in her efforts to raise money in Toronto for her Japanese mission.

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8. Published by the Physics Department in 1981.

9. Alison Prentice, et al, Canadian Women: A History (Toronto: Harcourt Brace Jovanovich, 1988) Table A.20, p. 428. Although data available for 1945-46 show the percentage of doctorates granted to women increasing to 11.5 in that year, the statistics by decade indicate a general dropping off after 1930-31, in both degrees, with women not reaching these percentages again until the 1960s or exceeding them until 1970-71.

10. University administrative records show Reed earning money typing for the department as early as 1906, and in various years prior to 1924-25 there are items recording her pay for stenographic and secretarial work. Reed was part of a trend, for it appears to have been during the second and third decades of the 20th century that University of Toronto faculties and departments began to add secretaries to their staff complements, often choosing top women graduates for these positions. Professor Dorothy Forward was one University of Toronto scientist who resisted such an offer, instead moving on to graduate study and a research and teaching career. See Alison Prentice, "Bluestockings, Feminists, or Women Workers? A Preliminary Look at Women's Employment at the University of Toronto," Journal of the Canadian Historical Association (1991) 243, 250 and 256. For a brief discussion of Annie Reed's importance to the department, see Allin, Physics at the University of Toronto, 10.

11. Allin, Physics at the University of Toronto, 11.

12. University of Toronto Archives, Newspaper Clippings Collection, A73-0026/009(68) Telegram, 6 October 1936. May Annetts' student card (UTA, A73-00261/009(68) shows her departure from England, followed by many more moves to various Canadian cities, moves which must have made the pursuit of her physics career difficult. Alyson King has nevertheless discovered one reference to her in the calendars of McGill, where she is listed in 1955-56 as a sessional lecturer in agricultural physics at Macdonald College.

13. Assistants and demonstrators appear to have been the lowest ranked appointments, followed by instructor, lecturer, and the various professorial ranks. Presumably only the professorial appointments carried tenure.

14. Both Hogg and Ford were married to Toronto professors, as was Mossie May Kirkwood (Professor of English and Dean of Women at University College and, later, Trinity). Yet Kirkwood felt some discrimination because of her marriage. See Prentice, "Bluestockings," 256-57; Alison Prentice, "Scholarly Passion: Two Women Who Caught It," in Alison Prentice and Marjorie R. Theobald, eds., Women Who Taught: Perspectives on the History of Women and Teaching (Toronto: University of Toronto Press, 1991), especially 269-72.

15. University of Toronto Directories; C.A.P. membership list, Physics in Canada, Supplement to Volume 8, No. 2 (Winter 1952). I am indebted to Alyson King, who searched the directories and other records to document the careers of Toronto's women Ph.Ds in the 1940s and beyond.

(continued on page 100)

USING NONSEXIST LANGUAGE

by Ruth King, York University

Many changes are necessary for women to achieve equality and visibility in society. Considerable research has shown that language plays an important role in constructing social reality and that sexist language has negative effects for girls and women. For instance, Briere and Lanktree (1983) found that women rated a career in psychology as more or less attractive in direct proportion to the use of nonsexist or sexist language in the career description. When gender-exclusive language was used, women were less interested in the career. Dayhoff's 1983 study of evaluations of women running for political office found that the use of sexist language in the campaign literature resulted in female candidates being more negatively stereotyped. Crawford and English (1984) found that women students recall information more efficiently when gender-inclusive terms such as *people*, *his/her* and *he/she* are used. The scholarly literature, then, shows that the idea that language use is a trivial matter is incorrect.

Forms of linguistic sexism include the treatment of male-as-norm (e.g. *Each candidate should include three copies of his résumé with the application*), irrelevant reference to gender (e.g. *That woman physicist is really smart*), irrelevant reference to physical appearance or to domestic relationship (e.g. *Jane Smith, wife of the well-known lawyer, Stephen Smith...*), and inappropriate forms of address (e.g. *Could you get me a copy of that report, dear?*). Linguistic sexism goes beyond word choice and what information is included: for instance, research by Nancy Henley et al (1995) shows that the use of the passive voice in news media reports of violence against women leads readers to take the violence less seriously.

Here are some suggestions for using nonsexist language, in writing and speaking. While I identify some problematic practices and suggest some solutions, I suggest that the reader consult a comprehensive set of guidelines that offers a fuller discussion of the issues.

(1) Use parallel forms of reference for women and men. For example, do not cite a male scholar by surname only and a woman scholar by first name plus surname; do not use a title to refer to or address a male colleague but refer to or address a female coworker by first name. In English, use *Mr* as a title for males and *Ms* as a title for females, unless you are certain that a woman prefers a title which indicates marital status (*Miss* or *Mrs*).

(2) In English, avoid so-called masculine generics such as the pronoun *he* (*his*, etc.) with sex-indefinite antecedents or man and its compounds (except in unambiguous reference to males). In French, avoid *l'homme* and *les hommes* (except in unambiguous reference to males).

(3) In French, avoid so-called generic occupational titles (*avocat*, etc.). Use masculine ones when referring to a man and their feminine equivalent when referring to a women (*avocate*). When sex is indefinite, use both (*les étudiants et les étudiantes de la première année, les étudiant(e)s*, etc.) Feminine equivalents for masculine titles follow the regular grammatical rules of the language. Avoid compounds with *femme* (*femme médecin*, etc.) which have the same connotations as English compounds with *lady* or *woman*.

(4) In both French and English, avoid using genuine generics as if they refer only to males (e.g. *Many immigrants come to Canada each year. Their wives have little access to language training.; On peut utiliser le langage pour beaucoup de raisons - discuter avec sa femme*).

L'UTILISATION D'UN LANGAGE NON-SEXISTE

par Ruth King, York University

Il reste plusieurs changements à faire pour que les femmes atteignent l'égalité et la visibilité qui leur revient. Plusieurs recherches ont démontré que le langage joue un rôle important dans l'établissement de la réalité sociale et qu'un langage sexiste a des effets néfastes pour les jeunes filles et les femmes. Par exemple, Brière et Lanktree (1983) ont trouvé que les femmes ont considéré une carrière en psychologie comme étant plus ou moins intéressante selon qu'un langage non-sexiste ou sexiste a été utilisé dans la description de l'emploi. Les femmes étaient moins intéressées par la carrière lorsque le texte n'employait que le genre masculin. En 1983, l'étude de Dayhoff concernant l'évaluation de candidates à des élections en politique, a démontré que l'utilisation d'un langage sexiste dans la documentation de leurs campagnes faisait en sorte que les candidates étaient stéréotypées plus négativement. Crawford et English (1984) ont trouvé que les étudiantes se rappellent plus efficacement de l'information quand une terminologie inclusive, comme personnes, leur, et il/elle, est utilisée. Donc, la littérature nous démontre que l'utilisation d'un langage est importante.

Des formes de sexisme linguistique incluent l'utilisation du genre masculin comme norme (e.g. Chaque candidat doit soumettre trois copies de son curriculum vitae avec son application), une référence superflue au sexe (e.g. *Cette femme médecin est très intelligente*), une référence superflue à l'apparence physique ou à la relation domestique (e.g. *Aline Robert, femme du célèbre avocat, Stéphane Robert...*), et des formes d'adresse qui ne sont pas appropriées (e.g. *Pourrais-tu me chercher une copie de ce rapport, chérie?*). Le sexisme linguistique n'existe pas seulement dans le choix des mots et dans l'information incluse: par exemple, la recherche de Nancy Henley et al (1995) indique que l'utilisation de la voix passive dans les rapports médiatiques sur la violence contre les femmes amène les lecteurs à considérer cette violence comme étant moins sérieuse.

Voici quelques suggestions pour l'utilisation d'un langage non-sexiste, en écriture et dans la langue parlée. Quoique j'identifie ici quelques habitudes problématiques et quelques suggestions, je vous suggère de consulter un guide complet qui examine plus en profondeur ce sujet.

(1) Utiliser des termes de référence parallèle pour les hommes et les femmes. Par exemple, ne pas citer un scientifique seulement par son nom de famille et une scientifique par son prénom avec son nom de famille. Ne pas vous adressez à un collègue par son titre en même temps que vous vous adressez à une consoeur par son prénom. En anglais, utiliser *Mr.* comme titre pour les hommes et *Ms.*pour les femmes, à moins que vous soyez certain qu'elle préfère un titre qui indique son statut marital (*Miss* ou *Mrs.*).

(2) En anglais, éviter les titres masculins, soi-disant générique, comme le pronom *he* (*his, etc.*) avec des antécédents de genre indéfini ou *man* (sauf quand c'est une référence non-ambigue à un homme). En français, éviter *l'homme* et *les hommes* (toujours sauf si la référence est à un homme).

(3) En français, éviter les titres d'occupation, soi-disant générique, (*physicien, avocat*, etc.). Utiliser les titres masculins en référant à un homme, et l'équivalent féminin en référant à une femme (*physicienne, avocate*, etc.). Quand le sexe est indéfini, utiliser les deux (*les étudiants et les étudiantes de la première année, les étudiant(e)s*, etc.) Les titres féminins suivent les mêmes règles grammaticales de la langue que les titres masculins. Éviter les composés avec le mot *femme* (*femme médecin* etc.), qui ont les mêmes connotations que les composés en anglais *avec lady* ou *woman*.

(4) Dans les deux langues, éviter l'utilisation de vraies expressions génériques comme si elles ne référaient qu'aux hommes (On peut utiliser le langage pour beaucoup de raisons - discuter avec sa femme, par exemple; Many immigrants come to Canada each year. Their wives have little access to language training).

(5) In English, avoid adding modifiers or suffixes to nouns that mark sex unnecessarily (e.g. *woman professor, stewardess*). (In French, the tendency is the opposite; feminine equivalents are preferred.)

Finally, it is important to bear in mind that sexist ideas dressed up in nonsexist language remain sexist. For example, using *"the worker...he or she..."* and *"the researcher...he or she..."* may, in some cases, be an adequate linguistic solution, but unless women's work and women's needs are discussed in the documents concerned, those documents remain sexist.

REFERENCES

1. Briere, John and Cheryl Lanktree. 1983. "Sex Role Related Effects of Sex Bias in Language" Sex Roles 9:625-32

2. Crawford, Mary and Linda English. 1984. "Generic Versus Specific Inclusions of Women in Language: Effects on Recall." Journal of Psycholinguistic Research 13:373-81

3. Dayhoff, Signe. 1983. "Sexist Language and Person Perception: Evaluation of Candidates from Newspaper Articles." Sex Roles 9:527-38

4. Henley, Nancy, Michelle Miller and Jo Anne Beazley. 1995. "Syntax, Semantics and Sexual Violence: Agency and the Passive Voice." Journal of Language and Social Psychology 14:60-84

Additional references regarding gender-neutral language

Talking Gender - A Guide to Nonsexist Communication, Ruth King, Copp Clark Pittman Ltd, Toronto, 1991.

Pour un genre à part entière: Guide pour la rédaction de textes non-sexistes, Ministère de l'éducation du Québec, Québec, 1988.

(5) En anglais, éviter l'ajout de modificatifs ou de suffixes aux noms qui indiquent le sexe de façon superflue (e.g. *woman professor, stewardess*). En français, la tendance est le contraire; en général l'équivalent féminin est préféré.

Enfin, il est important de rappeler que les idées sexistes enrobées de paroles non-sexistes demeurent sexistes. Par exemple, en utilisant *"le physicien ou la physicienne... il ou elle... et "le/la président(e)... il elle..."* on trouve une solution adéquate au problème linguistique, mais à moins que le travail et les besoins des femmes soit discuté dans ces documents, ces derniers demeurent sexistes.

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1. Briere, John et Cheryl Lanktree, 1983. "Sex Role Related Effects of Sex Bias in Language" Sex Roles 9, 625-32.

2. Crawford, Mary et Linda English, 1984. "Generic Versus Specific Inclusions of Women in Language: Effects on Recall." Journal of Psycholinguistic Research 13, 373-81.

3. Dayhoff, Signe, 1983. "Sexist Language and Person Perception: Evaluation of Candidates from Newspaper Articles." Sex Roles 9, 527-38.

4. Henley, Nancy, Michelle Miller et Jo Anne Beazley, 1995. "Syntax, Semantics and Sexual Violence: Agency and the Passive Voice" Journal of Language and Social Psychology 14, 60-84.

Des références additionelle concernant le langage non-sexiste.

Talking Gender - A Guide to Nonsexist Communication, Ruth King, Copp Clark Pittman Ltd, Toronto, 1991.

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RENDERING THE CAP BY-LAWS GENDER-NEUTRAL

by D. Poirier, INRS-Énergie et Matériaux

Original Text	Possible modification	Final Version
"An applicant for membership may be admitted as an affiliate if either	"An applicant for membership may be admitted as an affiliate if either	"An applicant for membership may be admitted as an affiliate if the applicant either
(a) he does not fulfil the requirements for membership as given in Section 2 but does possess a degree of Bachelor of Arts, Bachelor of Science, or an equivalent degree or diploma from a recognized institution;	(a) he or she does not fulfil the requirements for membership as given in Section 2 but does possess a degree of Bachelor of Arts, Bachelor of Science, or an equivalent degree or diploma from a recognized institution;	(a) does not fulfil the requirements for membership as given in Section 2 but does possess a degree of Bachelor of Arts, Bachelor of Science, or an equivalent degree or diploma from a recognized institution;
or	or	or
(b) he holds professional membership in an association acceptable for these purposes to the membership committee;	(b) he or she holds professional membership in an association acceptable for these purposes to the membership committee;	(b) holds professional membership in an association acceptable for these purposes to the membership committee;
or	or	or
(c) he has such other qualifications as Council may from time to time decide."	(c) he or she has such other qualifications as Council may from time to time decide."	(c) has such other qualifications as Council may from time to time decide."
"The elected officers of the Association and the Immediate Past President shall constitute the Executive Committee of the Council, hereinafter called "The Executive". In the event that the Immediate Past President cannot serve he shall be replaced by the most recent Past President available."	"The elected officers of the Association and the Immediate Past President shall constitute the Executive Committee of the Council, hereinafter called "The Executive". In the event that the Immediate Past President cannot serve he or she shall be replaced by the most recent Past President available."	"The elected officers of the Association and the Immediate Past President shall constitute the Executive Committee of the Council, hereinafter called "The Executive". An Immediate Past President who is unable to serve shall be replaced by the most recent Past President available."

"The Executive Secretary or his nominee shall be empowered to sign the bank's form of settlement and release."

"If a Member desires to vote proxies, he shall receive a ballot on which the Executive Secretary shall *initial* the number of proxies authorized."

"All nominations whether made by the Nominating Committee or by individual members must be signed by two members sponsoring the nominee, who by his signature agrees to accept the nomination."

"Marked ballots must be enclosed in a plain unmarked envelope which must be sealed by the voting member and returned by mail to the Executive Secretary to reach him on or before May 30th."

"The Executive Secretary or his or her nominee shall be empowered to sign the bank's form of settlement and release."

"If a Member desires to vote proxies, he or she shall receive a ballot on which the Executive Secretary shall *initial* the number of proxies authorized."

"All nominations whether made by the Nominating Committee or by individual members must be signed by two members sponsoring the nominee, who by his or her signature agrees to accept the nomination."

"Marked ballots must be enclosed in a plain unmarked envelope which must be sealed by the voting member and returned by mail to the Executive Secretary to reach him or her on or before May 30th."

"The Executive Secretary shall be empowered to sign the bank's form of settlement and release, and to delegate this authority."

"A Member desiring to vote proxies shall receive a ballot on which the Executive Secretary shall initial the number of proxies authorized."

"All nominations whether made by the Nominating Committee or by individual members must be signed by two members sponsoring the nomination, and also by the nominee, who thus accepts the nomination."

"Marked ballots must be enclosed in a plain unmarked envelope which must be sealed by the voting member and returned by mail to reach the Executive Secretary on or before May 30th."

LA MODIFICATION DE LA CONSTITUTION DE L'ACP POUR LA RENDRE NON-SEXISTE

par D. Poirier, INRS Énergie-Matériaux

Texte original

"Un candidat peut devenir membre affilié s'il remplit l'une des conditions suivantes:"

"Toute demande d'admission doit être faite au secrétaire exécutif à l'aide de la formule prescrite, ainsi qu'il est prévu ci-après, et indiquer la catégorie de membres à laquelle le candidat veut appartenir."

"Après avoir étudié les titres et qualités des candidats, le Comité d'admission doit:

(a) admettre le candidat dans la catégorie indiquée dans la demande;

ou
(b) demander au candidat de faire partie d'une autre catégorie;

ou
(c) informer le candidat des autres conditions qu'il doit remplir, conformément aux dispositions et normes énoncées à l'Article III."

Quatre directeurs représentent les diverses catégories de membres, à savoir:

un Directeur des membres élu par les membres titulaires de l'Association;

Modification possible

"Un(e) candidate(e) peut devenir membre affilié si il/elle remplit l'une des conditions suivantes"

"Toute demande d'admission doit être faite au/à la secrétaire exécutif(ive) à l'aide de la formule prescrite, ainsi qu'il est prévu ci-après, et indiquer la catégorie de membres à laquelle le/la candidat(e) veut appartenir."

"Après avoir étudié les titres et qualités des candidats et candidates, le Comité d'admission doit:

(a) admettre le/la candidat(e) dans la catégorie indiquée dans la demande;

ou
(b) demander au candidat ou candidate de faire partie d'une autre catégorie;

ou
(c) informer le/la candidat(e) des autres conditions qu'il ou elle doit remplir, conformément aux dispositions et normes énoncées à l'Article III."

Quatre directeurs(trices) représentent les diverses catégories de membres, à savoir:

un(e) Directeur(trice) des membres élu(e) par les membres titulaires de l'Association;

Version finale

"Toute personne peut devenir membre affilié si elle remplit l'une des conditions suivantes:"

"Toute demande d'admission doit être faite au secrétariat à l'aide de la formule prescrite, ainsi qu'il est prévu ci-après, et indiquer la catégorie de membres à laquelle la personne veut appartenir."

"Après avoir étudié les titres et qualités de chaque candidat(e), le Comité d'admission doit:

(a) lui admettre dans la catégorie indiquée dans la demande;

ou
(b) lui demander e faire partie d'une autre catégorie;

ou
(c) lui informer des autres conditions à remplir, conformément aux dispositions et normes énoncées à l'Article III.

La direction représentant les diverses catégories de membres comprend quatre postes, à savoir:

le poste de Directeur des membres élu par les membres titulairesd e l'Association;

un Directeur des membres affiliés élu par les membres affiliés de l'Association;

un Directeur-étudiant élu par les membres étudiants de l'Association;

et
un Directeur des membres corporatifs élu par les membres corporatifs de l'Association."

"Les mandats du président, du secrétaire-trésorier honoraire et des quatre directeurs sont d'une année. Le vice-président élu succède automatiquement au vice-président."

un(e) Directeur(trice) des membres affiliés élu(e) par les membres affiliés de l'Association;

un(e) Directeur(trice)-étudiant(e) élu(e) par les membres étudiants de l'Association;

et
un(e) Directeur(trice) des membres corporatifs élu(e) par les membres corporatifs de l'Association."

"Les mandats du président ou de la présidente, du secrétaire-trésorier honoraire ou de la secrétaire-trésorière et des quatre directeurs ou directrices sont d'une année. Le vice-président élu ou la vice présidente élue succède automatiquement au vice-président ou à la vice présidente.

le poste de Directeur des membres affiliés élu par les membres affiliés de l'Association;

le poste de Directeur-étudiant élu par les membres étudiants de l'Association;

et
le poste de Directeur des membres corporatifs élu par les membres corporatifs de l'Association."

"Les mandats des postes de président, de s.-t.h. et de direction sont d'une année. Le vice-président élu ou la vice-présidente élue succède automatiquement au vice-président ou à la vice-présidente."

The Early History of Women ... by A. Prentice **(continued from pg. 96)**

16. Rachel Schlesinger, "Volunteers for a Dream," Canadian Jewish Historical Society Journal 1, 1 (Fall 1988) especially p. 31. Mattie Rotenberg was active in Hadassah-Wizo, which is the subject of Schlesinger's article.

17. Cohen's career at Mount Holyoke left few traces in the Mount Holyoke College Archives, apart from notices of her appointment and eventual release from employment. There are occasional references to her, however, in the papers of Mildred Allen, her colleague in the physics department at the college. See also University of Toronto Archives, Newspaper Clippings Collection, A73-0026/064(17), "National Research Report 1930" for a brief account of her early research.

18. Stephen Speisman documents "the gradual intensification of anti-semitism in Ontario" from 1933 into the early years of World War II - just the period when Elizabeth Cohen and Mattie Rotenberg would have been trying to gain a foothold in physics at Toronto. See Speisman, "Antisemitism in Ontario: The Twentieth Century," in Alan Davies, ed. Antisemitism in Canada: History and Interpretation (Waterloo: Wilfrid Laurier Press, 1992) 125-29. See also Irving Abella, "Anti-Semitism in Canada in the Interwar Years," in The Jews of North America, ed. Moses Rischin (Detroit: Wayne State University Press, 1987).

19. University of Toronto Archives, Newspaper Clippings Collection, A73-0026/371(08) Telegram, 13 September 1941, "Made Professors at the University of Toronto." "Miss K.M. Crossley's work is in mechanics, hydrostatics and heat; Miss E. J. Allin is an authority on modern developments in physics, especially spectroscopy and problems having to do with the structure of the atom; Miss F. M. Quinlan is in charge of the teaching of physics to household science and music students." See also Allin, Physics, 34.

