SUMMARY OF THE INTERNATIONAL "DAWSON" SYMPOSIUM ON THE PHYSICS OF PLASMAS, CATALINA ISLAND, CALIFORNIA, SEPTEMBER 24-25, 1990

MEETING SUMMARY

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INTRODUCTION

In a festive and relaxed atmosphere on the island of Catalina off the coast of Los Angeles, California, the International "Dawson" Symposium on the Physics of Plasma was held during the typically sunny southern California days of September 24 and 25, 1990. The symposium was held on the occasion of Professor John M. Dawson's 60th birthday (September 30, 1990) (actually a week earlier because of the overlapping International Atomic Energy Agency conference) to reflect on his trek through research and achievements that have affected the communities of plasma physics and many allied fields. Some 70 participants from the United States, Canada, Japan, and Europe, including John's parents and his wife's mother along with their children and their spouses, gathered at this joyful event. The scientists there were not only from academia but also from many laboratories and private industries. They were his former students, postdoctoral students, associates, colleagues, and friends, and they still are.

The symposium was headed by the International Steering Committee listed in Table I and locally organized by the Internal Organizing Committee. Its proceedings were conducted under the stewardship of T. Katsouleas of the University of California-Los Angeles (UCLA). Thanks to the intense and sincere effort by the organizers, the format and contents of the gathering were at the same time reflective, informative, and thought provoking, organized in such a way to encompass a wide variety of the fields that Dawson has pioneered and cultivated in his illustrious career.

The speakers and their topics were divided into seven subcategories over the $1\frac{1}{2}$ days. They were (a) magnetic fusion, (b) basic plasma physics, (c) space physics, (d) laser fusion, (e) isotope separation, and (f) accelerators and light sources. The speakers are listed in Table II. As is obvious from the list, the far-ranging topics and the caliber of the speakers illustrate the kind of science and scientists with which Dawson has shared his life and ideas. If we were to try to summarize the entire symposium, it would take as many authors to cover them as there were speakers. Here we have to be content with a description of some of the highlights of the symposium. I ask leniency from those speakers whose talks I am not able to cover because of limited space. This is not due to the importance attached to the talks, but rather the judgment I made for the nature of

TABLE I

Organizing Committees

International Steering Committee	
R. Bingham	R. Kulsrud
B. Coppi	A. B. Langdon
B. Cohen	J. N. Leboeuf
P. Drake	J. Lominadze
R. Gould	C. S. Liu
W. Horton	J. Nuckolls
T. Kamimura	R. S. Pease
T. Katsouleas	A. Sessler
P. K. Kaw	P. Staudhammer
J. Kindel	R. Sudan
W. Kruer	H. Wilhelmsson
Internal Organizing Committee	
M. Abdalla	C. Joshi
F. F. Chen	C. F. Kennel
R. W. Conn	W. B. Mori
V. K. Decyk	C. Pellegrini
J. Foster	R. Peccei
B. D. Fried	

TABLE II

International "Dawson" Symposium on the Physics of Plasmas

Hosted by Institute of Plasma and Fusion Research at UCLA, UCLA Physics Department, TRW, and the Plasma Physics Research Institute at Lawrence Livermore National Laboratory (LLNL)

Monday, September 24

Session 0—Welcoming Remarks
- T. Katsouleas, Symposium Chairman
- R. Orbach, Provost, UCLA

Session I—Magnetic Fusion
Session Chair, B. Coppi
- H. Furth (PPPL), "Non-Maxwellian Fusion Plasmas and Other Curiosities"
- B. Coppi, "Magnetic Fusion"

Session II—Basic Plasma Physics I
Session Chair, W. Horton
- P. K. Kaw (Institute of Plasma Research, India), "AC Helicity Injection: Current Drive in Tokamaks Using Ponderomotive Forces"
- R. Sudan (Cornell University), "Sub-Grid Modelling in MHD Numerical Simulations"
- C. Oberman (PPPL), "Atoms in Intense Electromagnetic Fields"

Session III—Basic Plasma Physics II
Session Chair, W. Horton
- K. Nishikawa (Hiroshima University), "Dawson-Oberman Formula for Hi-Frequency Conductivity and Anomalous Absorption of Intense Electromagnetic Fields"
- K. Husimi (Professor Emeritus, Nagoya University and Osaka University), "Early Days of Institute of Plasma Physics in Nagoya and Professor Dawson"
- J. Kindel (Los Alamos National Laboratory), "Very Short Pulse Laser/Plasma Interactions"

Session IV—Space and Astrophysical Plasmas
Session Chair, T. Birmingham
- R. Bingham [Rutherford Appleton Laboratory (RAL)], "Simulation of Space Plasmas"

Tuesday, September 25

Session V—Inertial Fusion
Session Chair, T. Johnston
- W. Kruer (LLNL), "Supra-Thermal Particles and Other Plasma Effects in Laser Fusion"
- J. Lindl (LLNL), "Progress on Ignition Physics for ICF and Plans for a Nova Upgrade to Demonstrate Ignition and Propagating Burn by the Year 2000"

Session VI—Dawson Isotope Separation Process
Session Chair, J. Maniscalco
- F. F. Chen (UCLA), "Double Helix: The Dawson Isotope Separation Process"

Session VII—Computer Simulation
Session Chair, O. Buneman
- A. B. Langdon (LLNL), "30+ Years of Plasma Simulation"
- V. Decyk (UCLA), "Future Directions in Simulation"

Session VIII—Accelerators and Light Sources
- R. Bingham (RAL), "Plasma Accelerators"
- T. Johnston (INRS), "Beatwave Acceleration—Recent Fluid Simulations"
- C. Joshi (UCLA), "Frequency Up-Conversion of Radiation Using Plasma Techniques"

this journal. In particular, the subjects of magnetic fusion and of laser fusion and related topics are highlighted.