20. University of Toronto Archives, Oral History Collection, B93-0035, Karen Fejer's interviews with Elizabeth Allin, Toronto, May-June, 1993.

21. Elizabeth Allin refers to the pressure on married women to resign in Physics at the University of Toronto, 25. In a 1991 interview, Professor Allin was more forceful in expressing her view that bias against married women during the Depression was used as an excuse to "cut the staff" and "get rid of the women" at Toronto. Author's interview with Elizabeth Allin, Toronto, May 1991.

22. Allin, Physics at the University of Toronto, 30-34, and author's interview with Elizabeth Allin, May 1991.

23. Author's interview with Elizabeth Allin, May 1991; Karen Fejer's interview, May-June 1993.

24. Allin, Physics at the University of Toronto, Appendix 3, p. 77. Allin lists the recipients of doctorates by year, but only initials are given. To discover the exact numbers of women, one would need to go the university directories, as I have been able to do only for the years prior to 1940-41.

25. Allin, Physics, chapter 4 and p. 62. Not only had no women been hired, it would also appear that all of Allin's female colleagues had either retired or left the department by the end of the 1950s.

26. Author's interview with Elizabeth Allin, May 1991.

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mars/avril 1996

Physics and Education
La Physique et l'éducation

SOME WOMEN PHYSICISTS IN CANADA

Individual and Family Profiles

Featuring:

"The CAP 1994 Income Survey" by R.E. Green

"Women Physics Faculty in Canada" by J.B. Lagowski and J. McKenna

"Women Students in Physics in Canada: A Decade of Progress" by A.C. McMillan and E. Svensson

"WES-Women in Engineering and Science: A Canadian Success Story at NRC" by M. D'Iorio

"The Committee on the Status of Women in Physics of the American Physical Society" by L. Martinez-Miranda

Individual and Family Profiles of Women Physicists in Canada

Canadian Association of Physicists
Association canadienne des physiciens et physiciennes

Institutional Members // Membres institutionels
(Physics Departments // Départements de physique)

Acadia University
Bishop's University
Brandon University
Brock University
Camosun College
Carleton University
CEGEP Beauce-Appalaches
CEGEP de Chicoutimi
CEGEP Francois-Xavier-Garneau
Collège Jean-de-Brébeuf
Collège Montmorency
Concordia University
Dalhousie University
École Polytechnique
Lakehead University
Laurentian University
Le Petit Séminaire de Québec
McGill University
McMaster University
Memorial University of Newfoundland
Mount Allison University
Okanagan University College
Queen's University
Royal Military College, Kingston
Saint Mary's University
St. Francis Xavier University
Simon Fraser University
Trent University
University of Alberta
University of British Columbia
University of Calgary
University of Guelph
Université Laval
University of Lethbridge
University of Manitoba
Université de Moncton
Université de Montréal
University of New Brunswick
University of Northern B.C.
University of Ottawa
University of Prince Edward Island
Université du Québec à Chicoutimi
Université du Québec à Montréal
Université du Québec à Trois-Rivières
University of Regina
University of Saskatchewan
Université de Sherbrooke
University of Toronto
University of Victoria
University of Waterloo
University of Western Ontario
University of Windsor
University of Winnipeg
Wilfrid Laurier University
York University

* *

1996 Sustaining Members // Membres de Soutien 1996
(as at 1996 March 31)

A. John Alcock
H.R. Andrews
J. Brian Atkinson
C. Bruce Bigham
Bertram N. Brockhouse
Laurent G. Caron
Allan I. Carswell
Robert L. Clarke
Walter G. Davies
Gerald Dolling
Gordon W.F. Drake
Earl J. Fjarlie
Brian C. Gregory
Geoffrey C. Hanna
Elmer H. Hara
Akira Hirose
Roger Howard
David D. Isaak
Thomas E. Jackman
Allan E. Jacobs
J. Larkin Kerwin
James D. King
Ron M. Lees
Roger A. Lessard
A. David May
Jasper S.C. McKee
Ann C. McMillan
Jean-Louis Meunier
Elizabeth J. Nicol
Allan A. Offenberger
Roger Philips
Satti Paddi Reddy
Beverly E. Robertson
Lyle P. Robertson
John M. Robson
Donald W.L. Sprung
Alec T. Stewart
Boris P. Stoicheff
Eric C. Svensson
John G.V. Taylor
Henry M. Van Driel
Paul S. Vincett
Erich Vogt

THE CAP 1994 INCOME SURVEY

by Ralph E. Green
Retired Member

The CAP received 417 responses to the 1994 Income Survey. There were 324 responses with a salary income , 51 with a pension income, 34 with a consulting income, and 52 with a scholarship income.

An overview of the salary income is provided by the histogram, which covers the 324 responses with a salary income. All the respondents did not provide a year of graduation. For those who did, the responses are analyzed in the following 20 tables.

Tables 1a to 1d show the results for the four sources of income. There were 316 responses with salary income, 47 with pension income, 33 with consulting income, and 50 with scholarship income. The salary data are analyzed in more detail in the following 16 tables.

Tables 2a to 2c show the results according to the qualifications of the respondents. There were 13 responses with a bachelor's degree, 25 with a master's degree, and 277 with a doctorate degree.

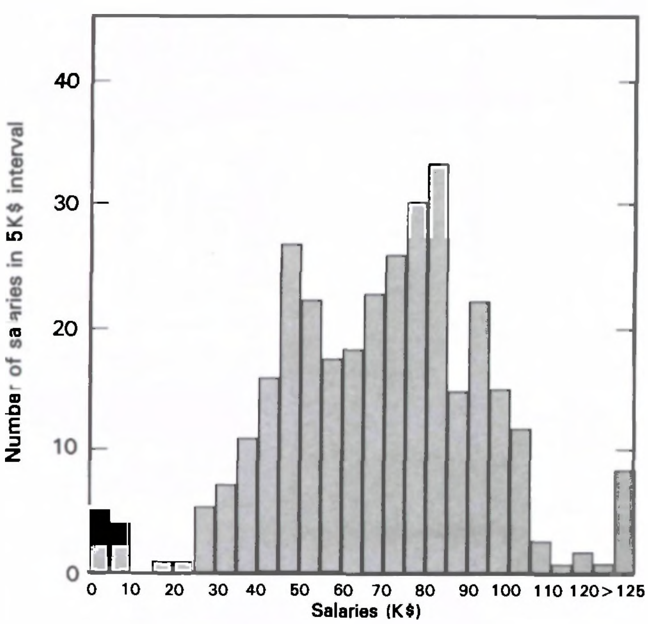
Tables 3a to 3e cover the areas of current employment. There were 186 responses from the academic sector, 66 from government agencies, 38 from industry, 9 from graduate students, and 13 from other areas.

Tables 4a to 4f cover the geographic region of employment. There were 29 responses from the Atlantic Provinces. 70 from Quebec, 122 from Ontario, 32 from the Prairie Provinces, 35 from British Columbia and the Territories, and 21 from outside Canada.

Tables 5a and 5b show the results by gender. There were 291 responses from males and 18 from females.

In each table, the medians and quartiles are given from five-year periods, based on the year of graduation with a Bachelor of Science degree. The final entry in a table covers the entire period of that table. The medians are not reported if there are less than three responses in period, to maintain confidentiality of the incomes. The quartiles are reported only if there are seven, or more, responses in a period.

The CAP wishes to thank all those who responded to the survey request, and welcomes suggestions for improving future surveys.



Histogram of 324 salary responses to the CAP 1994 Income Survey

TABLE 1a: SALARY INCOME

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
40-44	1		-	
45-49	3		75.0	
50-54	11	85.3	93.0	99.1
55-59	43	78.4	92.0	100.0
60-64	52	77.5	82.0	93.0
65-69	49	73.8	81.0	89.2
70-74	39	57.3	70.0	77.6
75-79	33	54.8	65.0	75.0
80-84	39	43.5	50.0	60.0
85-89	21	42.2	46.9	51.2
90-94	25	23.0	34.5	44.3
40-94	316	52.0	72.0	85.0

TABLE 1b: PENSION INCOME

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
25-29	1		-	
30-34	3		52.0	
35-39	1		-	
40-44	7	52.2	68.0	70.0
45-49	12	40.5	50.0	58.2
50-54	13	40.0	45.0	51.8
55-59	6		38.5	
60-64	2		-	
65-69	2		-	
25-69	47	40.0	48.0	57.9

TABLE 1c: CONSULTING INCOME

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
40-44	2		-	
45-49	3		3.0	
50-54	6		7.5	
55-59	5		4.5	
60-64	4		4.5	
65-69	4		8.5	
70-74	4		35.0	
75-79	1		-	
80-84	3		2.8	
85-89	1		-	
40-89	33	2.6	6.0	14.4

TABLE 1d: SCHOLARSHIP INCOME

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
75-79	1		-	
80-84	1		-	
85-89	7	13.8	15.0	17.6
90-94	41	13.0	16.0	20.0
75-94	50	13.0	15.6	19.2

TABLE 2a: QUALIFICATIONS: BACHELOR'S DEGREE

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
65-69	1		-	
70-74	1		-	
75-79	1		-	
80-84	1		-	
85-89	2		-	
90-94	7	3.5	20.0	33.2
65-94	13	17.0	40.5	58.8

TABLE 2b: QUALIFICATIONS: MASTER'S DEGREE

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
50-54	1		-	
55-59	1		-	
65-69	3		71.7	
70-74	3		52.0	
75-79	7	61.5	67.0	76.5
80-84	2		-	
85-89	3		46.0	
90-94	5		24.0	
50-94	25	40.0	52.0	71.8

TABLE 2c: QUALIFICATIONS: DOCTORATE DEGREE

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
40-44	1		-	
45-49	3		75.0	
50-54	10	85.0	92.9	96.6
55-59	41	78.8	91.0	99.2
60-64	52	77.5	82.0	93.0
65-69	45	75.0	82.0	89.2
70-74	35	66.2	70.0	79.5
75-79	25	54.0	62.5	74.2
80-84	36	43.0	50.0	60.0
85-89	16	42.5	48.3	52.0
90-94	13	38.6	44.0	47.6
40-94	277	54.0	75.0	86.7

TABLE 3a: CURRENT EMPLOYMENT: ACADEMIC

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
45-49	2		-	
50-54	9	85.8	93.0	97.4
55-59	36	81.5	92.0	98.0
60-64	37	80.0	85.0	95.2
65-69	23	75.0	82.4	93.8
70-74	18	60.0	70.0	76.5
75-79	14	54.0	61.8	74.0
80-84	25	41.8	50.0	53.5
85-89	11	41.0	46.0	50.8
90-94	11	24.8	31.0	41.5
45-94	186	53.0	76.0	92.0

TABLE 3b: CURRENT EMPLOYMENT: GOVERNMENT

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
45-49	1		-	
55-59	6		94.9	
60-64	14	74.0	77.6	80.4
65-69	12	70.8	77.5	84.0
70-74	11	67.5	69.0	71.0
75-79	9	64.2	67.0	71.2
80-84	7	52.5	60.0	62.0
85-89	1		-	
90-94	5		46.3	
45-94	66	62.0	70.0	79.0

TABLE 3c: CURRENT EMPLOYMENT: INDUSTRY

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
40-44	1		-	
50-54	2		-	
55-59	1		-	
60-64	1		-	
65-69	9	73.8	85.0	122.5
70-74	3		82.0	
75-79	5		80.0	
80-84	6		56.5	
85-89	5		46.0	
90-94	5		40.0	
40-94	38	45.0	60.3	85.0

TABLE 3d: CURRENT EMPLOYMENT: GRADUATE

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
65-69	1		-	
75-79	4		54.8	
90-94	4		2.5	
65-94	9	2.8	29.0	63.8

TABLE 3e: CURRENT EMPLOYMENT: OTHER

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
65-69	2		-	
70-74	6		66.1	
75-79	1		-	
80-84	1		-	
85-89	3		50.0	
65-89	13	50.0	55.0	84.2

TABLE 4a: EMPLOYMENT REGION: ATLANTIC PROVINCES

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
50-54	2		-	
55-59	5		83.0	
60-64	8	70.9	75.8	79.2
65-69	5		75.0	
70-74	3		70.0	
75-79	3		49.5	
80-84	3		42.0	
50-84	29	61.5	75.0	82.6

TABLE 4b: EMPLOYMENT REGION: QUEBEC

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
40-44	1		-	
50-54	1		-	
55-59	5		90.0	
60-64	8	81.5	82.0	83.0
65-69	11	71.1	80.0	84.0
70-74	13	65.9	75.0	80.5
75-79	9	53.5	60.0	72.8
80-84	9	48.0	53.0	61.6
85-89	8	48.0	51.0	56.5
90-94	5		40.0	
40-94	70	52.0	67.5	81.0

TABLE 4c: EMPLOYMENT REGION: ONTARIO

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
45-49	2		-	
50-54	1		-	
55-59	19	80.6	95.0	101.5
60-64	20	75.9	81.2	93.5
65-69	20	76.5	84.0	87.0
70-74	17	64.5	69.0	76.5
75-79	12	62.4	68.8	75.0
80-84	13	47.2	55.0	60.5
85-89	6	35.0	45.0	49.5
90-94	12	22.0	37.0	45.2
45-94	122	54.0	75.0	85.0

TABLE 4d: EMPLOYMENT REGION: PRAIRIE PROVINCES

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
45-49	1		-	
50-54	3		94.0	
55-59	4		94.0	
60-64	6		93.0	
65-69	4		116.0	
70-74	2		-	
75-79	4		67.5	
80-84	4		49.5	
85-89	1		-	
90-94	3		27.0	
45-94	32	48.5	76.1	95.0

TABLE 4e: EMPLOYMENT REGION: BRITISH COLUMBIA AND TERRITORIES

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
50-54	2		-	
55-59	8	67.6	92.7	100.0
60-64	6		87.8	
65-69	6		76.9	
70-74	2		-	
75-79	3		67.0	
80-84	5		50.0	
85-89	1		-	
90-94	2		-	
50-94	35	55.3	74.0	89.2

TABLE 4f: EMPLOYMENT REGION: OUTSIDE CANADA

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
50-54	2		-	
60-64	4		119.0	
65-69	2		-	
70-74	2		-	
75-79	1		-	
80-84	3		51.7	
85-89	4		48.3	
90-94	3		34.5	
50-94	21	46.7	80.0	128.6

TABLE 5a: GENDER: MALE

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
40-44	1		-	
45-49	3		75.0	
50-54	11	85.3	93.0	99.1
55-59	40	79.5	91.5	100.0
60-64	52	77.5	82.0	93.0
65-69	46	74.5	81.0	89.0
70-74	37	56.4	70.0	78.5
75-79	31	55.2	65.0	74.8
80-84	35	43.5	51.8	60.0
85-89	17	44.8	49.5	52.2
90-94	18	27.0	40.0	46.3
40-94	291	54.0	75.0	86.0

TABLE 5b: GENDER: FEMALE

Year of Graduation	Number	Lower Quartile (k$)	Median (k$)	Upper Quartile (k$)
65-69	3		85.0	
70-74	1		-	
75-79	1		-	
80-84	3		45.0	
85-89	4		42.5	
90-94	6		20.5	
65-94	18	34.5	45.0	60.0

WOMEN PHYSICS FACULTY IN CANADA

Summary of Results of a Survey Sponsored by the Canadian Association of Physicists

by Jolanta B. Lagowski, Dept of Physics, Memorial University of Newfoundland, St. John's, NFLD, A1B 3X7
and Janis McKenna, Department of Physics, University of British Columbia, Vancouver, BC, V6T 1Z1

INTRODUCTION

A recent international study(1) of women in physics showed that the representation of women in physics departments at the faculty level ranges widely - from a high of 47% in Hungary, 23% in France, Italy and Turkey, 6% in the Netherlands and New Zealand, to surprisingly low values of 3% in Korea and the U.S.A. Also, in general, as the educational degree level increases, the proportion of women in physics decreases.(2) This phenomenon is often referred to in the American literature as the "leaky pipeline".(2)

At the 1995 Canadian Association of Physicists (CAP) Congress hosted by Laval University in Quebec, an evening session on Women in Physics was arranged, and among the presentations were results of several surveys of women in physics. Several congress participants asked how Canada compares worldwide with respect to these statistics, as Canada was not listed in the international comparison study(1). Apparently, statistics have not previously been collected regarding the number of women in faculty positions in physics departments in Canadian academic institutions.

Sponsored by CAP, a simple survey was distributed in order to estimate the number of female faculty in Canadian physics departments. This survey was never intended to be as exhaustive as that performed by the Committee on the Status of Women in Physics (CSWP) of The American Physical Society, but it is a first attempt to present quantitative data on women physicists in Canada. A brief summary of the recent female physics graduates (at the B.Sc. and Ph.D. levels) is also given.

THE SURVEY

Early in the Fall of 1995, the CAP survey was sent to 63 physics departments in colleges, CEGEPs and universities in Canada, including all 54 CAP member physics departments. The CAP survey that was mailed to Canadian academic institutions is shown in Table 1.

TABLE 1: THE SURVEY MAILED TO CAP PHYSICS INSTITUTIONS.

1. Does your institute grant PhD's in physics? ______

2.a. How many students have received a BSc in physics from your department from 1993-95? ______

2.b. Of these BSc graduates, how many were female? ______

3.a. How many students have received a PhD in physics from your department from 1993-95? ______

3.b. Of these PhD graduates, how many were female? ______

4.a. How many faculty members are presently in your department? ______

4.b. Of these faculty members, how many are female? ______

4.c. How many tenured faculty members are presently in your department? ______

4.d. How many female tenured faculty members are presently in your department? ______

4.e. How many tenure-track faculty members are presently in your department? ______

4.f. How many female tenure-track faculty members are presently in your department? ______

4.g. If 4f + 4d does not equal 4b, or if 4c + 4e does not equal 4a, please state discrepancy.

5. If you have any comments on women in physics issues that you'd like to share with us, please feel free to include any comments.

Information supplied by: ______
Position: ______
Department of Physics,
University: ______
Phone: ______
Email: ______
Fax: ______

RESULTS AND DISCUSSION

A total of 40 responses to the survey were received in the late Fall of 1995; 25 were from PhD granting institutions, and 15 from non-PhD granting institutions. The survey data[1] are summarized in Table 2. No attempt was made to verify numbers that were provided to CAP. That is, percentages were tabulated based on the data given without changes or interpretation (e.g. numbers reported by the respondents as "approximate" were treated the same way as the more "accurate" numbers).

1. Some universities (2) did not supply data for B.Sc. graduates. The faculty total is not equal to the sum of tenured faculty plus tenure-track faculty due to the inclusion of visiting faculty positions, faculty with emeritus status, and part-time faculty positions which respondents listed as faculty, but neither tenured nor tenure-track faculty.

TABLE 2: SUMMARY OF SURVEY RESULTS ON WOMEN IN PHYSICS IN CANADA.
(Received From 40 Canadian Academic Institutions and Collected in the Fall of 1995.)

All Canadian Physics Departments

	Total Number (Men & Women)	Number of Women	Percentage Women
B.Sc. Graduates †	1613	284	18
Faculty	707	34	5
Tenured Faculty	621	12	2
Tenure-Track Faculty	76	21	28

† total number of degrees granted in the period 1993-1995.

Canadian PhD Granting Physics Departments Only

	Total Number (Men & Women)	Number of Women	Percentage Women
B.Sc. Graduates †	1453	261	18
Ph.D. Graduates †	336	44	13
Faculty	612	27	4
Tenured Faculty	539	8	1.5
Tenure-Track Faculty	65	18	28

† total number of degrees granted in the period 1993-95

The survey results show that in Canada, 18% of all recipients of a B.Sc. Degree in Physics, and 13% of all recipients of a Ph.D. Degree in Physics are female. 5% of all physics faculty members and 2% of tenured physics faculty members are women: the "leaky pipeline" trend is present in Canada, in fact very similar to the situation observed by our American colleagues in their country.

The percentage of women faculty at non-Ph.D. granting institutions is somewhat higher (7%) than in the Ph.D. granting institutions (4%). However, it is encouraging to see that approximately a quarter of all tenure-track faculty positions in the physics departments in Canada are currently held by women. It should be noted that tenure-track faculty members (of both gender) constitute only 11% of all physics faculty members.

In Table 3, results from a similar American survey [2] in 1994 are summarized for comparison with the Canadian survey results presented in Table 2.

The survey results also showed that of the forty Canadian academic institutions that responded, 80% of them have one or no woman faculty member, and almost a half of the responding institutions (45%) have no woman faculty member in their physics departments. While it is true that the smaller non-PhD granting institutions tend to have fewer physics faculty members, and hence fewer women faculty members, a very large fraction of them have no women faculty members at all (60%) and hence

(continued on page 112)

TABLE 3: SUMMARY OF RESULTS FROM AN AMERICAN SURVEY SIMILAR TO THE ONE PRESENTED HERE.

The American Study provided information on faculty rank (full, associate, assistant professor), which is approximately equivalent to the tenured and non tenured categories presented in Table 2 in this CAP study.

American PhD Granting Physics Departments Only

	Total Number (Men & Women)	Number of Women	Percentage Women
Faculty	4746	229	5
Assoc. & Full Prof.	3584	132	4
Asst. Prof.	592	60	10

Data are based on information in Reference 3.

TABLE 4: PERCENTAGE OF PHYSICS DEPARTMENTS WITH ONLY ONE OR NO WOMAN FACULTY MEMBER

Number of Women Faculty	All Canadian Physics Departments	Canadian PhD Granting Physics Departments	Canadian non-PhD Granting Physics Departments	American PhD Granting Departments*
none	45%	36%	60%	36%
none or one	80%	72%	93%	69%

* Statistics for American Physics Departments are from Reference 3.

WOMEN STUDENTS IN PHYSICS IN CANADA: A DECADE OF PROGRESS

by Ann McMillan, Atmospheric Environment Service, 4905 Dufferin St., Downsview, Ontario, M3H 5T4
Eric Svensson, AECL, Chalk River Laboratories, Chalk River, Ontario, K0J 1J0

INTRODUCTION

The CAP collected some data on graduate students in university physics as far back as 1983/84, from which it is possible to deduce the representation of women. Then, a decade ago, the CAP carried out a survey of Canadian university physics departments to estimate the proportion of physics students in Canada who were women. There was little Canadian data available at that time on physics, although Statistics Canada had data on engineering and physical sciences which could have included a rather different population. The results of that 1985/86 survey were presented at the CAP Congress in 1986 and put in context with representation of women in high school physics classes and in the ranks of practicing physicists. Two other CAP surveys were carried out, one in 1986/87 and one in 1988/89. Now, a decade after the 1985/86 survey, a new survey has been carried out in order to update the numbers and to get an indication of how the representation of women in physics has changed over the past decade.

In the fall of 1995, a survey of students was sent to Canadian physics departments in parallel with the survey of women faculty reported on elsewhere in this issue of Physics in Canada by Lagowski and McKenna. The survey sheet that was distributed is shown in Figure 1. It repeats the 1988/89 survey and is rather similar to the 1985/86 and 1986/87 surveys in content and layout, except that it now does not ask for data before third year and it does ask for data at the Post Doctoral level.

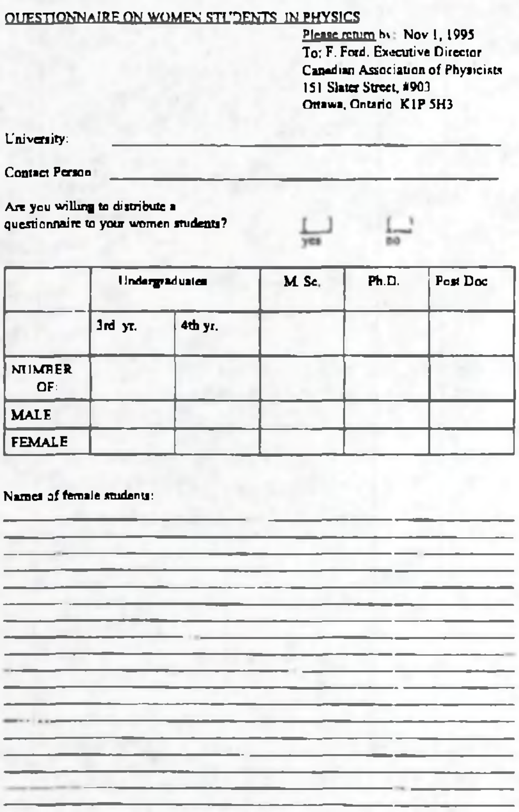
RESULTS

The earliest CAP data concerning the representation of women in Canadian physics departments is summarized in Table 1 under the column for 1983/84. These numbers are the result of Mona Jento, who was the Executive Secretary of the CAP for many years, extracting the number of women from the lists of graduate students submitted to the CAP [1]. While 31 universities submitted lists, a number only showed the initials of the students and some did not break out responses by degree level. The data shown were assembled from 24 universities.

TABLE 1
Results of CAP surveys

	1983/84	1985/86	1986/87	1988/89	1995/96
Number of university responses	24	18	33	37	38
3rd year					
number of women	*	60	105	120	103
number of men	*	477	788	661	557
total	*	537	893	781	660
women as % of total	*	11	12	15	16
4th year					
number of women	*	45	93	107	130
number of men	*	406	654	655	554
total	*	451	747	762	684
women as % of total	*	10	12	14	19
MSc					
number of women	23	30	59	73	91
number of men	357	310	474	474	409
total	380	340	533	547	500
women as % of total	6	9	11	13	18
PhD					
number of women	11	24	25	43	102
number of men	233	299	411	404	684
total	244	323	436	447	786
women as % of total	5	7	6	10	13
Post Doc					
number of women	*	*	*	9	24
number of men	*	*	*	114	151
total	*	*	*	123	175
women as % of total	*	*	*	7	14

* not available from survey



QUESTIONNAIRE ON WOMEN STUDENTS IN PHYSICS

Please return by: Nov 1, 1995
To: F. Ford, Executive Director
Canadian Association of Physicists
151 Slater Street, #903
Ottawa, Ontario K1P 5H3

University:

Contact Person:

Are you willing to distribute a questionnaire to your women students? yes no

	Undergraduates		M. Sc.	Ph.D.	Post Doc
	3rd yr.	4th yr.			
NUMBER OF:					
MALE					
FEMALE					

Names of female students:

Fig.1 CAP Survey Form

The results of the four CAP surveys are also summarized in Table 1. For these, a request was sent to the university physics departments to complete a form similar to that shown in Figure 1. Response rates increased dramatically after the first survey. There were only 18 responses to the 1985/86 survey, while there were 33, 37 and 38 responses, respectively, to the 1986/87, 1988/89 and 1995/96 surveys, out of 63 departments. Many of the later responses included only the numerical summary, but most university respondents expressed a willingness to circulate a questionnaire to women students. As yet, we have not attempted to do this.

Table 1 includes the total responses received from all the surveys. Unfortunately, a different subset of universities responded to each survey, limiting the comparability of the results. It is nonetheless clear that the representation of women students in Canadian university physics departments has increased over the time period. It is interesting that in general the number of physics students declines with increasing academic level, with the latest survey being a marked exception.

TABLE 2
Results of surveys at 17 universities which responded to both

	1985/86	1995/96
3rd year		
number of women	58	74
number of men	472	313
total	530	387
women as % of total	11	19
4th year		
number of women	44	95
number of men	403	362
total	447	457
women as % of total	10	21
MSc		
number of women	30	48
number of men	310	232
total	340	280
women as % of total	9	17
PhD		
number of women	24	58
number of men	299	361
total	323	419
women as % of total	7	14
total number of women	156	275
total number of men	1484	1268
grand total	1640	1543
women as % of total	10	18

In order to make more meaningful comparisons, different subsets of the data are displayed in Tables 2 - 4. In Table 2, the results for the 17 universities that responded to both the first and last survey are shown. Note that while these 17 universities represent only 45% of the universities that responded in 1995/96, they represent 59% of the total number of physics students. While the detailed university responses are not shown here, it is interesting to note that, except at the MSc level, the percentages of women are slightly higher in 1995/96 at these 17 universities than at the "new responders", as indicated by the 1995/96 numbers in Table 1.

While the representation of women has markedly improved, the number of male students in physics at these 17 universities has decreased over the last decade, except at the PhD level. It is not clear why the third year class in the 1995/96 survey is so much smaller than the corresponding class in 1985/86. MSc numbers are also down at these 17 universities, but PhD numbers are up 30%. Is this just the "tail end" of a larger group that has passed through or are students staying at university longer to finish their PhDs because of the shortage of jobs and the economic situation generally?

last surveys at these universities, although not so substantially at these 25 universities as at the 17 covered by Table 2. The number of women at each level also increased over the period, although the number of men decreased at every level except PhD, and fell 10% overall. The total number of physics students has remained relatively constant for these universities, but their distribution among the academic levels has changed markedly, with the number of PhD students up 56% in this sample of universities. Tables 1,2 and 3 all indicate that the number of women in third year at the present time (1995/96), and their representation, is slightly less than in fourth year. This could be the beginning of a reversal in the trend to increased representation. Future surveys should help to clarify this point.

TABLE 3
Results of surveys at 25 universities

	1986/87	1988/89	1995/96
3rd year			
number of women	75	68	85
number of men	581	474	477
total	656	542	562
women as % of total	11	13	15
4th year			
number of women	77	61	89
number of men	521	403	362
total	598	464	451
women as % of total	13	13	20
MSc			
number of women	54	62	72
number of men	396	388	319
total	450	450	391
women as % of total	12	14	18
PhD			
number of women	22	33	76
number of men	350	390	504
total	372	423	580
women as % of total	6	8	13
total number of women	228	224	322
total number of men	1848	1655	1662
grand total	2076	1879	1984
women as % of total	11	12	16

TABLE 4
Results from 20 universities submitting data for both 1983/84 and 1995/96

	1983/84	1995/96
MSc		
number of women	20	64
number of men	297	276
total	317	340
women as a % of total	6	19
PhD		
number of women	11	66
number of men	218	458
total	229	524
women as a % of total	5	13

Table 3 shows the results for the universities that responded to the later surveys. There were 17 universities which responded to each of the 1986/87, 1988/89 and 1995/96 surveys and another 8 that responded to both the 1986/87 and 1995/96 surveys. For these 8 universities, linear interpolation was arbitrarily used to estimate numbers for 1988/89. Table 3 shows that the representation of women in physics has definitely increased between the first and

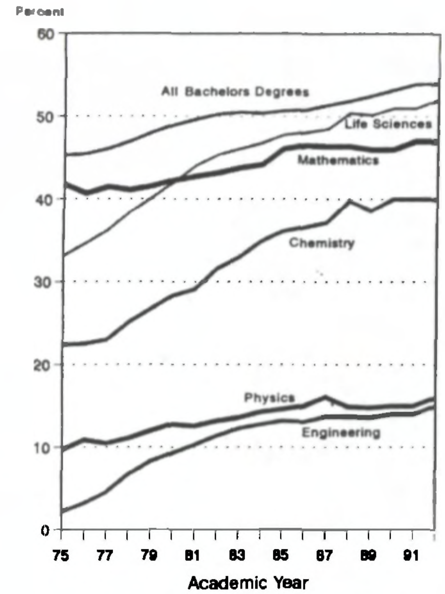
Table 4 shows results for the 20 universities submitting data for both 1983/84 and 1995/96. The percentages of women in graduate schools have nearly tripled over this period at these universities. The total number of PhD students has more than doubled, while the number of Masters students has increased less than 10%. Note that the actual number of women at the PhD level as shown in this sample has gone up a factor of 6.

DISCUSSION AND CONCLUSIONS

The CAP survey data indicates several things: that the representation of women students in Canadian university physics departments has increased substantially over the period surveyed, that the number of women physics students in Canada has increased substantially and that the representation of women university physics students still decreases with increasing academic level.

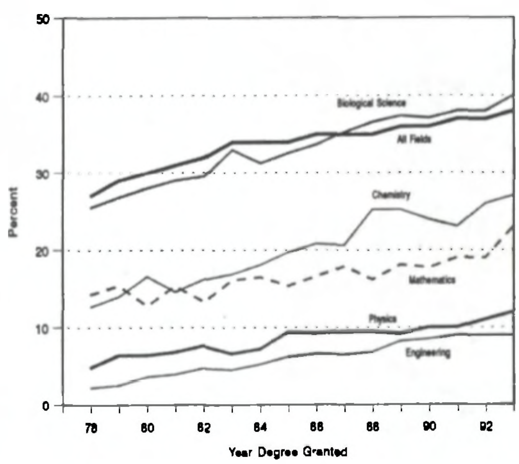
Tables 1, 2, 3 and 4 all indicate that the representation of women students has increased. The size of the increase varies somewhat with the data sets used. It is most striking that, at the PhD level, representation has essentially doubled over the last decade.

These results can be put into context with those given by Statistics Canada in "Women in Canada: A Statistical Report" [2]. Table 5, from this report, gives data for full time enrolment by field of study for



Source: U.S. Department of Education

Fig. 2 Percent of Bachelors Degrees in Selected Fields Earned by Women, 1975 to 1992.

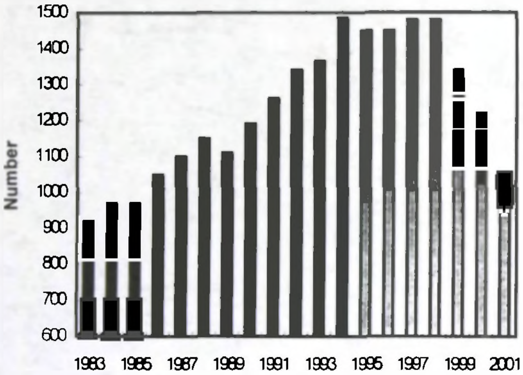


(Source: NRC Summary Report, various years. The data cited for physics PhDs earned are from the AIP Enrollments and Degrees Reports ***)

Fig. 3 Percent of PhD's Earned by Women in Selected Fields, 1978 - 1993.

1972-73, 1981-82 and 1992-93. The numbers given for engineering/applied sciences in 1981/82 and 1992/93 are similar to those shown in our Tables and, in fact, agree with the overall percentages shown in the last line of Table 2 for 1985/86 (10%) and 1995/96 (18%).

Figure 2 [3] shows the representation of women in the U.S.A. obtaining bachelors degrees in selected fields. In physics, the percentage of bachelors degrees awarded in the U.S.A. has risen from about 10% in 1975 to about 16% in 1992. If we compare these figures with those from our survey for the fourth year and MSc levels, we see that the increase in representation



Year
Projected Number of Degrees, 1995-2001
Source: AIP Education and Employment Statistics Division

Fig. 4. **The dark bars indicate actual physics PhD production between 1983 and 1994. The two-tone bars indicate high and low estimates for projected PhD production.**

appears more rapid in Canada. Our results from 1985/86 in Table 2 imply that about 10% of the bachelors degrees in physics were awarded to women and that, by 1995/96, the number had essentially doubled.

Figure 3 [3] shows the representation of women in the U.S.A. obtaining PhD's in selected fields. The representation in physics has risen from about 5% in 1978 to about 12% in 1993. These figures are very consistent with, for example, the 5% in 1983/84 and the 13% in 1995/96 shown in our Tables 1 and 4. Hence, although representation appears to be increasing more rapidly in Canada than in the U.S.A. at the bachelors level, the increase in representation at the PhD level seems about the same in the two countries.

Tables 1, 2, 3 and 4 show that not only the representation, but also the number of women university physics students has increased in Canada. This increase is most dramatic at the PhD level. It is still sobering to reflect on the very small actual number of women physicists at that level.

It is clear that to change the overall representation in the Canadian professional physics community will take a very long time.

In general, for most of our surveys, the number of women students drops off with increasing academic level, as does the total number of students. This is not universally true, however, and the 1995/96 survey results are different in this regard. In the 1995/96 survey, summarized for different groups of universities in Tables 1, 2, 3 and 4, the number of women PhD students is greater than the number of women MSc students. Furthermore, the number of male PhD students and hence the total number of PhD students are also greater than the corresponding numbers at the MSc level.

Table 5
Full-time university enrolment of women, by field of study, 1972-73, 1981-82 and 1992-93

	1972-73			1981-82			1992-93		
	000s	%	Women as a % of total in field	000s	%	Women as a % of total in field	000s	%	Women as a % of total in field
Field of study									
Education	33.4	21.2	56.2	45.0	18.4	67.0	40.4	13.8	66.5
Fine/applied arts	5.9	3.8	59.9	10.8	4.4	63.6	11.2	3.8	61.8
Humanities	19.4	12.3	48.1	23.5	9.6	58.8	36.7	12.6	59.8
Social sciences	24.4	15.4	28.9	66.4	27.2	44.8	94.5	32.4	53.5
Agricultural/biological sciences	8.9	5.6	40.4	12.5	5.1	52.2	21.2	7.3	56.8
Engineering/applied sciences	0.7	0.4	2.7	4.7	1.9	10.4	9.8	3.4	18.0
Health professions	10.3	6.5	51.2	17.0	7.0	63.1	21.2	7.3	65.6
Mathematics/physical sciences	4.1	2.6	19.1	8.2	3.3	26.3	9.8	3.3	28.4
Total[1]	157.7	100.0	40.4	244.1	100.0	48.6	292.0	100.0	52.2

[1] Includes those with no specialization and those for whom no specialization was stated.
Source: Statistics Canada, Education, Culture and Tourism Division.

Table 6
Women as a percentage of full-time university enrolment, by level and field of study, 1992-93

	Bachelor's and first professional degree	Master's	Doctorate	Total
Field of study				
Education	66.8	65.8	60.0	66.5
Fine/applied arts	62.2	58.8	45.5	61.8
Humanities	61.2	55.8	45.7	59.8
Social sciences	54.4	46.6	44.7	53.5
Agriculture/biological sciences	59.0	49.6	33.2	56.8
Engineering/applied sciences	18.5	18.2	10.6	18.0
Health professions	67.7	62.0	43.4	65.6
Mathematics/physical sciences	29.9	27.1	18.6	28.4
Total[1]	53.4	46.2	35.2	52.2

[1] Includes those with no specialization and those for whom no specialization was stated.
Source: Statistics Canada, Education, Culture and Tourism Division.

Figure 4 [4], based on American Institute of Physics (AIP) data for the U.S.A. offers a possible explanation. In the U.S.A., the number of physics PhD's is expected to peak between 1994 and 1998 and then to decline rather dramatically to levels about the same as those a decade earlier. If the situation in Canada is similar, it would explain the large number of physics PhD students reported in our 1995/96 survey. This explanation is also reinforced by the numbers in third year in our 1995/96 survey. For some universities (Tables 1 and 2), the third year class is smaller than the fourth year class. The number of women students is also lower, as is their representation. Further surveys will be required to establish whether or not this apparent change in trend is real.

The data shown in Tables 1, 2, 3 and 4 indicates that in all years except 1995/96 the representation of women falls off with increasing academic level, typically by about 4-5% (out of 11-19%) from third year to PhD level. Table 6 [2] shows that the representation of women in engineering/applied sciences in 1992/93 fell from 18.5% (bachelors) to 10.6% (PhD) according to Statistics Canada. Figures 2 and 3 indicate that the representation of women physics graduates in the U.S.A. in 1992 was about 16% at the bachelors degree level and about 11% at the PhD level.

This decrease in the representation of women with more advanced academic level is a phenomenon not limited to physics. Table 6 also shows that the representation of women in all fields drops from 53.4% at the bachelors degree level to 35.2% at the PhD level. These Statistics Canada figures indicate that, in 1992/93, women made up more than half the university enrolment at the undergraduate level in every field except engineering/applied sciences and mathematics/physical sciences. Even at the PhD level, representation of women is at least 33% in every field except these two. Figures 2 and 3 for the U.S.A. indicate that the representation of women at the bachelors degree level overall was about 54% in 1992 while at the PhD level it was about 37%. Engineering and physics are the two areas in which representation is the lowest.

These results indicate that, in the university community as a whole, representation of women at the undergraduate level is no longer a serious concern. However, the science-based professions, particularly physics and engineering, continue to have a problem attracting women students and the loss of partially trained women students is a problem in the university community for all disciplines.

Although women are now equitably represented in university education in Canada, and their representation in physics has almost doubled over the past decade, physics still remains one of the areas where representation of women is poorest. In addition, women still drop out of physics education relatively more frequently than men do. Current physics student demographics leads one to expect that, over at least the next several years, the representation of women among the new hires in Canadian physics positions, and hence among the total Canadian professional physicist population, will exhibit a slow increase. It will, however, be several decades, if ever, before there is an

(continued on page 113)

WES-WOMEN IN ENGINEERING AND SCIENCE: A CANADIAN SUCCESS STORY AT NRC

by Marie D'Iorio, Institute for Microstructural Sciences, National Research Council of Canada, Ottawa, Ontario K1A 0R6

In November 1990, the National Research Council (NRC) launched a Women in Engineering and Science program in its laboratories to encourage the participation of Canadian women in the science and engineering professions. Each year since 1991, twenty-five outstanding first year female students enrolled in a Canadian University or in a final year of CEGEP have been selected from across Canada to work for three summers or co-op terms in NRC laboratories while studying in scientific or engineering disciplines in which women are traditionally under-represented. The student is paired with a NRC scientist who acts as a mentor to link the academic training, work assignments and career aspirations of the student. In particular, the mentor helps identify a project suited to the student's interest and provides guidance when needed. The students are encouraged to experience different research environments and supervisors, although some prefer to "grow" within a research group for the three work terms.

The students accepted into the Program are expected to serve as role models for other women contemplating careers in science and engineering and must represent the National Research Council when the opportunity presents itself. Two groups of WES students have now completed the Program and more than 85% of these have registered into graduate school or are pursuing careers in science and engineering. Criteria for selection of WES participants include: academic interests and performance, extracurricular pursuits, employment history, initiative, community involvement and communication skills. Each university can recommend up to three students.

Elke Aippersbach from the University of Alberta spent three summers in Jenny Phipps' laboratory in the Institute for Biological Sciences (IBS), Tissue Regeneration and Transgenics Group. During her second work term at NRC, Elke commented: "In a lab like this there's so much to get involved with. This year, I worked on the effect of a peptide of hormonal origin on the cellular cycle. Last year, I was involved in a collaborative SIMS (Steacie Institute for Molecular Sciences) and IBS project studying a possible treatment of cancer"*. As she headed towards pursuing graduate degrees in Biochemistry at the University of Toronto, Elke had a good idea of what a professional researcher's career entailed. She added: "In school, you get an idyllic view of research. If your experiment doesn't work, you still know the results you were supposed to get. At NRC, you don't always get the results you're looking for, but you have to learn to be open to what your failures can teach you." Her mentor's perspective on interacting with students was: "They ask questions that we have forgotten to ask somewhere along the way". Jenny Phipps was busy answering questions and guiding the research of four students working with her that summer. Since 1991, preference has been extended to candidates in fields in which women are underrepresented: mathematics, physics, and engineering.

The students who were chosen for this year's program were invited to an orientation session at NRC in August. There, they met prospective mentors, learned about the research projects in various Institutes, and talked to other WES students in their first, second and third year in the Program. The WES participants have established an effective network of information and activities providing the mutual support which often drives first class students to surpass excellence.

projet et de directeur de recherche bien Those of us who have served as mentors hope that the WES Program will continue to enrich our personal and professional lives for years to come! Information about this program is available through the university awards office and through NRC at the following address:

Carole Greffe
National Research Council of Canada
Human Resources Branch
Recruitment Office
Ottawa, Ontario K1A 0R6
Tel: (613) 993-3543
FAX: (613) 990-7669

* Sphere, May 1994

Sheri-Lynn Lewis with Dr. S. Elgazzar, Institute for Information Technology/Institut de technologie de l'information, Ottawa.

Karla Randell with Dr. J. Balsevich, Plant Biotechnology Institute/Institut de technologie des plantes, Saskatoon.

PIC-PROGRAMME D'INGENIEURES ET CHERCHEUSES: UN PROGRAMME CANADIEN COURONNÉ DE SUCCÈS AU CNRC

par Marie D'Iorio, Institut des sciences des microstructures,
Conseil national de recherches du Canada, Ottawa, Ontario K1A 0R6

En novembre 1990, le Conseil national de recherches du Canada (CNRC) a mis sur pied un programme d'ingénieures et chercheuses (PIC) visant à encourager les Canadiennes à poursuivre des études en sciences et en génie. Chaque année depuis 1991, le CNRC a invité vingt-cinq étudiantes très douées, venant des quatre coins du pays, à travailler dans ses laboratoires pendant trois étés ou semestres co-op tout en poursuivant des études dans des disciplines où les femmes sont traditionnellement sous-représentées. Les étudiantes doivent avoir terminé une première année d'un programme de premier cycle dans une université canadienne ou un niveau équivalent au Québec. L'apprentissage de ces étudiantes est facilité par le jumelage de chaque participante à un scientifique du CNRC dont le rôle de conseiller consiste à aider l'étudiante tout au long des trois années du programme, de la guider dans le choix de projets de recherche, de la conseiller quant à l'orientation de sa carrière et d'être disponible pour discuter de ce qui a trait aux objectifs du programme de formation et aux affectations. Les étudiantes sont encouragées à diversifier leurs choix de que certaines préfèrent un apprentissage au sein d'un même groupe de recherche pendant trois ans. Les étudiantes admises au programme doivent servir de modèles à d'autres femmes qui envisagent de faire carrière en sciences ou en génie et doivent représenter, si nécessaire, le Conseil national de recherches dans le cadre de salons de l'emploi et journées d'orientation sur les campus universitaires. Deux groupes d'étudiantes ont complété leur apprentissage au sein du programme et plus de 85% de ces diplômées poursuivent des études de deuxième et troisième cycle ou se sont engagées dans des carrières en sciences et en génie. Parmi les critères de sélection pour les participantes du PIC, on compte les intérêts sur le plan académique et parascolaire, l'esprit d'initiative, les activités communautaires, la communication orale et les expériences de travail. Chaque université peut poser la candidature de trois étudiantes.

Elke Aippersbach de l'université de l'Alberta a oeuvré pendant trois étés dans le laboratoire de Jenny Phipps de l'Institut des sciences biologiques (ISB), groupe de regénération tissulaire et de recherche transgénique. Au cours de son troisième été au CNRC, Elke a parlé de sa recherche en ces termes*: "Dans un labo comme celui-ci, il y a de nombreux projets auxquels vous avez la chance de participer. Cette année, j'ai étudié l'effet d'origine hormonale sur le cycle de la cellule. L'an dernier, j'ai participé à un d'un peptide projet en collaboration avec l'Institut Steacie des sciences moléculaires sur un traitement possible du cancer." Alors qu'elle s'apprêtait à commencer une Maîtrise en biochimie à l'université de Toronto, Elke avait déjà une idée assez précise de ce que serait sa carrière de chercheuse. Elle ajouta: "À l'université, on vous présente une vision idéalisée de la recherche. Si votre expérience ne marche pas, vous savez au moins quels auraient dû être les résultats. Au CNRC, il arrive que vous n'obteniez pas les résultats recherchés, mais on s'attend à ce que vous appreniez aussi de vos échecs." Selon sa conseillère, Jenny Phipps, "le fait de travailler avec des étudiants nous force à être plus vigilants. Ils nous posent des questions que, parfois, nous avons oublié de nous poser en cours de route." Jenny Phipps était bien placée pour parler puisqu'elle supervisait les travaux de quatre adjoints d'été dont Elke. Depuis 1991, la préférence est accordée aux étudiantes inscrites dans des domaines où les femmes sont sous-représentées soit les mathématiques, la physique et le génie.

Les étudiantes qui ont été choisies pour le concours de 1995 ont été invitées à une journée d'orientation au CNRC au mois d'août. Elles ont rencontré des conseillers et conseillères, ont eu un bref aperçu des projets de recherche de divers Instituts et ont pu rencontrer des étudiantes participant au programme des ingénieures et chercheuses depuis un, deux et trois ans. Les participantes du PIC ont mis sur pied un réseau d'information et organisé des activités qui les épaulent durant leur séjour au CNRC leur permettant d'aller au-delà de l'excellence.

Pour ceux et celles parmi nous qui ont eu le plaisir d'être conseiller et conseillère, il ne reste plus qu'à espérer que le programme d'ingénieures et chercheuses continuera d'enrichir notre vie personnelle et professionnelle pendant les années à venir! Pour de plus amples informations sur ce programme du CNRC, veuillez communiquer avec le service des bourses de votre université ou avec le CNRC à l'adresse suivante:

Carole Greffe
Conseil national de recherches du Canada
Direction des ressources humaines
Groupe de recrutement
Ottawa, Ontario K1A 0R6
Tél: (613) 993-3543
FAX: (613) 990-7669

* Sphère, mai 1994

Women Physics Faculty ... by J. Lagowski and J. McKenna
(continued from pg. 107)

have no role models for their undergraduate women students.

In Table 4 these Canadian statistics are compared with the analogous statistics in the United States of America for 1994.(3) The situation in Canada is indeed very similar to that in American universities.

CONCLUSIONS

This article should not be taken as a definitive study (see for example footnote 1, also no attempt was made to estimate the accuracy of final numbers) on women in physics in Canada. The results of this survey suggest that further studies could be undertaken in order to address questions such as: (1) What was the effect of Women's Faculty Awards (WFA) (a program sponsored by the Natural Sciences and Engineering Research Council) on the above percentages? (2) Do women progress to tenure more slowly than men? (3) How would the inclusion of institutions that chose not to reply to the survey affect the above results? and possibly other questions that would indicate ways of assessing and improving the situation for female physicists in the Canadian institutions. We conclude by stating that with 5% representation of women in physics departments at the faculty level, the situation for women in physics in Canada is comparable to that in the United States of America, and notably worse than that of many European countries.

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(3) American Institute of Physics; Education, Employment and Statistics Division, data for the year 1994.

THE COMMITTEE ON THE STATUS OF WOMEN IN PHYSICS OF THE AMERICAN PHYSICAL SOCIETY

by Luz Martinez-Miranda

The Committee on the Status of Women in Physics of the American Physical Society (CSWP) was chartered in 1972. Over the years, the Committee has sponsored activities aimed both at increasing the participation and representation of women in Physics and related fields.

The CSWP has nine members appointed to three year terms by the APS. Currently, the CSWP is organizing three subcommittees: Education, Industry and International, to better enable the committee to take advantage of the many eager volunteers who wish to contribute to the committee's projects.

For more information on CSWP programs, please contact Tara McLoughlin at APS headquarters (301) 209-3231 or e-mail tara@aps.org.

Some of the activities the CSWP sponsors are:

1. a Roster of Women in Physics;
2. Women in Physics (WIPHYS), a moderated internet forum;
3. a colloquim/seminar speaker's list;
4. travel grants for women speakers;
5. Physics Department Site Visit Program.

In addition, CSWP publishes The Gazette, a quarterly newspaper, and sponsors symposia, receptions and presentations at the general and divisional meetings of the American Physical Society. Most recently, CSWP has sponsored a breakfast meeting of women in industry, jointly with the Committee on the Applications of Physics. These programs are described in the following.

ROSTER OF WOMEN IN PHYSICS

The Roster of Women in Physics is a database containing the names, addresses and fields of expertise of women in physics at all levels from student to professional. Academic institutions, government and industrial laboratories interested in reaching a pool of potential job applicants in a specific field can contact APS and request a search of the database. APS will mail job announcements and pertinent information to candidates whose qualifications match the institutions' specified requirements. The information contained in the Roster is confidential and therefore the list is not available for distribution. A Roster application form appears in every issue of The Gazette.

WOMEN IN PHYSICS (WIPHYS)

WIPHYS is a moderated Internet forum for the discussion of issues related to women in physics. This electronic forum offers unique possibilities to assist in creating an atmosphere of cooperation, mentoring and support in a field where women are a minority, and thus often feel isolated. WIPHYS was "officially" started in January, 1993, and now has over 600 subscribers.

Examples of discussions on WIPHYS:

- announcement of government or privately sponsored programs designed to aid in establishing the careers of women scientists;
- postings of job listings;
- news about women in physics;
- on-line mentorship (issues recently discussed include sexual harassment, the impact of changing one's name on publications and research, advice on the tenure process);
- information on women's events at APS meetings (postings on informal and planned dinners, receptions, sessions, help for those seeking roommates);
- advice on teaching (suggestions for textbooks, discussion of different learning styles).

In order to subscribe to WIPHYS, send an e-mail message to: listserv@aps.org
The subject line should be blank, and the text of the message should read: subscribe wiphys

COLLOQUIM AND SEMINAR SPEAKER'S LIST OF WOMEN IN PHYSICS

The Colloquim and Seminar Speaker's list of Women in Physics is published every year and distributed to all Physics Department Heads in the U.S.A. and others by request. This booklet contains the names of women speakers and seminar titles arranged by field, geographical area and presentation level (general audiences, high school audiences, technical seminar). The list serves as a resource for departments interested in inviting women speakers to their seminar series.

TRAVEL GRANTS FOR WOMEN SPEAKERS

The Travel Grants for Women Speakers Program is aimed at increasing the visibility of women in the field as well as providing students, both female and male, with active female role models, especially in those physics departments that do not have any women in their faculty. In the U.S.A. more than one third of the research universities have no women faculty. APS reimburses institutions up to $500 (US) for the travel expenses of one or two women speakers. This program has been very successful since its establishment and in 1993, the APS Council voted to increase its funding by one third. All Physics and/or Science Departments in the US are encouraged to apply. Canadian and Mexican Institutions are eligible also, provided that one of the invited speakers is currently employed by a US Institution.

THE PHYSICS DEPARTMENT SITE VISITS PROGRAM

The Physics Department Site Visits Program is sponsored jointly by the APS and the American Association of Physics Teachers (AAPT). Funded by the National Science Foundation and the APS, this program was aimed at determining which factors affect the retention and success of women in Physics Departments at all levels (undergraduate, graduate and faculty) at research universities in the U.S.A. The final report on this program, written by Profs. Mildred Dresselhaus, (MIT); Judy Franz, Executive Officer of the APS, University of Alabama; and Bunny Clark, Ohio State University, is available from APS by contacting Erika Ridgeway at (301) 209-3269. This report details specific recommendations to improve the climate for women in Physics Departments. As the report points out, many of these recommendations, including the availability of safe undergraduate study rooms, recruitment of women faculty, and guidance for those combining work studies with family responsibilities benefit women as well as men, and can lead to a better working atmosphere for all department members and students. The program has received many more requests for visits than funding or time allows. The CSWP plans to continue this program, visiting approximately three institutions per academic year. Funding will be provided both by the CSWP and the department visited.

Women Students in Physics ... by Ann McMillan and E. Svensson (continued from pg. 110)

equality of numbers of women and men in the physics profession in Canada.

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PHYSICS INDIVIDUAL PROFILE - IRINA CONDREA

After I graduated from the University of Iasi in 1989 with a degree in physics, I decided to continue my studies at the Bucharest University for a Master's degree in plasma physics. In Romania at that time there was only one Master's degree program and only 15 were admitted each year. These 15 people were the best students from all the Romanian Faculties of Physics (there were 5 in the country). Since I had a very good average for the whole 4 years of undergraduate studies, I was accepted into the Master's program. The time period for taking the Master's degree was one year which included 3 obligatory courses during the year, and research with a thesis at the end. As I was already interested in a certain subject which I presented in my graduate thesis, I decided to continue it. I kept in touch with my professor in Iasi who was the head of the plasma physics group at Iasi University, but for the most part I had to deal with my problems alone. It was a very interesting experience - I could play with all kinds of calculations, assumptions and comparisons with other fields of physics. Of course, one year is a very short time for a Master's, but in the end I managed to develop an original view on double layers and on the potential relaxation instabilities in a confined plasma column.

I successfully finished my studies in 1990 and, after three months, was offered an 8-month post-graduate fellowship at the Fusion Department of the Energy Research Centre in Frascati, Italy. My task was to make spectroscopic measurements on the plasma of a medium- sized tokamak (FTU-Frascati Tokamak Upgraded). When I arrived in Italy I had no knowledge of the Italian language. Even though my colleagues spoke English, I soon understood that I needed to learn to speak Italian. Also, upon my arrival I had no knowledge about fusion programs. While I had learned something about the principles of fusion and the use of a tokamak for nuclear fusion purposes, Romania is too poor to be able to finance such an important program, so few there know anything about it, with the exception of a some people at the Atomic Institute in Bucharest who collaborate with other European Institutions.

This will give you an idea of the feeling I had when I started to work in the Energy Research Centre. In Romania I had been very appreciated for my work, but here I felt like a "nobody". I started to feel better after a few months as my Italian improved considerably and I started to understand the system. Coming from a place where you don't have many opportunities to one where everything is possible takes a lot of getting used to. I was certainly handicapped at the beginning by my origins, by the fact that I was Romanian and that I had other ways of looking at things. Adjustment depends on the person also, and I can assure you that from the moment I understood that this was the case, I made a lot of progress. I was speaking Italian comfortably after one year (without taking any lessons) and I was progressing much more easily in my field after a few months. Because of this, my director prolonged my fellowship for another 8 months and also gave me a lot of responsibilities.

I probably forgot a very important aspect of my life in those years, my marriage.

At that time, my husband had to remain in Romania for bureaucratic reasons. He is Romanian, too, and you may not know it, but in Western Europe there are very strong laws which impede people from Eastern Europe from working or staying for extended periods in other countries. I could say plenty about the reasons for those laws, but I don't think it would resolve anything. The point is that nobody from the Italian authorities wanted to know about the presence of my husband in my life. Sometimes I even got the suggestion to "find yourself an Italian and marry him and your problems will be resolved". No comment. After almost 10 months, I managed to get a work permit and a job for my husband. He is a metallurgical engineer with excellent skills so it wasn't really very difficult to find an appropriate job for him even if he had to totally change fields (to micro-mechanics). We started to have a happy life, we were 90% adjusted to Italian society and we had a few very good friends. The problems appeared when the 8 month fellowship was coming to an end and I had no place to go. According to their laws I had to leave Italy. My director proposed a 2-year long research contract, very well paid and including some expenses for conferences, work visits etc. There was a lot of work but I accepted immediately because I loved my work and I loved Italy.

The years in Italy were very happy for me and my husband. There were still some clouds in our sky and once again it was our worst enemy- the authorities. My husband because of his work permit could stay in Italy as long as he worked but I had entered Italy with a student visa and even though I was working, I couldn't get a work visa. So, after the 2 year contract I was supposed to leave Italy. This situation caused us a lot of despair. Only someone who has lived with this situation can know what I mean.

Fortunately, we are positive thinkers and so, 6 months before the end of my contract we discussed our future plans very seriously. Should I remain in physics? It seemed very difficult for 2 reasons apart from my visa: first- only an Italian citizen can be hired in a research Institute because it is state-run; second - industry is not very interested in hiring physicists and if they do it is for software development. Should we stay in Italy? Where would we go? There was no way that we could go back to Romania. After serious thinking, I decided that I'd like to continue my studies to a PhD degree and my husband agreed. Tired of the problems we had because of our citizenship, we decided to emigrate to Canada.

Here we are now, in Montreal, Canada. I am doing my PhD studies in fusion at the Centre Canadien de Fusion Magnètique, Varennes. I intend to measure the ion temperature and the impurity density in the central plasma of Tokamak de Varennes by injecting a neutral beam in the plasma. It's an interesting and complex subject. I have already finished all the courses and I have started to work on my research subject. My husband found a job in a metallurgical company, where he is production manager. When we arrived here, we again felt like we were "nobodies" because we didn't speak French (even though we had studied it in school) and also because this society is different from the European one. I think that I can say at this point that we have once again managed to adjust to this society. We now both speak English and French and we feel well integrated in our work groups. We have Romanian and Canadian friends and we love all the occasions in which we can make new contacts with people from all around the world.

Maybe you'll say that I wrote too much about our problems with visas instead of speaking about physics. Well, in my life, both things were correlated. It is sad to see how many impediments a Romanian scientist has to face if she/he wants to continue their chosen career.

Still, I don't regret being a woman in physics. My male colleagues continue to tell me that we, the women, have a lot of advantages in our work field. I don't think so. Even if there are laws which are supposed to help women, I find it very difficult to obtain a position. Males continue to say that they want to have women in their labs but when they have to sign for a position they prefer a man. There are special cases such as my director in Frascati, Dr. R. Bartiromo, who never made me feel like I was a woman; he considered me first and foremost as a physicist. I am very grateful to him because he never abused his power and he offered me the opportunity to change my career and my life. Our male colleagues are not used to having women in their labs and I think that is up to us, the women, to show them that we can speak about physics with them and that we are capable of doing good research. We have to cooperate, to give the best of ourselves and also to accept differences in each other.

I don't know if the fact that I'm a married woman changes anything in my career. Certainly it was not easy for both of us to change countries and jobs, but with a bit of reciprocal understanding we have managed to have a happy life. Even now that I know how difficult it is to get a job in physics I would still choose to do this. I'm sure that all the women physicists can make important contributions to physics.

PHYSICS INDIVIDUAL PROFILE - NANCY REMAGE EVANS

Where did I start? I went to university with an interest in science but not an exclusive interest. It wasn't until second year that almost by accident I selected a course in astronomy, and after that I was hooked. I have thought about whether the fact that I was at a women's college (Wellesley) had an effect. As with many areas, there are probably pros and cons. Certainly the atmosphere in the 1960's (graduated 1966) which emphasized serious career choices for women and classes where there was no pretending they were really aimed at someone else were highly beneficial.

Among things that particularly excited me as an undergraduate were the way in which clusters of stars provided information about the physics of the evolution of stars fundamental data such as the masses of stars. Altough I would not have guessed it at the time, I have continued to work in some of the same areas, largely because of the exciting new observations which have become possible both because of technical advances in ground-based observations and also new wavelength regions made available throughofsatelliteobservations. Encouraged by graduation with honours and membership in Sigma Xi, I continued to graduate school, supported by a variety of fellowships.

For graduate school, I came to the Astronomy Department at the University of Toronto, where I did a thesis on observations of variable stars, supervised by Dr. J.D. Fernie. It is possible to determine the radii of pulsating stars by combining measurements their light, color, and velocity variations. This was my first work on Cepheid variable stars, which are particularly important in the determination of distances to galaxies beyond our own Milky Way galaxy. (As a Hubble Space Telescope key project, Cepheids were featured in a TIME magazine cover story last year).

This period was the beginning of the juggling of career demands with family demands, culminating with the arrival of a second child and a thesis at nearly the same time. This combined with a husband with tenure (Marting G. Evans, Professorof Organization Behavior in the Faculty of Management Studies at the University of Toronto) limited possibilities to travel for a post-doc. It was quite fortunate that Dr. J.R. Percy offered me a part-time post-doctoral fellowship at the University of Toronto. Though I continued to observe at David Dunlap Observatory (DDO) in Richmond Hill, Ontario, I concentrated on different aspects of spectroscopy than before.

In this case, the masses of Cepheids were badly needed to confirm our understanding of the physics of the history of the stars, particularly since they are so important in extragalactic distances. In order to determine masses, pairs of stars in binary systems are needed. Although it was thought at the time that no suitable Cepheid binaries existed, velocity observations at DDO (and elsewhere) began to turn up candidates for orbit determinations. This same approach also led to information about how frequently binary systems occur. This is important information about star formation (are stars likely to form single or in pairs or groups?) which is a very active research area currently. Ultimately it has bearing on how frequently conditions needed to form planetary systems exist.

In the family/career area during this period as I began to search for a permanent job, I sometimes wondered whether cover letter statements that the work had been done part-time were really taken into consideration when evaluating productivity. Likewise, one can only hope that cover letter statements about a variety of experience are considered as strong a proof of broad experience as physical mobility.

There is a lively debate at the moment in the weekly email newsletter on women's issues from the American Astronomical Society about the best age is to have children during a scientific career. Perhaps the most healthy aspect of the discussion of a complex problem is the diversity of opinions ranging from early (the energy factor is important) to waiting until you are established. I can certainly attest that while it was not easy to do both graduate work and post-doctoral work on a part time basis, that is option which I found to be workable as well as very rewarding.

After a year of teaching at Erindale College at the University of Toronto, I took a position as Resident Astronomer at the International Ultraviolet Explorer satellite (IUE) run from NASA's Goddard Space Flight Center just outside of Washington, D.C., USA. This is a small astronomical statellite for which half a dozen astronomers supervised all aspects of the project: taking the data, data processing, and assisting with the scientific analysis with visiting astronomers. Working with a small team on such a breadth of projects was an exciting and demanding experience, and left me at times busier than I have ever been.

In my own research, adding the ultraviolet observations to the long-term velocity observations I had been making in Ontario provided the ability to attack many scientific questions. A mass determination of the Cepheid SU Cyg became possible by measuring the velocity of its hot companion using the IUE satellite (with Dr. C.T. Bolton, University of Toronto). This has lead directly into a more extended program of additional stars (Bohm-Vitense, Evans, Carpenter, and Robinson) using the more powerful Hubble Space Telescope. In addition, further work on Cepheid companions using both the IUE and Voyager satellites has given much clearer information about binary frequency and about the importance of rotation of mixing in stellar evolution. So far the 39 successful statellite proposals have contributed to 45 refereed publications (and numerous conference proceedings).

The family situation was more complicated. After 3 years of looking (involving a combination of commuting and sabbatical leave), my husband was not able to find a position in the area. We moved back to Toronto, where I continued research on soft money. When the Institute for Space and Terrestrial Science (ISTS) was set up as one of the Ontario Centres of Excellence, I took a scientific position in the Space Astrophysics Laboratory (SAL, 1988) and eventually became Associate Director of the Laboratory.

In addition to research, we worked on a number of astronomical statellite projects sponsored by the Canadian Space Agency. The scientific background in SAL allowed us to have interaction with small Ontario high tech companies with interests in space related technology. During this period, I also became and Adjunct Profesor at York University, and was pleased to find that my applications for operating grants to the Natural Science and Engineering Council, Canada (NSERC) were well received and my grants continued to increase. This meant that I was able to support several graduate students, as well as undergraduate summer and work study students. They worked mainly on projects usually using satellite data, though this was often combined with data obtained at DDO.

Unfortunately in 1994 a decision was taken at the Institute to reduce science and concentrate only on industrial work and the laboratory was closed. I looked for work extensively in Canada for a year.

In 1995, I was offered a position at the Harvard Smithsonian Center for Astrophysics to work on the Advanced X-Ray Astrophysics Facility (AXAF) and I relocated to Boston. The work on this project which is NASA's next major satellite project is very exciting, as is readjusting my research to another wavelength region. High energy studies with this satellite are promising ways to provide a better understanding of magnetic activity in stars (including Cepheids). Such activity (the sunspot cycle) has important effects on many phenomona on earth, such as communications and growth cycles. I also hope some work on star clusters will lead to a better understanding of processes producing X-rays in hot stars.

Commuting between Boston and Toronton (where my husband is) is also requiring some readjustment, although it is possible now that the children are in university and graduate school. I can only thank my husband for his support in this crazy existence!

Can I predict what is next? I wouldn't dare - either in science or in job title.

PHYSICS INDIVIDUAL PROFILE - DIANE PINSONNEAULT

A 31 ans, physicienne, je travaille depuis 4 ans pour l'Institut National de la Recherche Scientifique *INRS-Énergie*, un centre de recherche universitaire dans le groupe de physique des plasmas. Nous sommes une vingtaine affectés au laboratoire du Centre Canadien de Fusion Magnétique *CCFM* pour étudier la fusion dans le but de transformer la matière en énergie. Pourtant, bien que comme pour la plupart de mes collègues, la carrière dans laquelle je me trouve n'était pas mon premier choix.

Du plus loin de mes souvenirs, je m'émerveillais devant les ressources de la nature et comment elles pouvaient être transformées en nouvelles applications. Je m'interessais à la mécanique et à l'outillage de l'atelier de mon père. Le soutien de ma famille a joué un rôle déterminant dans mon cheminement. Mes parents ont suscité chez moi le désir d'indépendance et de réussite. Pour ma mère, l'éducation était prioritaire. Fascinée par la transformation de la matière et curieuse de nature, le génie chimique répondait à mes aspirations. Au moment du choix, les sciences se sont imposées d'elles même. Je n'ai donc pas hésité à m'engager dans une carrière en sciences appliquées. Cependant, durant mes études au cégep, un excellent professeur de physique, un bon vulgarisateur scientifique a su me captiver et susciter mon intérêt pour la physique. Il m'a fait découvrir la satisfaction de comprendre le fond des choses et le défi que ça représente. Dès lors, c'était décidé, j'allais poursuivre des études en physique. Après l'obtention de mon diplôme B.Sc. de l'Université de Montréal, j'ai décidé de continuer ma formation en physique des plasmas aux études supérieurs. Les plasmas qui représentent le quatrième état de la matière sont peu familiers sur terre mais très répandus dans l'univers. Une matière mystérieuse pour laquelle j'ai développée un grand intérêt.

Partagée entre le désir d'être confrontée à un milieu industriel et celui d'acquérir une bonne connaissance théorique des plasmas ainsi que de découvrir leurs applications, je me trouvais très heureuse quand j'ai eu l'occasion de combiner études et recherches au CCFM. J'ai entrepris une maîtrise en physique des plasmas à l'Université de Montréal sous la direction d'un professeur qui était membre du CCFM. Ce centre participe à un programme mondial pour le développement d'une source d'énergie viable à long terme à partir de la fusion, un aspect fort intéressant qui me plaisait. À Varennes, près de Montréal, le centre exploite une machine de type tokamak, TdeV *(Tokamak de Varennes)*, qui permet de confiner efficacement le plasma afin d'étudier la fusion. La complexité d'un projet de cet ampleur exige un travail d'équipe composée de chercheurs, d'ingénieurs, de techniciens et d'informaticiens. Ce milieu multidisciplinaire qui fait appel à la technologie de pointe et à l'expertise des entreprises industrielles m'a permis de développer des connaissances et une expérience en recherche scientifique. J'ai dû acquérir la formation voulue pour travailler au sein de cette équipe dont la qualité des travaux est reconnue. Ce fut une expérience parfois difficile mais qui s'est révélée très enrichissante. Comme de fait, avant la fin de ma maîtrise, le CCFM m'a proposé un poste, alors que les emplois en science se faisaient rares. Mon cheminement académique a pris fin et je me suis jointe à l'équipe du centre. Ma motivation à devenir professionnelle m'a permis de rédiger mon mémoire de maîtrise tout en occupant un poste de chercheur.

Je suis très satisfaite de mon emploi qui est aussi enrichissant qu'exigeant. Responsable d'un projet d'équipe, je dois entre autre, gérer un budget, faire des études scientifiques, faire de la programmation, mettre en application mes connaissances acquises pour concevoir et réaliser des appareils pour mesurer des paramètres du plasma et de les rendre disponibles. Dans le but de favoriser les collaborations internationales et l'échange de connaissances, on est appelé à rédiger des articles scientifiques et assister à des congrès, ce qui m'amène à voyager souvent. Ceci me permet de diversifier mon expérience et d'étendre davantage mes connaissances.

Une carrière en science est exigeante, je suis souvent amenée à faire un choix entre ma carrière et ma vie personnelle. Dès le début, j'ai du m'engager à fond afin d'acquérir les compétences requises et faire mes preuves. Il faut s'intégrer à son milieu de travail. Au CCFM, le milieu est moins compétitif que dans d'autre institutions. En sciences, où les hommes sont majoritaires, j'étais intimidée par la complicité dont ils font preuve entre eux. Cependant, j'ai su développer des affinités avec certains confrères créant une atmosphère de travail agréable. J'avoue que j'ai toujours soigné mes relations. Bien encadré, je suis encouragée et souvent épaulée par mes camarades de travail.

Au CCFM, c'est l'état qui subventionne la recherche à long terme. Compte tenu du contexte économique actuel, l'avenir du centre est incertain et les perspectives de carrière en physique sont peu nombreuses. D'après une convention, une carrière de scientifique requiert un diplôme PH.D et de plus en plus un post doctorat afin de mener leurs propres expériences. Par contre, je ne regrette pas mon choix. Avec qu'un diplôme de maîtrise, je suis très heureuse d'avoir un emploi qui me permet de faire de la recherche et de me mettre en valeur. Pour le moment, mes récompenses résident plus dans la satisfaction du travail bien fait que dans le salaire ou la stabilité d'emploi.

Jusqu'ici, avec une carrière aussi bien remplie, je vois évoluer mes intérêts et multiplier mes activités qui s'étendent de la musique à la plongée sous-marine. La discipline, l'organisation et la persévérance me permettent de concilier ma carrière et mes multiples intérêts.

PHYSICS INDIVIDUAL PROFILE - DEBORAH POIRIER

I have loved science since I was a little girl, drawing mould spores in grade two and sitting on the balcony in a thunderstorm with my father to watch the lightning. Neither of my parents is a scientist, but both have always shown a great deal of respect for the sciences and both gave me a strong sense that it was a very honourable career to pursue. In high school, I took extra physics and biology classes and decided that I wanted to become a doctor, since I expected that it involved diagnosing and puzzle-solving. I began CEGEP in a health sciences program which included mandatory humanities and literature courses, which I viewed as a dilution of my studies. However, my mind quickly changed on that point - within one semester I had changed into a social sciences program and declared confidently to my shocked mother that I would NEVER take calculus again.

During my two years in CEGEP I became involved in the school newspaper, The Champlain Bugle, working as copy editor and later as news editor. When one of my stories was picked up by the Canadian University Press I seriouslyentertained the idea of becoming a journalist, and even worked a few evenings at the McGill Daily. I began dating the entertainments editor, a young blues musician, who introduced me to jazz. (That was 14 years ago. Now HE's a doctor and we're still together...) I took courses in Middle East politics, philosophy, and TV production, and made friends who spent their afternoons painting and sculpting. But slowly I began to long once again for the structure and discipline of science, and added a biology class as an elective. I decided then and there that I was far more comfortable and happy when thinking about science, and began applying to university science programs. I suppose we don't ever really know what's good for us, but in retrospect, I am grateful that I had the opportunity for my brief foray into the arts, which opened before me a whole new world.

I then had to pick a major to write on my application forms. I can credit (or blame) Mr Fahmi, my high school physics teacher, for making my decision for me, although he probably doesn't know it. He was the type of teacher whose enthusiasm for understanding physical systems was infectious. He turned exploring physics into an exciting journey with lots of hands-on laboratory work and problem-solving. Mr. Fahmi only gave oral exams, because he was most interested in seeing us think a problem through, rather than memorize a proof and dutifully scribble it down.

I have since read that some girls learn science better when it is taught interactively and they are given solid, hands-on examples of the concepts that they're trying to grasp. That certainly holds for me, so it was a natural choice for me to turn to experimental physics as an undergraduate at Concordia University. Up until my arrival there, it hadn't really occurred to me that physics was an unusual choice for a girl. My family had always supported my scientific leanings, taking me to the library every weekend when I was a girl, and telling me that absolutely anything was possible. Being the only child of a father who was (and is) a born tinkerer ended up being excellent preparation for experimental work. We would build things together and frequently go to the lumber yard or the hardware store for provisions. I expect that had I had a brother these "unfeminine" pursuits may have fallen to him, but I guess I just got lucky! By the time I moved into my first apartment, I could tune a car, and change my brakes.

Despite my Mr. fix-it upbringing, I still had the feeling that men just magically knew about all things mechanical, and cars in particular. That notion was finally dispelled one day when I was working on my car in my parents' driveway. I had moved out a year earlier, but still returned to the house to do car maintenance in case I should get myself into a jam. My father came out to look at what I was doing and after a while I realized that I knew more about my old car than he did, mainly because I had spent so many hours banging away at it with the shop manual in my hand. I learned that he didn't necessarily know every detail about fixing cars, but he had the confidence to tackle any problem that came up. I did my next big car job in my own driveway.

My graduating class at Concordia had all of six students, with two women. The previous year had one, so I always had women in my study groups, and together we were very involved in the society of physics students. We also all worked as lab demonstrators and course markers. One single woman did however lament that her chosen field was hardly an aphrodisiac to suitors. We found that most young men's reactions to our being in physics fell into two categories: the "You must be smart", and the "Hah! I failed that in high school". My single friend was very pleased when one fellow said, "Oh, $e = mc^2$!". I think that we all felt comfortable and accepted in the department and didn't necessarily feel an imbalance. The only problem that came up was a visiting lecturer showing slides of scantily clad women during the course of a serious talk.

From Concordia I went on to INRS-Energie, a graduate arm of Université du Québec, to do a Master's degree in plasma physics. I carried out my experimental work on Tokamak de Varennes, Canada's largest fusion facility. I am now nearing the end of my doctorate, and actually have the pleasure of sharing a lab setup with another woman. What happens after I finish is anyone's guess!

At an American Physical Society meeting of the Division of Plasma Physics a few years ago, I attended a wine and cheese for women in physics, along with the 20 or so other women delegates (and at least as many hungry men). Until then I don't think I ever really felt the impact of the lack of women in physics. It was a real pleasure to meet these women, especially the more established physicists, as until then I had yet to meet a senior experimentalist who was a woman. One even came along with her physicist husband and their baby. Since then I have come to the strong belief that role models are essential for young women considering science as a career. It helps enormously to see someone like you successfully doing the thing for which you are training. Gymnasts and divers have to visualize difficult moves before they can be attempted. Perhaps the same is true for young women in physics.

It was after that APS meeting that I met Ann McMillan and Eric Svenssen, two tireless members of the Committee to Encourage Women in Physics of the CAP. We and several others have worked together over the past several years to constructively change the face of physics, and this special issue on women is just one of the ways. We hope you like it.

PHYSICS INDIVIDUAL PROFILES - RENAISSANCE WOMEN

It has long been a mystery to sociologists and educators why more women tend to study the liberal arts than the mathematical sciences. This could be caused by many reasons, including the influence of society or biological differences between the sexes. My purpose here is not to examine these reasons, but rather, to present the story of four young Canadian women who are presently finishing their fifth and final years at McMaster University having completed the requirements for both honoursPhysics and Arts degrees. During their undergraduate education they have explored both sides of campus and have found that perspectives from the arts and sciences are often complementary.

Michelle Hilts
Michelle Hilts was born and raised in Deep River, Ontario, but jokes that her parents are the only two non-physicists in town. Her father teaches physical education and history and her mother art and english at the local high school. With an arts and science background, Michelle had always planned to study both areas at university. She was enticed into Physics in first year when her professor urged her to apply for the Targeted NSERC Summer Award.

After two years of intense Physics training, Michelle longed for some variety in her studies. She decided to include a few more Anthropology courses in her program and was later surprised to learn that the two fields were connected. Last summer Michelle had the opportunity to use Physics with Archaeology in a summer NSERC award held at Simon Fraser University. She worked with Dr. Erle Nelson using Magnetometery to search for buried earth ovens.

Michelle believes that Physics has helped her studies in Anthropology by giving her the ability to approach problems analytically. She finds that she has profited from a study of Anthropolgy by becoming a more complete person and by gaining a greater understanding of humanity. Michelle is planning to explore the connections between the two fields in more depth during graduate studies in the application of Physics to Archaeology.

Catherine Lucas
As long as she can remember, Catherine Lucas has always been interested in science. She enjoys the theoretical aspect of Physics and, like Michelle, what started as an elective blossomed into a major interest. Catherine was interested in a wide variety of areas and wanted to cultivate new ideas and develop necessary skills. Catherine is firmly opposed to the segregation of the arts and sciences, and is encouraged by the recent trend in universities to promote interdisciplinary fields.

Catherine found that Physics enabled her to bring a logical and systematic viewpoint to Comparative Literature. Apart from the obvious enhnacement of writing skills, she believes that Comparative Literature has other contributions to make to Physics. She says: "Comparative Literature is the study of literature in different languages. The central problem of Comparative Literature is: how much of the meaning is lost in translation? An interesting problem for the physicist to think about is, with Mathematics being the language of Physics, do we lose meaning in the translation to verbal language?" Since it is with language that we teach and communicate physics to other people, how can we be sure that the presented picture is complete?

Soumi Ghosh
Soumi Ghosh is the kind of student who just wants to know everything. She thought Physics would be a good place to start. Her interest in Psychology began her second year of university and she has sampled a variety of courses covering everything from abnormal Psychology to Neuroscience. She views the psyche as a 'black box' and now seeks to know what it is that makes us think and act in the way that we do. For Soumi, it is through Physics that one tries to find truth in the universe and it is through Psychology that one tries to find truth in humans. She plans to bring these ideas together through graduate studies in the Philosophy of Science.

Soumi contends that studying Physics has helped her appreciate the material side of human behaviour. And how does she see Psychology influencing Physics? "Theories in Physics are very much motivated by the personality type of the kind of person that studies Physics. Think of how Mozart or Monet or even Karl Marx would have described Physics and how their theories might have given Physics new insights." Soumi believes that by studying Psychology we can eliminate the human bias in science and come to an understanding of the fundamentals of the universe.

Carrie Klatt
As for me, I am finishing off my undergraduate studies in theoretical Physics and Philosophy. After my first few years of Physics I was disillusioned by the fact that I could now solve many mathematical and artificial Physics problems but, I had not yet had an opportunity to question the foundations of what I was being taught. I have found that the two subject areas have a great deal to offer one another. Physics offers Philosophy more problems to work on and provides an alternative understanding of the universe. For me, it was Philosophy that gave Physics back its beauty. Its critical style opened new arenas to consider and various interpretations to try. I found that it was only through a combination of the two that I was able to make sense of either.

After asking my three classmates about their interests and opinions, two points became overwhelmingly obvious. First, we all agreed that today. especially in academia, we are confronted with the problem of specialization. To know something so deeply at the expense of how it relates to other areas is to not know it completely. As a result, specialization, especially at an early point in one's education, proves limiting. As students and scientists it is important to appreciate the position of others and how their interests relate to our own.

Second, as expressed most clearly by Michelle, "women aren't men and the shouldn't try to be". Even though women have the same potential and interest in Physics as do men, they often bring a different viewpoint to the study. Soumi commented that I could have done this article on men and women who are studying Arts and Physics but most of my examples would still have been women. It would seem, at least for this group of students, that there is something in the liberal Arts that is not in Physics that we just cannot, and perhaps, should not, do without. If women have a natural interest in more Artsy endeavours then this will add to the diversity in Physics. Women also develop different approaches to problems and introduce a warmer and more cooperative environment. Basically, we bring those things to the Physics community that are part of women and not of men.

The moral of the story is that as women in physics, we do not need to enter the profession as sheep in wolves' clothing in order to be successful and productive. There are special attributes that a female presence brings to the contemplation of the universe. Their specific interests can only add a new dimension to the study of Physics.

PHYSICS INDIVIDUAL PROFILE - MARY ANNE WHITE

Dr. Mary Anne White has been a member of the CAP since shortly after receiving her PhD, although all her degrees are in chemistry. However, she has long been of the opinion that physics and chemistry are very closely related subjects. Indeed, some of the most interesting science occurs at the interface between physics and chemistry.

A native of London, Ontario, Mary Anne graduated from the University of Western Ontario in 1975 with the Alumni Gold Medal in Chemistry. Her first research experience was in the Physics Department at UWO in 1972, when the first-year physics lab instructor, Pat Chefurka, hired Mary Anne as a summer research assistant to work on Langmuir-Blodgett films. It was this taste of research, along with a love for teaching, that determined Mary Anne's career path.

Supported by an NSERC 1967 Science and Engineering Scholarship, Mary Anne studied for her PhD with the late Jim Morrison, who was then Director of the Institute for Materials Research at McMaster University. Although Jim taught chemistry at McMaster, he supervised both chemistry and physics students, and his lab was located in the physics wing. In addition, without knowing their addresses, it was difficult to guess whether the (many) visitors to the lab were physicists or chemists. This atmosphere provided an excellent introduction to first-class research without labelling it "physics" or "chemistry". Mary Anne's PhD thesis title was "Orientational Ordering in Solid Methane at Low Temperatures".

In 1979, Mary Anne was awarded an NSERC Postdoctoral Fellowship, and she used the opportunity to spend two years at Oxford University, splitting her time between calorimetric studies with Lionel Staveley in the Inorganic Chemistry Laboratory, and neutron scattering studies with John White (who was then Director of l'Institut Laue-Langevin, Grenoble). In addition, Mary Anne held a Junior Research Fellowship at St. Hilda's College, providing her first (and very interesting) experience with a women-only educational institution.

In 1981, NSERC smiled on Mary Anne again, and she was awarded an NSERC University Research Fellowship, which she initially took up as an Assistant Professor (Research) at University of Waterloo. In 1983, with the offer of a tenure-track position, Mary Anne moved the NSERC URF to Dalhousie University in Halifax, where she has risen through the ranks to the present position of Professor of Chemistry and Professor of Physics. Although Mary Anne teaches only in Chemistry, she has had research students from both Chemistry and Physics.

Like most professors, Mary Anne's work involves a balance of teaching, research and administration. Not only does Mary Anne enjoy teaching and research, but she has received several recent recognitions for these aspects for her work, notably the Faculty of Science Award for Excellence in Teaching (1993), the Alumni Association Award for Teaching Excellence (1993), the Stig Sunner Memorial Award of the Calorimetry Conference (1994) and the Noranda Award of the Canadian Society for chemistry (1996). In 1991, Mary Anne visited 11 Canadian Physics Departments as a CAP lecturer, presenting a lecture "Properties of Matter: From Fudge to Photocopying".

Mary Anne's area of research is thermal properties of materials, especially solids with weak orientational forces where dynamical disorder is possible. She leads an experimental effort in which the approach is measurement of thermal (and related) properties of solids, usually with custom-designed apparatus, in order to understand fundamental processes governing such matters as heat conduction, polymorphism, and thermodynamic stability. The systems studied have been chosen to probe particular intermolecular interactions; inclusion compounds have been very useful in this regard, leading to a general understanding of heat conduction in molecular systems which is quite different from the "textbook" cases of simple solids. (Optic modes play important roles in molecular materials). The work is "chemistry" in the sense that the systems studied are mostly molecular, but most of the measurements can be called "physics" if you adhere to the old adage that vacuum lines distinguish the fields (metal for physicists, glass for chemists).

At present Mary Anne has five students in her research group - two PhD students, two MSc students and one honours project student. Four students have complete PhD's in her group, and one student has completed an MSc. Of those completed, all are employed in the USA. Of the chemists, two hold positions at universities and two are in the pharmaceutical industry. The physics PhD has chosen to apply his excellent experimental and theoretical skills in the field of medical physics.

Most of the work in Mary Anne's lab is supported by NSERC through research grants. She has also held contracts or grants from NATO; Stelco; E.I. DuPont; Energy, Mines and Resources; S.C. Johnson; Canadian Industrial Innovation Centre. Mary Anne has been author or co-author of more than 70 research papers and one book chapter. In addition, she is just completing a textbook (working title: "Properties of Materials") for a materials science class which she has developed.

On the personal side, Mary Anne is married to Robert White. Although they met when they were both graduate students in chemistry at McMaster, they really got to know each other on the baseball field (Rob was the captain of the organic chemistry team, and Mary Anne - being a physical chemist - was the team statistician). Rob is also a faculty member at Dalhousie University. Their research areas are quite far apart (Rob is a biological chemist) and they have never yet managed a laboratory collaboration (those biological systems require too high temperatures for Mary Anne's cryogenic interests!), but they have collaborated on two children - David (b. 1982) and Alice (b. 1985).

Outside of teaching, research and family, Mary Anne is interested in music and also in bringing science to the general public. With several others she helped open Discovery Centre, an interactive science centre in Halifax. She also has been involved with Discovery Channel (she had a spot called "How Things Work" in their inaugural season), classroom visits and radio (e.g. Quirks & Quarks). Altogether, she has a very full and fun life!

MARRIED TO A FELLOW PHYSICIST, 2000 MILES AWAY

by Anna Hayes and Stephen Sterbenz

The family profile of a physics couple might seem a mundane subject to feature in a journal. As one friend put it, "you don't really want to tell about any of the interesting stuff and the rest nobody cares about". Nonetheless, we decided to accept the invitation to produce a profile, encouraged partially by the hope that it might help raise awareness of some of the issues facing physics couples.

The major difference between our family and "normal" families is that Steve is a staff member at Los Alamos National Laboratory in New Mexico and I am a staff member at the Chalk River Laboratories of AECL in Ontario. These two labs are about 2000 miles apart. Thus, we find ourselves running two households and living apart most of the year. We have two children, Maeve (7 years old) and Ciara (2 years old), who talk about 'our house in Candada' and 'our house in Mos-ahmos'.

Living this odd life style has been difficult, but we feel that in some sense it was almost inevitable. Dual physics couples are confronted with three possibilities: (1) one of the two quits physics, (2) both stay in physics but live apart, or (3) they obtain positions together (or at least in the same geographic region!). Situation (3) is obviously the ideal one. However, it is also the most difficult to achieve. Situation (2) is easier to arrange than (3), but of course much harder to arrange than (1), since one of the two can always quit. Unable so far to achieve (3), we have for now made the agonizing choice between (1) and (2) in favour of (2). We have encountered a wide range of opinions on the wisdom of this choice.

A brief history of our careers may help clarify how we got ourselves into the second of these classes, working now at opposite ends of the continent. We were graduate students together at Yale at the nuclear physics lab under D. Allan Bromley, and we got married while at Yale. Steve is an experimentalist in nuclear physics and I am a theorist. After graduate school we maintained situation (3) for a while, obtaining postdoctoral positions together at the University of Minnesota. From Minnesota we moved to Los Alamos to take up our second postdoc positions.

Toward the end of our postdocs at Los Alamos (1991) I was offered a permanent position at Chalk River. Everyone in nuclear theory was (and still is) finding it very difficult to get a permanent position, and so this seemed quite a stroke of good fortune. However, there simply wasn't a position at Chalk River for Steve at the time. Nonetheless, Chalk River being a large institution, we had some hope that things might open up in a year or two. Just after I took up my position at Chalk River, Steve was offered a permanent position at Los Alamos. There was no position for me there, but again there might be possibilities in a year or two! We did not foresee what the job climate and research budgets were to become.

We would define ourselves as a very '90s family' - which means complicated. Ciara, our younger daughter, lives with me in Canada most of the year, and Maeve has just begun to do extended stays with Dad in Los Alamos. Changing schools halfway through the year seems to be something you can get away with when you're seven years old, and Maeve actually doesn't seem to be uncomfortable with that. For me, though, trying to raise two children alone while doing physics is no easy task. I learned quickly to change some of my parental standards. For example, being late for school and eating frozen dinners in the evening has become part of daily life. Dressing the children in matching socks is a thing of the past, but so far we have no evidence that our situation has been harmful to them.

However difficult the logistics of single parenting, I see that the one living away from the children has the harder role by far. Like all parents, witnessing and sharing the various milestones our children pass brings us great joy. Hearing by phone, or even worse, by e-mail or voice-mail, that your toddler has learned to walk or to talk, or that your second grader can read or is in the school play can really make you question why you're doing physics 2000 miles away. Of course, we talk on the phone as a family several times a week (the phone company loves us), but when it comes to two-year-old children, the phone is not a particularly good form of communication. In fact, half the time we're not quite sure if Ciara is even listening, and the rest of the time we're not sure she knows she's talking with a person.

That we have not chosen to switch to the first of the three options I presented above for dual career couples reflects the reward we get from physics. The greatest reward is probably just that which every physicist feels who has the luxury of being paid to do what he/she loves to do. We both agree that physics has been a good career choice in terms of on-the-job satisfaction. Furthermore, being married to a fellow physicist has had some advantages. One of these is having someone to whom you can ask that dumb question that you're too embarrassed to admit your confusion on to anyone else. We probably engage in more shop-talk than even the average physics couple, since we share the same subfield. The experimental vs. theoretical split in the family helps to keep egos under control. In fact, we published a comment in Phys. Rev. together recently. Another advantage is that we tend to know about twice as many people in physics as we otherwise might, and some of these connections have lead to fertile collaborations.

A large fraction of our conversations concern physics. The fraction probably crosses the 50% margin if you include physics gossip! Daughter Maeve recently provided an interesting comment about this. Steve found himself lacking a babysitter one Saturday and ended up taking Maeve to sit at the back of the meeting room at a physics conference. When I asked her later what she thought, she said that it was no different than the usual conversations Mom and Dad get into, especially when we have our friends over.

I think it's fair to say that the details of our careers are not particularly significant when it comes to explaining how it is that we find ourselves working at different institutions. This is because in the present job climate it is unrealistic for most couples to expect to find positions together. At the same time, the 1990 AIP survey of members of the American Physical Society shows that about 70% of women members are married to another scientist. It's worth noting, however, that the same survey found that "women do not appear to be in favour of special consideration; most of them simply want the barriers to their success removed". I subscribe to this point of view myself.

A barrier that some women have faced involves opinions held by some other physicists on the issue of possible pregnancy or maternity leave and its bearing on a woman's application for a job or a fellowship. The question of how pregnancy might affect our job performance has never been raised explicitly with us by any employer. However, both of our daughters were born during frantic and critical times in our careers and we were very concerned about this issue. In fact, in connection with Maeve's birth (while we were at U. Minnesota), I spent not more than about three weeks away from work, thanks largely to my sister's being able to come over from Ireland and act as nanny for a while.

Perhaps the trickiest obstacle we have met at job interviews is the grilling to which we are generally subjected on the issue of the 'trailing spouse'. This arises because most potential employers do not want to make a job offer to someone who may turn the offer down because his or her spouse can't find a job at the same institution. In all job interviews, we tried to make it clear that we were not asking for two jobs, because we felt that our probability of success in a close-coupling arrangement was dramatically diminished. Nonetheless, at one university, we discovered indirectly and long after my interview that although I was the top candidate, I was not offered the job because I was married to a physicist. Eventually, the problems that this issue raised at job interviews became so serious and frustrating that we thought of circulating a rumour that we were about to get a divorce!

In surveying some male physicists whose spouses are not physicists, we found that in general they were not asked to spend significant time discussing their spouses during job interviews. In our opinion, this male/female asymmetry is unfair. We feel that the best candidate should be offered the job and that couples should be given the opportunity to decide for themselves whether or not they want to chose the second of the three options. We recognize that this policy may have difficult practical implications for university departments and laboratory administrators, but would ask them to consider the far more profound implications for people like us. Making an offer on merit alone makes the selection clearer and easier, and little real harm is done. If the candidate does chose to decline the offer because of the spouse's lack of an offer, then the institution can still make an offer to the runner-up if the decision is demanded in a timely fashion.

Since setting up our two separate homes in 1991, we have managed to live together as a family for an extended period only when Ciara was born. About a month before the birth, Steve took family leave from Los Alamos. During this month we both worked at Chalk River, Steve keeping up with things back in Los Alamos but also helping on a volunteer basis in an experiment here. After Ciara was born I took maternity leave from Chalk River and moved to Los Alamos. Being a physics fanatic, I used my leave as a "sabbatical" at Los Alamos, and so we lived as a 'normal' family in situation (3). I worked essentially full-time in the theoretical division at Los Alamos, who kindly provided me an office and computational facilities but no salary or expenses. From a physics point of view this was a good year, and I was able to use the opportunity to get involved in new collaborations. However, my drive to do physics did cost us many thousands of dollars in daycare expenses. The luxury of living together as a family and working full-time in physics seemed worth the cost.

Our careers have been very rewarding and successful for us as individuals. Steve is now managing a very large program at Los Alamos, and I feel I have achieved reasonable recognition in my field, but these successes have come only with great sacrifice. The overall situation, involving family trips as frequently as can be arranged (about every six weeks to two months), has been bearable, but only by a small margin. Maeve enjoys a very good relationship with Dad which may have been developed in part as a result of our unusual lifestyle. She appears to accept our situation with only minor complaint and is pretty much a happy kid. Ciara is too young to express her feelings in the form of a complaint. She talks about Dad a lot, but between visits she sometimes seems even to forget what he looks like. We haven't found the ultimate solution to our problematic situation. In fact, I do not know whether there is a perfect solution to the obvious problem that we and most other physics couples face. But we still remain hopeful that, in our case, it is somehow just around the corner.

PHYSICS FAMILY PROFILE: JOHN BERLINSKY AND CATHERINE KALLIN

We are delighted to have the opportunity to write for *Physics in Canada* about our experiences as a "physics couple." This type of article is useful for a number of reasons. On the one hand, it documents some of the internal barriers which are built into the academic/research system and which are more or less invisible to everyone except those who are directly affected. At the same time, it allows those of us who are in this situation to "compare notes". In our experience, this type of comparison frequently reveals a surprising consistency and recurrence of similar experiences. For these reasons we hope that our contribution to this collection of articles will be useful and interesting to other present or prospective physics couples and also to their colleagues, supervisors and administrators.

How we first got together as a physics couple is a long and (for us) interesting story which we have decided to defer to our memoirs. The most noteworthy event for the purpose of this article is that we were married in May 1983 at a small, private ceremony in West Point Grey, Vancouver. Catherine was then a grad student in her third year at Harvard, and I was an established, i.e. tenured, Physics faculty member at UBC. At the time of our marriage, Catherine was spending the semester at the Institute for Theoretical Physics (ITP) at UC Santa Barbara, where her Ph.D. thesis supervisor, Bert Halperin, was on sabbatical. When we returned there and announced our new status at lunch on the Santa Barbara pier, Bert first chastised Catherine for making such an important move without consulting her supervisor and then ordered a round of champagne to celebrate.

The following year Catherine completed her thesis on cyclotron resonance and electron-electron interactions in the two-dimensional electron gas. At that time the fractional quantum Hall effect was a hot topic and her thesis work was a useful contribution toward understanding excitations from the FQHE state. In the Fall before graduation, like any other finishing graduate student, she sent out a number of letters applying for post-doctoral positions and then waited. Being Canadian she also applied to NSERC which had generously supported her graduate work. As frequently happens, she then spent months biting her nails, waiting for replies, then had one day of pure ecstasy when the first offer letter arrived, and next was plunged into confusion with the arrival of the second offer. The two key offers happened to come from two Nobel prize winners who were known to be somewhat competitive. The matter of which offer to accept loomed as a decision which could just as easily end a career as start one. In the end, diplomacy paid off and Catherine emerged unscathed. Fortunately she still considers both prospective employers to be friends.

The decision was to accept an offer from the ITP in Santa Barbara where the Director was the Condensed Matter theorist, Bob Schrieffer. Not long afterward, NSERC came through with a post-doctoral fellowship, which we used to negotiate an agreement with Santa Barbara and UBC so that Catherine could spend several months each year working in Vancouver. This agreement turned out to be particularly important the following year when our daughter was born. The transition from grad school to post-doc changed a trans-continental commute into a short North-South hop. Also the difference between graduate and post-doc salaries was enough to cover our phone bills and to allow me to pay off the line of credit which had been steadily accumulating at the bank.

The ITP was a lively pace in 1984/85 and quite hospitable to a young commuting couple. We met a generation of post-docs who are now professors scattered across North America and grad students who are working their way through the ranks. One physics couple, who we did not even realise were a couple, were secretly married with a child being raised by grandparents in England. It was a good surprise to everyone when we were invited to a party where this was announced. Steve Kivelson, now at UCLA, and Daniel Arovas, now at La Jolla, worked with Catherine and Bob Schrieffer on the "correlated ring exchange" theory of the FQHE, an original and intuitive alternative way of looking at Laughlin's wave function, and I garnered thousands of frequent flier miles with Western Airlines, which finally earned me a free ticket that I was never able to use because it arrived as we were leaving California. Most important of all, however, was the unexpected but welcome realization that we were fated to become parents.

This was where the flexible arrangement with ITP and UBC paid off. I rented a small house on a large lot in the Dunbar area of Vancouver, and Catherine moved up at the beginning of August 1985, with the understanding that she would be back by late December for the last six months of her post-doc at ITP. I had an agreement with my department that I would do all of my teaching in the Fall and then spend the following semester at ITP, and Catherine was given the office of Myer Bloom who was away on research leave. We also started to worry about Catherine's next job since, with only six months left at ITP and a new baby, we needed to cut down on the commuting. Almost miraculously we heard that UBC would be nominating someone for an NSERC University Research Fellow position. However we soon learned that this opportunity was likely to be a long shot. When Catherine approached the Chair of the hiring committee, she was told that the department was looking for applicants "...with letters from Nobel Laureates," but that it was OK for her to apply as long as she wouldn't be disappointed if she didn't get the nomination.

Our schedule for early September revolved around childbirth classes, which we attended, graduate Stat Mech and undergraduate Quantum Mechanics, which I was teaching, the Physics Colloquium, which I was organizing, and arranging for letters from Nobel Laureates. Catherine's job talk was scheduled for September 11, which fortuitously fell on the birthday of our daughter, Ann Berlinsky Kallin (*no hyphen*). Catherine's talk on the Correlated Ring Exchange Theory of the Fractional Quantum Hall Effect was postponed for two weeks. The department had great difficulty dealing with Catherine's application and, in the end, no one was nominated. Immediately after this decision was made, our friend Steve Girvin arrived to give a colloquium on the quantum Hall effect, and I had the pleasure of introducing his talk on the day after von Klitzing received the Nobel Prize for discovering the effect.

With no job prospects at UBC, we began scouring the market in earnest. After years of commuting we made the conscious decision to market ourselves as a package. Wherever we went we interviewed as a couple with babe in arms. This led to many hilarious situations, far more than we have space to describe, but we did end up rating places on how well they handled the special circumstances of our interviews - whether they arranged full schedules of independent interviews, what care they provided for Ann, and whether sufficient time was allowed for nursing, rest, etc. In this regard, the two Canadian universities where we interviewed, Waterloo and McMaster, did very well. By contrast, certain California universities performed abysmally. Not only were they insensitive to the logistics of interviewing a couple with an infant, but we were also introduced to reverse nepotism, and more than one case of token interviews. On the other hand, we had one delightful interview at a U.S. national weapons lab, which we were not so interested in, but which treated us graciously, and we will always cherish the image of Ann with a security badge pinned to her bootie.

Ultimately we were very fortunate in finding positions at McMaster. I traded teaching for administration and took over the Directorship of the Institute for Materials Research which Jim Morrison, a chemist, had just relinquished; and the Physics Department was happy to appoint Catherine to a tenure track Assistant Professor position in Condensed Matter Theory which they had been trying to fill for over a year. Catherine was the first woman in the physical sciences at McMaster, and we have learned a lot from that. Much of what we learned has now been incorporated into a mentoring program for junior faculty in Science and Engineering which was instigated, at Catherine's initiative, two years ago.

Having two real jobs in Hamilton imposed an unfamiliar stability on our lives. We spent a year finding a large house in downtown Hamilton, which we love but which will never be worth what we paid for it. Of central concern was child care for Ann. Our child care in the U.S., which had worked well, consisted, fortuitously, of a succession of three wives of male, Korean physics graduate students, each of whom had two small boys of her own. Our first child care in Hamilton was with a couple who took in several children in their home. Although they came highly recommended and are still used by other physics parents, we found after a few days that we were uncomfortable with them and quickly made different arrangements. Having complete confidence in your childcare providers is an absolute necessity for working parents, and even misplaced apprehension (as ours may have been) is unacceptable. A newspaper ad led us to Yolanda (Ann always called her "my landa"), a young mother with two small boys, who was happy to care for one child in her home. Yolanda loved having Ann, since she very much wanted a daughter. By the time that Ann moved on to day care, Yolanda had four sons, but still no daughter.

We put Ann into day care because Yolanda and her family had moved to a farm in an outlying suburb of Hamilton, and the drive was just too long. McMaster has two day care centres, one located on the campus and one, run by the McMaster Students Union (MSU), a few blocks off campus. We never experienced the on-campus day care because we never made it to the top of the waiting list. However Ann was accepted into the MSU day care after only a few weeks. Although the Students Union sponsors the day care, the staff and management are full-time professionals. In fact, we found the quality of the care in this centre to be outstanding. Ann stayed there through senior kindergarten.

Preschool child care is designed for the convenience of working parents, but the school system has not yet come to grips with the concept of two-working-parent families. As a result they start inconveniently late, end at a time when most parents have to be at work, and are closed on holidays and "professional development days" when everything else is open. In Hamilton, the slack is taken up by a service called First Base, which is run by the YMCA and which provides before and after school child care and day care when the schools are closed. This works well for younger children, but eventually they outgrow it. When we realised that that was happening for Ann (toward the end of second grade), we hired Kathleen who comes to our home every day in time to meet Ann when she comes home from school. After a very short time, we found that Kathleen was taking care of us too, and she has since become an indispensable part of our family. Many years ago, Mildred Dresselhaus of MIT, a member of one of the more famous physics couples, advised us that the key to success for working couples was to get as much help as you can. (Millie's other tip for women physicists was to have a good husband.) Money spent on child care, house care, or just about any other kind of care that you would otherwise have to do yourself, is money well spent. We have certainly found this to be the case and have benefitted greatly from the people who have provided us with these services.

One issue whch is closely related to child care and to balancing family and work is that of travel, which can range from day trips, through conferences and committee work, to leaves and sabbaticals. Over the past ten years we have accumulated considerable experience with all of these and more. A particularly complicated situation is when both parents have to travel at the same time independently. In those cases and in the absence of nearby grandparents, having the possibility of overnight child care, which for us was provided by Yolanda and later by Kathleen, is essential. Of course when both parents travel together, it is frequently possible to bring the kid(s) along. We have done this many times - sometimes bringing our sitter, sometimes arranging on-site child care, and sometimes just "winging it" - and Ann actually considers it a perk. She has particularly enjoyed the weeks that we have spent over several summers at the Aspen Center for Physics where she has met many other physics kids.

Research leaves and sabbaticals present different problems. One problem is coordinating them. Catherine had two leaves, one for 4 months at AT&T Bell Labs in New Jersey (paid for in part by her Sloan Fellowship) and the other for 8 months at Cornell which was part of her first real sabbatical, for which Ann and I remained in Hamilton. Of course we visited a lot, and, in the case of Cornell, I learned that by leaving Ithaca with Ann at 3:00 a.m., I could drive back to Hamilton in time to drop her off for school. Once, in 1991, we were able to coordinate a six month leave together which we spent at UBC and which allowed me to resurrect a long-standing and extremely fruitful collaboration with Walter Hardy and, in fact, to bring Catherine into it too. Next year, for the first time, we will be able to take a full year research leave together at Stanford.

We are now in our 10th year at McMaster, and we have had ample time to reflect on the barriers and pitfalls which beset Physics couples, as well as some of the benefits. We know we have been lucky, and we have a great appreciation for the progress that has been made in mitigating the situations of women faculty and couples. Programs such as parental leave, which were not available to us, are crucial for making academic careers livable for new parents. No mother should have to lecture two weeks after her child's birth, nor should one highly qualified member of a couple have to languish in un- or under-employment because of traditional prejudices about women or working couples. Adequate child care facilities are essential for working couples and for single parents. A variety of types of child care are required for different stages of the children's and the parents' development. Although there has been much progress in these matters over the past decade, the way has been slow and painful, and flexibility and imagination are still essential tools for survival. Equally well, the experience of others can be a useful guide. The advice that we received over a decade ago from Millie Dresselhaus has proven invaluable for us, and we hope that some of the anecdotes in this article will be of use to future physics couples.

PHYSICS FAMILY PROFILE: JENIFER AND MICHAEL THEWALT

When we were invited to submit an article to this special issue of Physics in Canada it was impossible for us to ignore the opportunity. Besides being one of the few (two?) married couples in Canada to hold faculty appointments in Physics Departments, the guest editor of the issue is none other than Jenifer's sister Ann McMillan. Any sense of professional responsibility prompting us to write the article has thus been magnified enormously by sisterly duty. As this is primarily the story of Jenifer's attempts to seek permanent academic employment since the early 1990's, the article will be written from her perspective. The 'women's issue' this article will address is that of targeted appointments, in particular spousal appointments. Many readers may have well-formed opinions about this issue: perhaps this article will provoke some philosophical reassessments.

The invitation to write this family profile came in the summer of 1995, a time of considerable turmoil in our careers - I will elaborate on this later. First, though, I will summarize our personal and professional backgrounds. Married for 13 years, we met in 1981 when I was a graduate student in Chemistry at Simon Fraser University and Mike was a young Assistant Professor of Physics and NSERC University Research Fellow. Following a 10-month courtship, we married the following summer, having neglected to develop detailed plans for our future careers. Mike had no real need to plan, having already achieved international recognition in his area of experimental physics: low-temperature luminescence of semiconductors. He worked single-mindedly and enthusiastically, developing ever better spectroscopic methods to further the understanding of the optical properties of semiconducting materials. On the other hand I was now geographically tethered: there are just two universities in the Lower Mainland of British Columbia. Fortunately, one of the world's leading research groups in my area, NMR applied to membranes, is located in the Physics Department at the University of British Columbia under the intellectual umbrella of Myer Bloom, currently Emeritus Professor. I obtained an NSERC postdoctoral fellowship to go across town following my Ph.D., arrived at UBC five months pregnant, and took advantage of the maternity leave provisions of the NSERC awards to spend one full year at home with our son Eric in 1988.

The first years back in the lab were, in retrospect, challenging ones. Initially there was some insecurity involved with being in a new environment, with new people, and embarking on new research projects. Added to this was the inevitable worry about Eric's well-being: he was looked after by a lovely and caring young nanny during the day, but no matter how exemplary the person, changes in child-care arrangements are always accompanied by some anxiety. Evenings were fully occupied with Eric, an active and captivating toddler who had the habit of being wakeful between the hours of one and three a.m. This habit was broken out of necessity shortly after I started work: Mike's membership on the condensed matter NSERC grant selection committee entailed a week-long sojourn in Ottawa in February, during which I managed to convince Eric of the value of uninterrupted slumber. Mike continued to have tremendous committee work responsibilities during Eric's early years, an aspect of professorial life he relished somewhat less than his research. Travelling would take its toll, he often returned not only tired but viral, to be greeted by a fatigued 'Physics widow' who had held the fort in his absence.

This unbalanced life-style persisted until a chance remark by one of my UBC colleagues raised my consciousness. Asked where Mike was, I replied that he was in Ottawa, serving on the (now defunct) NSERC Women's Faculty Award (WFA) selection committee. This prompted the ironic realization that Mike was helping distribute jobs to my peers while I was 'at home watching the kid'!

Overcoming my natural tendency to finish experimental studies but leave until an undefined 'later' the writing up and publishing of results, I began to heave my CV out of the doldrums, with the aim of eventually applying for a WFA. A gentle suggestion from Myer Bloom that I concentrate on forming links with other departments, given my chequered Physics past, was duly noted. My pedigree consists of an undergraduate degree in Biophysics and a doctorate in Chemistry, followed by postdoctoral work in a Physics lab. Physics department traditionalists still often frown on expertise outside 'pure' Physics, regarding such knowledge as contaminating rather than enhancing a researcher. Other departments have the complementary view, by and large. Since career advice from Myer was rare (he prefers a non-directive supervisory approach), I took it seriously, especially since interdisciplinary work dovetailed with my preferences. A fledgling collaboration with Neil Kitson in the Division of Dermatology at UBC, studying the physical properties of skin lipids, was nurtured and gradually began yielding papers.

Neil's encouragement included vague references to faculty positions in Dermatology, and the following year - 1993 - I hatched the scheme of creating a WFA position jointly between Physics and Medicine at UBC. Neither Mike, whose lab was by now fully established, and who held an NSERC Industrial Research Chair at SFU absolving him from teaching for five years, nor I, who loved my work at UBC and whose parents live nearby, wanted to move away from Vancouver. However, creating a position for oneself is never a straightforward process and creating such a position spanning faculties is even more difficult. In this case, though, the process was facilitated by the Head of the Division of Dermatology, David McLean, who enthusiastically supports links between Medicine and 'hard science'. Similarly supportive was the Head of the Physics Department at UBC, Brian Turrell, who feels that a Physics approach can be invaluable for problems outside traditional Physics, and who also feels that the discipline of Physics can benefit by being perceived as useful by researchers in other disciplines. In the summer of 1993 the Division of Dermatology took the initial step, in the form of a five-year plan entry for a membrane biophysicist, toward creating a position for which my skills would be ideal. Under Brian Turrell's direction, the UBC Physics department's Committee on Initial Appointments evaluated my WFA research proposal, solicited letters of reference, asked me to give a colloquium and interviewed me. In other words I received fair treatment, despite the complication that UBC had imposed a hiring freeze which extended even to the subsidized WFA program. This point, however, became moot once the Physics department discussed whether or not to support my WFA nomination. Objections were raised because the position had not been advertised. How one would go about advertising a position under a university hiring freeze was not clear, but, nevertheless, the department decided not to support the application. This was a disappointing turn of events, but my nomination went to Ottawa anyway, with the sole support of the UBC Dept. of Medicine.

Thus ended six weeks of the most grueling effort I can remember. Mike had had two week-long trips to Japan during that time, and I operated on 3-4 hours of sleep, hiring baby-sitting in shifts, and becoming more and more frazzled. The excitement of working to a deadline, and having the potential to generate a permanent position, was enough to sustain this fairly short-term effort. Over the long term it would have been painful to see the effects on Eric, who was, no doubt, being neglected by his mom: small cracks began to appear in his demeanor, his musical education stopped progressing with the customary rapidity, and he seemed generally less content. This intense work paid off in one sense however: for Mike it was concrete evidence of my ambition, and he became more fully appreciative of my desire for an academic career.

In January, 1994, the WFA committee met. Mike had tried unsuccessfully to resign from the committee once it became clear that my nomination was on its way to Ottawa. This sort of committee work is largely thankless: like the peer review process it relies on the continuing generosity and community-mindedness of scientists in Canada. Mike was left in the awkward position of standing anxiously outside in the hall for 20 minutes while the committee discussed my application. As a side remark: the ethics of the committee were flawless and Mike was given no hint of the fate of my application. This rather inhuman adherence to the rules was most unsatisfactory for me - while Mike was in Ottawa, I had had the usual single parent experience made orders of magnitude more unpleasant by the odd situation. Psychologically it was difficult having my spouse in a perceived position of power over my career and there was an inevitable build-up of resentment as a result. At the time of my nomination I was one year beyond the recommended 'time since Ph.D.' for the WFA awards, and was thus not overly optimistic about the outcome. Six uncomfortable weeks passed before I heard that I had been unsuccessful, and even though the news was not unexpected, it was still a blow. Self-doubt, self-blame and feelings of rejection were prevalent mental states for some time following the announcement: there was a sense of doors closing permanently - a frustrating scenario for me at the age of 36. These feelings were compounded by our continuing failure to conceive a second child. The unadvertised creation of a position for another young physicist at UBC in the late spring was a further source of frustration, as was the decision by the UBC Physics department to advertise for a WFA position that year. Meanwhile Mike was suffering in sympathy, and the death of his father in June compounded his grief.

In contrast, my research effort was going well, with the first comprehensive papers from the Dermatology collaboration being accepted for publication, and with an invitation to speak at the annual meeting of the C.A.P. in Regina. Mike spoke at the same meeting, and for the first time we travelled together on a joint business trip. I stayed only two days, then left to get back to Eric and to stop the accumulation of non-deductible extra child-care costs. It was a good trip: I returned feeling a sense of renewed energy due to the positive comments my talk had received. In addition, I had had the chance to catch up with my sister Ann, always an encouraging and understanding figure.

Later that summer, Mike, never one to tolerate sub-optimal situations unless given no choice, began considering career options for us. A casual comment here and there at SFU regarding my lack of a permanent position and the potential necessity for us to move away from Vancouver began a series of events whose velocity and acceleration surprised even Mike. I was fortunate in that my interdisciplinary background fitted in well with Dean of Science Colin Jones' plans to enhance cross-disciplinary research: an attractive area for graduate students. Over the fall months of 1994 informal discussions were held among various departmental chairs and the Dean of Science regarding the possibility of creating a position for me at SFU. These discussions led to a proposal by Colin to establish a targeted joint appointment between the Department of Physics and the Institute of Molecular Biology and Biochemistry (IMBB). This was not a decision that was made casually: there was extensive discussion in the Physics Department about the situation. Prof. Frindt, department chair, sent a memo to his faculty advising them of the problem, emphasizing Mike's central role in the department's success in raising research funds, and outlining my background, appending my WFA research proposal and the external reviews thereof. The Dean met with the Department of Physics as a whole to discuss the establishment of the joint appointment and also held discussions with the Director of the IMBB. By secret ballot in which Mike did not participate, a decision was made in favour of pursuing the idea of creating a position for which I would be considered. The decision was not unanimous: some members of the department felt that the exercise was one in which pragmatism was completely outweighing 'principle'. In the end, the department made the courageous choice to proceed with their evaluation of me, clearly labelling the potential job a spousal appointment.

An appointments committee was formed at this stage, letters of reference were solicited in the usual manner, and I was interviewed on May 1, 1995 by both the Physics Department and the IMBB. The interview did not feel in any way watered down due to the 'spousal' nature of the position: I presented two one-hour talks, a teaching demonstration and a research seminar, met with members of both departments, and was thoroughly exhausted at the end of the day. Monday May 1st was also the deadline for NSERC Collaborative Project Grant proposals to arrive in Ottawa, and I had been busy up until the Friday before putting the finishing touches on a grant application. (This process was a little frustrating since I had discovered rather late that I was ineligible to apply for such a grant due to my lack at that time of a firm offer of appointment - the application instead was submitted in the names of my collaborators.)

Time passed, as one member of the appointments committee was away. When the committee members were reunited, they wrote a report recommending me for the position. The members of the IMBB had voted unanimously in favour - a much-appreciated vote of confidence. Finally, the Physics Department ratification vote was held, and achieved in excess of the required two-thirds majority. SFU's Board of Governors approved my appointment in late July, and my employment contract was signed soon after. This would normally signal the 'Happy Ending' of this article.

Instead, events took a turn into the arena of academic pulp fiction. One day in mid-August, while I was making measurements at UBC, one of my colleagues came in and took me aside. He told me that he had heard that I had been the subject of a talk radio program that morning. Stunned, I inquired further, and was told that a particular retired SFU Physics professor had taken his 'principled' objections to my appointment to the airwaves. My name had been mentioned, along with Mike's. A few phone calls turned up a copy of the tape, which I listened to that night. Factually correct but highly selective in content, the interview was insulting and biased. For example, throughout I was referred to as 'Mrs. Thewalt' - certainly not the appropriate title to use in matters relating to my career. Resisting the urge to respond to this attack on SFU's character, I tried to forget that the incident had happened. I was able to do this easily, as I was preparing to give an invited talk at a Gordon Conference the following week. The day before I left for the conference, however, I happened to encounter an acquaintance who had heard the radio show but who had not connected me with the content: embarrassment of both parties was kept to a minimum, but my anger level increased as I realised that my newly-minted public reputation was significantly less flattering than I would have preferred. Over the next few weeks there was a flurry of media articles in the local papers concerning my spousal appointment. The headline 'SFU Denies Nepotism' enhanced the vocabulary of the local tabloid's readership at the same time as it gave unwarranted negative publicity to the university. Finally, the university papers wrote their pieces about the issue, and the dust settled.

Emotional fall-out takes more time, but when I took up my appointment in September I felt generally warmly welcomed and comfortable. Notice received in October that the collaborative grant had been awarded was most welcome, and gave me a greater sense of autonomy, as did my recent appointment as Adjunct Professor of Medicine at UBC. Myer Bloom has continued to be an important source of support, and Mike has managed to navigate the minefield of playing the dual roles of husband and colleague with admirable dexterity. As far as being a two-career family goes, I feel exceptionally fortunate in two respects: Mike's preferred method of relaxation after work involves cooking, and Eric's live-in nanny, Petra Persch, is without peer.

The current over-supply of highly qualified people searching for university faculty positions at a time when university budgets are being reduced is regrettable and resentment of holders of targeted appointments of one kind or another is inevitable. In an ideal world, no-one would be under-employed. Spousal appointments are not a new phenomenon. Our situation was unusual in that Mike already had a position when my spousal appointment was created, but the end result is identical. Again, in an ideal world, jobs suiting both partners in a marriage would exist automatically within a confined geographical area. This is obviously an impossible wish. Some might say that one partner should sacrifice their career for the other's, and in fact we feel that I have done this in the past to some extent, although 'sacrifice' is too strong a word. Certainly, the combination of academic career and child-rearing is challenging for both parents. In our case, we feel that the slower start to my career, which will inevitably have a big impact on my lifetime earnings, is a reasonable price to pay for the lifetime privilege of having children.

MOVE BEYOND THE UNCERTAINTY PRINCIPLE IN FAMILY AND CAREER

by Ying Qi, Atmospheric Environment Service, 4905 Dufferin St., Downsview, Ontario, M3H 5T4

In physics and mathematics, there is a well-known uncertainty principle, which says "the precise measurements of time and frequency are fundamentally incompatible, since frequency cannot be measured instantaneously". In our life, career and family, particularly for a woman, are often in conflict with each other. A career woman may be successful at a cost to her family life. In this sense, family and career seem also to observe the uncertainty principle. It is hard for a woman to have both of them in perfect harmony!

I am an atmospheric scientist and now work at Atmospheric Environment Service (AES), Environment Canada as a contract research scientist. I have a simple family, my husband Jingnan Zhou and me. My husband is also an atmospheric scientist and now works as a research assistant at the Department of Earth and Atmospheric Science, York University. Actually, a three person family would be more exact as we will soon have a new member to come in the world --- our unborn baby. I once believed in and was bound up by the uncertainty principle in considering career and family, but finally I have moved beyond the influence of the principle in my life.

TO BE ALONE

Before I met Jingnan 8 years ago, I had decided to sacrifice my family life to develop my career in atmospheric sciences. When I was a child, I dreamed of being a great scientist in the world. Gradually, I realized that a woman with a normal family had a very difficult time to be successful in her career in science. As a matter of fact, many famous scientists, not only women but also men are single. In China, at least half or even more of the female fellows of the Chinese Academy of Sciences were single before 1989. These facts reminded me always of the existence of the uncertainty principle for family and career. I did not dare to expect not to be bound by the principle like Mrs. Curie , because somehow, I always believed in science much more than in luck.

Another reason for my decision to sacrifice my own family life to make my career successful was probably the love of my parents, elder sister and brother. They always supported me to develop my career family life. Each time I had a vacation, they invited me to go home so sincerely that I could not turn down invitations from them until I left China to Canada, even after I was married. They always let me feel part of the happiest family no matter what happened. Their love and care made me feel that I already had a happy family. I would not regret spending the rest of my whole life on my career.

MARRIED

Eight years ago, because of common interest in boundary-layer meteorology, I met Jingnan by chance. He was a lecturer at Nanjing Institute and I was a graduate. Jingnan is a person who likes to talk, particularly in the language of meteorology. He loves his career, too. However, different from me, he also wanted to develop a family not only his career. Moreover, he thought that common interest was one of the bases of a happy family in addition to love, understanding and care. During each meeting, although atmospheric science was always the topic of the meeting, we came to understand each other more and more Jingnan's personality influenced me and reminded me that I would lack something valuable in my life if I kept focussing on my career. Finally, I found our meetings were not only for meteorological conversation but also a part of my life which could not be lost. We got married one and half years later.

After we were married, we did not want a baby as a normal family would because I was still afraid of the uncertainty principle. However, I was not alone any more. When I was a Ph.D graduate at Nanjing University, Jingnan and I had a chance to work in the same computer terminal room as he had a cooperative program with Nanjing University at that time. When I was a postdoctoral fellow at Institute of Mechanics, Chinese Academy of Sciences, Jingnan was a visiting researcher at the same institute so we again, had a chance to share the same office. Frankly, Jingnan made much more contribution than I did to create our small but comfortable family. Perhaps, in a certain sense, I owed him a lot. While we enjoyed our special family, Jingnan got an excellent young professor foundation award in Jiangsu province. I got my Ph.D and published more than 15 papers and 1 book about my own research achievements. Shortly after that I was awarded the highest category of Changwang Tu's Young Meteorologist Prize by the Chinese Meteorological Society.

MOVE BEYOND THE UNCERTAINTY PRINCIPLE

In December 1993, I came to Canada as an NSERC visiting fellow, accompanied by Jingnan. We began to create our new family and career environment. Living abroad provided us more experience. We had more things to face and to deal with in each of our careers while we had to get used to the language, foods, etc. in Canada as soon as possible. We examined again whether we were under control of the uncertainty principle

A few months after we came to Canada, Jingnan got a position as a research assistant at the Department of Earth and Atmospheric Science, York University. We continued our common interest in boundary-layer meteorology and mesoscale meteorology. In the meantime, I realized that it would be more helpful both to Canada and to my career if I would make a direct contribution to Canadian atmospheric research science since I lived in Canada. Therefore, I further expanded my research domain and developed my two new areas. One is joining the research community for a new Canadian state-of-the-art mesoscale numerical model MC2. The other is exploring the applications of a new mathematical tool, wavelet analysis, to meteorological and air quality research. The latter is quite a though topic since wavelet analysis is described by modern functional mathematical language. To achieve the objectives, I have not taken any vacations since I came to Canada in December, 1993. It was our happy and relaxed family talk that often released me from intense work. We both enjoy the life style. In the mingling of intense work and happy family life, I have made some very encouraging progress in my new research areas. I have modified and improved one of the important schemes in the MC2 model and have successfully applied wavelet analysis in meteorology and air quality research. I thank Air Quality Research Branch at AES for supporting my work after the NSERC visiting fellowship was finished.

Over the past two years, we have experienced a lot and improved ourselves a lot, too. We surprisingly find that we can really comfortably balance our careers and family life. Perhaps experience has given us the ability. Whatever, we have enough confidence now to start a normal family life during our continued pursuit for careers in atmospheric sciences. We are ready to welcome our baby into our lives. Finally, I realize that I have moved beyond that uncertainty principle. Moreover, in a sense, I feel that the relationship between a family and career seems to be more like the relationship between water and a boat: water can carry a boat but water can also capsize a boat. Family life may be in conflict with career, sometimes apparently controlled by the uncertainty principle, but a happy family life can also become a source of inspiration for one's career life. Development of one's career can thus be greatly accelerated because of the existence of a happy family.

I should be thankful to Jingnan. He makes me own a complete life!

Books Received / Livres reçus

The following books have been received for review. Readers are invited to write reviews, in English or French, of books of interest to them. Books may be requested from the book review editor André Roberge by email at andre@gollum.phys.laurentian.ca or at Department of Physics, Laurentian University, Sudbury, Ontario, P3E 2C6. Tel: (705) 675-1151, ext. 2234. FAX: (705) 675-4868. Please check out our new Web site at http://www.laurentian.ca/www/physics/CAP/ and give us your comments.

Les livres suivants nous sont parvenus pour la critique qui peut être faite en anglais ou en français. Si vous êtes intéressés de nous communiquer une revue critique sur un ouvrage en particulier, vous êtes invités à vous mettre en rapport avec le responsable de la critique des livres, André Roberge par courier électronique via andre@gollum.phys.laurentian.ca ou au: Département de physique, Université Laurentienne, Sudbury, Ontario, P3C 2C6. Tel: (705) 675-1151, poste 2234. Télécopieur: (705) 675-4868 S.V.P. allez visiter notre page W3 à http://www.laurentian.ca/www/physics/CAP/ et faites-nous part de vos commentaires.

GENERAL INTEREST

The Demon-Haunted World, by C. Sagan, 1995, pp: xviii + 457, ISBN 0-394-53512-X; Q175.S215, Price: $35.95 (Can)

Glimpsing Reality: Ideas in Physics and the Link to Biology, edited by P. Buckley and F. D. Peat, University of Toronto Press, 1996, pp: xv + 199, ISBN 0-8020-0575-6 (hc) 0-8020-6994-0(pbk); QC15.B83 Price: $55 (hc), $19.95 (pbk)

How Life Begins; the Science of Life in the Womb, by C. Vaughan, Times Books, 1996, pp: xiv + 290, ISBN 0-8129-2103-8; RG525.V38, Price: $32 (Can, hc)

The Physics Quick Reference Guide by E. R. Cohen, AIP Press, 1996, pp: x + 209, ISBN 1-56396-143-1, QC61.C65 (spiral bound)

A Tour of the Calculus, by D. Berlinski, Pantheon, 1995, pp: xvii + 331, ISBN 0-679-42645-0; QA303.B488, Price: $38.50 (Can, hc)

Universe Down to Earth, by N. de Grasse Tyson, Columbia University Press, 1995, pp: xiv + 277, ISBN 0-231-07561-8; QB982.T97, Price: $14.95 (pbk)

Wonders of the Ancient World, National Geographic Society, 1994, pp: 304, ISBN 0-87044-982-6; CB311.W63, Price: $49 (Can, hc)

GRADUATE TEXTS AND PROCEEDINGS

Chemical Kinetics and Catalysis, by R.A. van Santen and J.W. Niemantsverdriet, Plenum, 1995, pp: xi + 280, ISBN 0-306-45027-5; Price: $69.50 (hc)

The Collected Works of P.A.M. Dirac 1924-1948, edited by R.H. Dalitz, Cambridge University Press, 1995, pp: xxiii + 1310, ISBN 0-521-36231-8; QC21.2.D57, Price: $250 (hc) (Editor's note: This is a truly exceptional book. I expect to get many requests for this book and I've decided NOT to honour requests on a first-come basis as is usually the case. Instead, I ask the potential reviewers to provide a rationale as to why they should get to review this volume and will use those rationales to decide who will have the honour of reviewing this book.)

Core Level Spectroscopies for Magnetic Phenomena; Theory and Experiment, edited by P.S. Bagus, G. Pacchioni and F. Parmigiani, Plenum, 1995, pp: viii + 274, ISBN 0-306-45006-2; Price: $ 89.50

Lorentzian Wormholes - From Einstein to Hawking, by M. Visser, AIP Press, 1995, pp: xxv + 412, ISBN 1-56396-394-9; QC173.6.V57 Price: ?

Nuclear Decay Modes, edited by D.N. Poenaru, IOP, 1996, pp: xv + 577, ISBN 0-7503-0338-7; Price: $320 (hc)

Optical-Thermal Response of Laser-Irradiated Tissue, edited by A.J. Welch and M.J.C. van Gemert, Plenum, 1995, pp: xxvi + 925, ISBN 0-306-44926-9; QH642.O65 Price: $139.50 (hc)

Structural Electron Crystallography, by D.L. Dorset, Plenum, 1995, pp: xiii + 452, ISBN 0-306-45049-6; Price: $ 69.50 (hc)

Theory and Application of Laser Chemical Vapor Deposition, by J. Mazumder and A. Kar, Plenum, 1995, pp: xii + 395, ISBN 0-306-44936-6; TS695.M39 Price: $89.50 (hc)

EN FRANÇAIS

L'Aventure de la fusion nucléaire, par M. Trépanier, Boréal, 1995, pp: 303, ISBN 2-89052-527-9; HD9698.C22T73, Prix: 24.95 $ (pbk)

Book Reviews/ Revues des livres

Riddles in Your Teacup, 2nd edition, by P. Ghose and D. Home, IOP Publishing, 1994, pp: xiii + 173, ISBN 0-7503-0275-5; Price $22 U.S. (pbk)

In this revised and enlarged second edition of Riddles in Your Teacup, the authors, P. Ghose and D. Home, have collected and have given brief scientific explanations for numerous examples of natural phenomena and commonplace activities. This book, based on the authors' regular columns in Indian popular science magazines and newspapers, is intended for the young with a high school background in science.

The book is divided into seven chapters of questions and puzzles with solutions, followed by a chapter of unanswered problems. The grouping of questions is not based on a traditional curricular classification of topics in physics, but is rather based on the locations where a puzzle can be faced, such as in the kitchen, on the playground, or in popular films and novels. Questions are posed on common occurrences and activities such as the buzzing of bees, the spin on tennis balls, and the causes of lightning, as well as on certain aspects of science fiction, such as the theoretical flaw in Wells' Invisible Man. As well, the thorough solutions provided are easy to comprehend and are not replete with the technical jargon abundant in puzzle books of a similar nature. However, the most intriguing questions are found in the final chapter of "unsolved" riddles, which involve questions that remain unanswered, or have complex solutions. The majority of the puzzles are accompanied by comical illustrations by Suparno Chaudhuri, which enhance the laid-back style of the book and reinforce its appeal to lay persons. It is unfortunate that the majority of solutions are not enhanced with figures and illustrations, which greatly help in understanding the underlying physical principles behind a specific problem.

In all, Riddles in Your Teacup is a delightful foray into the deciphering of puzzles and common occurrences found in everyday life, lacking, however, the jargon and technical explanations that do not appeal to the young and to lay persons. The price of $22 U. S., or about $30 Canadian is too steep for a paperback book of only 173 pages; nonetheless, the book is an ideal choice for high school libraries, and may be added as an interesting supplement to traditional high school physics texts. It is recommended, however, to anyone with an interest in science, because, as Dr. Paul Davies aptly states in the foreword, "all scientists are young at heart".

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Of One Mind: The Collectivization of Science, par J. M. Ziman, AIP Press, pp: xvii + 406, ISBN 1-56396-065-6; QC16.Z56A3 Prix: 29,95 $US (couverture cartonnée).

John Ziman n'est plus qu'un ex-physicien ayant trouvé refuge, après une carrière scientifique fructueuse, au département d'études sociales et économiques de l'Imperial College à Londres. Du moins, est-ce ainsi qu'il se présente, un peu à la blague, dans le dernier d'une trentaine d'essais non-techniques rassemblés par les Presses de l'American Institute of Physics dans le cadre de la série "Masters of Modern Physics". Rares sont ceux qui possèdent la lucidité de longues années de pratique conjuguée avec une compréhension théorique approfondie de la sociologie propre aux communautés scientifiques et des mécanismes gérant l'évolution de la connaissance. Trop souvent, les commentaires et discours s'inscrivent dans deux traditions déficientes: celles du scientifique improvisé sociologue qui livre une image myope et navrante de son univers familier ou du philosophe qui n'a de la science qu'une connaissance livresque bien souvent dépassée ou tout bonnement fausse. Ziman, heureusement, fait partie de l'élite des commentateurs de la vie scientifique et évite les écueils habituels.

Of One Mind: The Collectivization of Science, le tout dernier recueil de John Ziman apporte donc une profondeur rafraîchissante aux discussions entourant le pourquoi et le comment du processus de la découverte. L'auteur n'hésite pas un instant à replacer dans une dynamique sociale les comportement des chercheurs et l'avancée des connaissances par la recherche. Ceci est particulièrement vrai dans les portraits critiques qu'il trace de quelques grands physiciens tels Einstein, Dyson et Landau, et plus encore dans son analyse des changements fondamentaux qui ont transformé la recherche mais aussi la communauté de chercheurs depuis plus de 50 ans.

On ne peut que regretter que les bouleversements des dernières années dans la communauté scientifique mondiale échappent à l'analyse lucide de Ziman puisque la plupart des essais rassemblés ici furent écrits durant la première moitié des années 1980. Avec la réduction marquée des fonds pour les grands projets et la fermeture de grands laboratoires de recherche industrielle, il n'est pas certain que la collectivisation de la science, qui justifie le titre du recueil, demeure la voie du futur en science. Sa discussion des autres aspects de la vie des scientifiques demeure valide, toutefois, que ce soit le côté néfaste du jugement par les pairs, les jeux de pouvoirs et de reconnaissance, le refus par les scientifiques d'assumer leurs responsabilités, etc.

Il n'est pas certain que tout physicien se reconnaîtra dans le portrait de la science et de la communauté scientifique que trace John Ziman. Une chose est sûre, toutefois, l'image nuancée et complexe décrite dans ce livre ne peut que nous amener à réfléchir sur nous-mêmes, nos interactions avec nos collègues et avec la société en générale, et à découvrir que plusieurs des mythes que nous entretenons sur notre communauté ne trouvent guère contact avec la réalité.

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Université de Montréal

INVENTORS AND DISCOVERERS, Changing Our World, National Geographic Soc., 1988, pp 320. ISBN 0-87044-751-3; 0-87044-752-1 deluxe alk. paper; T18.I57. Price: $ 21.95 hc; 29.95 deluxe, hc.

The introduction to this eleven chapter opus indicates that the scope of the book presumes to begin at the beginning of the 18th century and ends with some indications of promises of the Technology of Tomorrow. *The Power of Steam* uses an historical approach dating from about 1690 (Denis Papin of France). A one page insert outlines the work of George and Robert Stephenson, and a two-page spread is dedicated to the contributions of Robert Fulton, one of the early successful developers of the steamboat. Chapter 3 takes us on an historical trip into *The Age of Electricity* beginning with the early work of the Volta. Special sub-sections are devoted to the work of Thomas Edison, Nikola Tesla, and Graham Bell. *On Wheels & Wings* takes on the story of the motorcars and airplanes. The famed Gottlieb Daimler and Carl Benz get a three-page spread of their work in car and motor development. Henry Ford's contribution to the car industry is outlined in a five-page section. The Wright brothers (Orville and Wilbur) also get a special four-page sketch of their contribution to the development of airplanes. The historical developments of modern day materials is found in Chapter 5, *A World of New Materials*. It begins with the early works of about 1850 describing attempts to make "rubber" into a "useful" product. Included is an interesting look at the story of the new plastics and alloys. Charles Goodyear (rubber) and Leo Baekeland (Bakelite) have special sub-sections devoted to their work. *Capturing the Image*, traces out the development of photography. Special inserts look at the life and contributions of William Henry Fox Talbot, George Eastman, and Edwin Land. Strangely, though, there is no mention of present-day digitization of pictorial elements - which would bring the reader to the very latest advancements in the field of photography. The chapter entitled *Messages by Wireless* traces out the early days of telegraphy, radio, radar, television. A three-page biography of Guglielmo Marconi, and a four-page description of the contributions of Bell Laboratories scientists - which include such notables as Walter Brattain, John Bardeen, William Shockley, and Clinton Davisson - are indeed very interesting sub-sections of this chapter. *Power Particles* deals mainly with atomic energy. A special section of the chapter is devoted to the works of Ernest O. Lawrence of cyclotron fame. Another sub-section is devoted to the contributions of Enrico Fermi, the great nuclear physicist. Modern day inventions are based in large part on computer chips, the subject of Chapter 9. The history takes us from the early days of the abacus to the modern age of computers. A special section of the chapter is devoted to John von Neumann, a name almost synonymous with computer design. The penultimate chapter is entitled *Engineering Life*. Here we find reference to the work of Jenner, Pasteur, Lister, and Paul Ehrlich. So too are discussed the works of Fleming, of Selman A. Waksman, and of Banting and Best, and Jean- François Borel. A special section in this chapter is devoted to the work of William J. Koff, a pioneer in the field of artificial organs. The text proper ends with *Technology of Tomorrow*. It begins with a discussion of the development of superconductors, then goes on to describe some modern-day applications. There is also a description of the potential of DNA studies from location of human genes to the plans for the analysis of the bases' sequencing.

The main body of the text is followed by a section about the authors, an important part of the book, since INVENTORS AND DISCOVERERS, Changing Our World, is a multi-author publication. A second section on Acknowledgments, and a third on Illustration Credits, precedes a six-page three-column per page Index. The special inserts, which give us a short biography of a number of inventors and developers, are easy to spot as to their beginning, but sometimes the end of the inserts are a little harder to locate. The typescript is almost the same as that of the main body, thus if you are reading the main text, it is sometimes a little bothersome to have to hunt to find its continuation!

The text is very well edited. I found only one slight error of vocabulary viz: on p. 45, the expression electric battery is used when electric cell is intended. Too, I was amused by a line in discussing some of Graham Bell's work: "While vacationing at the Bell home in Ontario, Canada ...", (p. 54).

The illustrations are indeed excellent and the write-ups are very well done! It would be excellent background material for use as complementary material especially for university science lectures. On the other hand, since the work contains very little mathematics, anyone with a modicum of learning can profit from its reading. I do believe that it could be a source of inspiration, for students of all ages. Thus I do believe that INVENTORS AND DISCOVERERS, Changing Our World should be found in all libraries.

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LONG-RANGE CASIMIR FORCES, THEORY AND RECENT EXPERIMENTS ON ATOMIC SYSTEMS, edited by Frank S. Levin, David A. Micha, Plenum, Press, 1993, ppxv + 357. ISBN 0-306-44385-6; QC680.L63. Price: $75.00 (hc).

Forty-eight years ago, Casimir, motivated by experimental puzzles on the stability of colloids showed that parallel uncharged metal plates were attracted by a force per unit area equal to within a numerical constant to the reciprocal of the distance between them to the forth power times Planck's constant and the speed of light. For other symmetric shapes the force can be repulsive. It is not obvious intuitively why the effect is proportional to the speed of light and how to predict the sign of the effect. Experimentally this effect, and analogous effects all due to retarded interactions, have been checked experimentally to the order of ten percent.

It is the purpose of this book to elucidate recent attempts to measure Casimir forces to high accuracy in an atomic physics experiment. This first chapter by Spruch is a delightful tutorial, clear, discursive, amusing on the physical origin of the Casimir effects and much more. The most sensitive method to study the Casimir forces appears to be in very high precision experiments on Rydberg States of Helium.

Lundeen describes beautiful experiments on the $n = 10$ fine structure of Helium. The measurements, accurate to better than a kilohertz, measure the small Casimir energy contributions to a precision of 10 percent. In order to determine the Casimir energies it is necessary to know all other energy contributions including relativistic and quantum electromagnetic to a very high accuracy. Drake, who calculates the non-relativistic energies to better than fourteen figures and also the relativistic and Lamb shift contributions, presents clearly the procedures and results of this remarkable numerical work. Drachman, in the spirit of Rydberg, calculates the energies of these states in perturbation theory. Although not as accurate as the numerical calculation, his results are perhaps easier to interpret physically and are sufficiently accurate for the existing experiment. Finally Sucher and Feinberg present a more "high brow" account of the theoretical foundations.

Much of this book is a joy to read - so put down your Christie mystery and pick up your "Casimir Forces".

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QUANTUM MECHANICS, AN INTRODUCTION FOR DEVICE PHYSICISTS AND ELECTRICAL ENGINEERS, by D.K. Ferry, IOP, 1995, pp: ix + 288. ISBN 0-7503-0327-1 (hc) 0-7503-0328-X (pbk).

This book uses a nontrivial approach to teach quantum mechanics, by emphasising modern applied aspects. The material is very concise and to the point. Note that this could cause some problems to freshmen. However if we ever want to excite students about quantum mechanics, we should show them how useful it really is: this book does that in an excellent way.

Quantum Mechanics ... is divided into 9 chapters. Following the introductory chapter which introduces the concept of waves and particles and discusses modern nanostructure experiments, the next seven chapters guide the reader through Schroedinger equation, tunnelling, harmonic oscillator, operators, perturbation theory and motion in centrally symmetric potentials. The last and more advanced chapter deals with electrons and anti-symmetry.

Quantum Mechanics ... can be used as a textbook for teaching QM since every chapter is supplemented with several problems. I strongly recommend this as supplementary reading to students studying QM, but not as a first textbook. Students studying it will find a very useful material that illustrates important aspects of modern solid-state electronics and quantum mechanics. These topics are becoming more and more important in today's microelectronic and optoelectronic devices, not to mention the new emerging field of nanoelectronics.

In conclusion, this book will be a valuable addition not only as a teaching source for quantum mechanics but also as a source of information on the principles of modern nanoelectronic devices for research physicists.

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PALE BLUE DOT: A VISION OF THE HUMAN FUTURE IN SPACE, by Carl Sagan, Random House, New York, 1994, pp xviii+429 ISBN 0-679-43841-6 (hardcover)

Carl Sagan is a well-known planetary astronomer and science popularizer, the latter most notably for his "Cosmos" television series. In this book he discusses a wide range of topics related to the general theme of planetary astronomy and the exploration of the solar system, at a level similar to "Cosmos", i.e. suitable for the "interested lay reader". Like his other works, this book blends science, history, speculations on the future, and the author's own philosophical and political views.

The author begins by examining "... the widespread claims made over all of human history that our world and our species are unique, and even central to the workings and purpose of the Cosmos." He describes how these claims have gradually yielded to modern scientific views of our unprivileged place in a naturalistic cosmos and our essential similarity to other species. Readers of differing philosophical or religious persuasions might take issue with the author's strongly articulated humanistic views here, but I found these interesting and quite compelling, though somewhat disconnected from the remainder of the book.

The author then moves on to the central focus of the book: the unmanned robotic exploration of the planets. He first briefly discusses the extent to which life on Earth is detectable from space at various resolutions and wavelengths. He then describes in more detail various missions by the United States and the former Soviet Union to the Venus, Mars, Jupiter, Saturn, Uranus, and Neptune systems. The author does an excellent job of conveying the excitement of scientific discovery here, describing several cases of conflicting results and interpretations of ambiguous data. I particularly enjoyed his discussion of the conflicting evidence for whether Saturn's moon Titan may have hydrocarbon lakes or oceans.

The author argues strongly that astronomy, by its very nature, tends to foster international cooperation: researchers "... discover that splendid work, work that complements their own, is being done by researchers in other nations; or that to solve a problem, you need data or a perspective (access to the southern sky, for example) that is unavailable in your country.". He describes several examples of important global effects on Earth that were first discovered by planetary astronomers, notably the danger of nuclear winter and the depletion of the ozone layer by chlorofluorocarbons.

Like most astronomers, the author is very skeptical of manned space programs. He discusses the Apollo program's minimal emphasis on science, and ponders at some length whether future manned missions to Mars are a justifiable expenditure in the late 20th and early 21st centuries. The author then turns to a consideration of the consequences and likelihood of catastrophic comet or asteroid impacts on the earth. He argues that inventorying potentially-impacting bodies is "...prudent, it's good science, and it doesn't cost much.". But he argues strongly against the immediate development of systems to deflect such bodies, because of their immense potential for misuse, by deflecting otherwise near-missing bodies to hit the Earth. He argues that it's better to wait - and take the roughly 1 in 1000 risk of a catastrophic impact - until humanity is (hopefully) more unified in a century or two. The author forecasts that humanity may have a well-developed, unified, and environmentally benign Earth-wide civilization by the 22nd century. Assuming this, he argues that we, and indeed all civilizations at comparable stages of development, will inevitably be driven to voyage out into our solar system. He discusses the prospects for terraforming Venus, Mars, and a few of the Jovian and Saturnian moons.

Finally, the author discusses SETI: the search for extraterrestrial intelligence. In the past 35 years this has gradually become a serious branch of astronomy, and a growing number of increasingly sensitive searches have been made. The author describes some of major radio SETI searches to date, and the prospects for much more sensitive and hopefully better-funded ones in the future. He outlines some of the arguments regarding the Fermi paradox (if they're out there, why haven't we seen them yet?), and closes with some speculations on a distant future when humans voyage to the stars.

Overall, I enjoyed this book. I found the author's wide-ranging discussions fascinating, inspiring, and thought-provoking. The many color photographs and paintings nicely complement the text, and are beautifully reproduced. The book deserves a wide readership.

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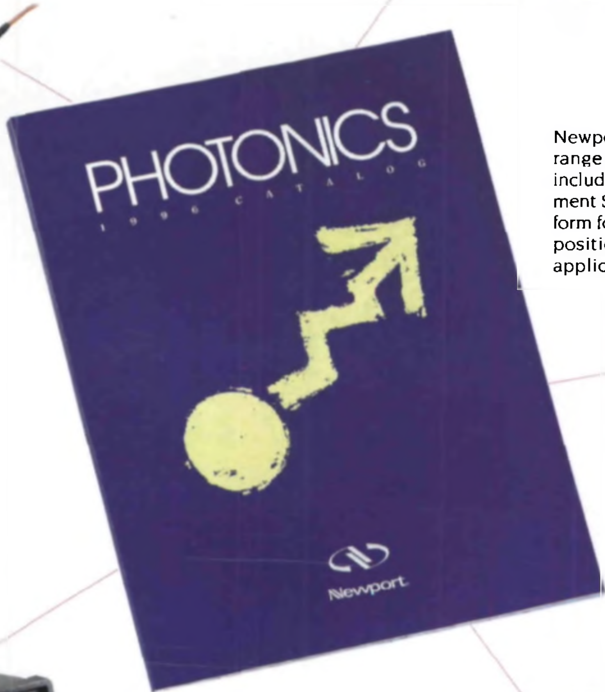

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