We also survey the accomplishments of John Dawson as a scientist and as a man. When it is appropriate and helps to enhance the contents, my personal reminiscences are occasionally inserted.

MAGNETIC FUSION

Although I never asked explicitly, it seems that magnetic fusion was Dawson's first professional love, as he went to Princeton Plasma Physics Laboratory (PPPL) immediately after completion of his PhD dissertation on atomic physics at the University of Maryland in 1956. He quickly rose to the leadership of the theory division there. During his Princeton era, he made many epoch-making works, including the one-dimensional exact solution of nonlinear plasma oscillations, computer modeling of plasma kinetics, radiation from and interaction with plasma, and others.

H. Furth of Princeton University highlighted among these the concept of "two-component" plasma reaction in the first talk of the symposium. In 1971, Dawson, along with Furth and Tenney, published the idea of operating a non-Maxwellian fusion plasma.[1] This was the eve of the announcement of the stunning results of the Russian tokamak.[2] Dawson realized that the most reactive particles are those of high energy and that it is thus advantageous to maintain a populous concentration of energetic deuterons as much as possible by injecting a beam of deutrons at a high energy into plasma. Their calculations showed that with ~150-keV injection energy of deuterons into as low as 4-keV plasma (electron) temperature, one can reach a "scientific breakeven," i.e., the Q value [the ratio of fusion energy to the energy supply (or loss)] reaching unity. Furthermore, he showed the energetically optimal operation for fusion energy multiplication (the multiplication factor $F \equiv Q$) for various electron temperatures (see Fig. 1, taken from Ref. 1). The graph shows the range of deuteron injection energies from 150 to 300 keV and the maximum multiplication of $Q \sim 4$ at electron temperature $T_e = \infty$ (i.e., >100 keV). Such an operation is sometimes called the wetwood burner, as opposed to ignition, which is characterized by $Q = \infty$. Dawson continued to pursue his interest in the wetwood burner.[3,4] The condition for $Q = 1$, which imposes conditions on the plasma density and temperature through the plasma reactivity, is often called the Lawson criterion of fusion breakeven.

Furth emphasized[5] that by allowing a non-Maxwellian plasma (or plasma with a beam component), the neutron yield and thus the fusion power are greatly enhanced under given conditions (see Fig. 2). Therefore, the recent major experiments have been run in this mode to achieve higher fusion yield (see Fig. 3).

B. Coppi gave a talk on his intersection with Dawson's work on the possibility of advanced fuel fusion. He commented that he was not aware of Dawson's efforts in advanced fuel until the early 1980s, as the comprehensive article on the subject was published in 1981 (Ref. 6). While Coppi explores advanced fuel application in the second stability regime of the tokamak (the higher plasma beta regime),[7] Dawson was exploring plasma confinement configurations radically different from tokamaks. Dawson explored a concept summarily called surface confinement or surmak.[8,9] This may be regarded as an outgrowth of an octupole (or multipole) concept.[10] By increasing the number of multipoles, the fields increase near the magnets and decrease rapidly away from them, thereby providing a plasma nearly devoid of magnetic fields sufficiently away from the surface toward the interior. These attempts by Dawson and Coppi seek to achieve high-beta plasmas so as to reduce synchrotron radiation from high-temperature plasmas.[6,11] It is well known[6] that the cross section of advanced fuel such as D^3-He reaches its peak at much higher energies than that of deuterium-tritium (D-T) (and typically less cross section even then). Thus, it is necessary to achieve higher plasma temperatures (and longer confinement times), leading to more radiation losses. He also pursued aneutronic reactors of p-^{11}B fuels.[12] Dawson thought that it was worth exploiting synchrotron radiation

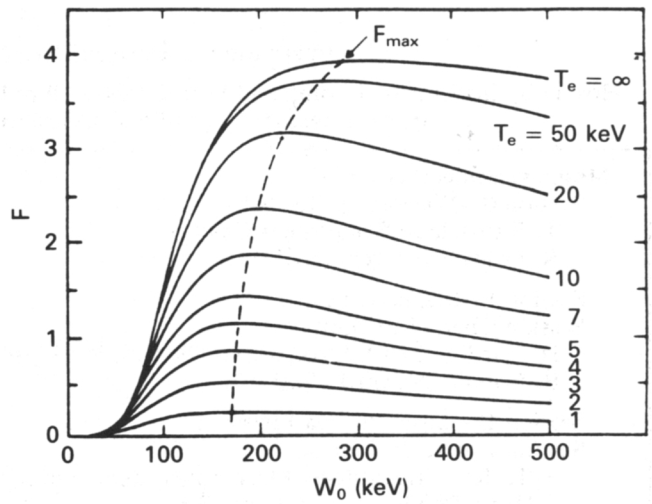

Fig. 1. Energy multiplication factor F ($\equiv Q$) as a function of deuteron injection energy W_0 for various electron temperatures of cold triton target plasma, assuming total energy release of 22.4 MeV (from Ref. 1).

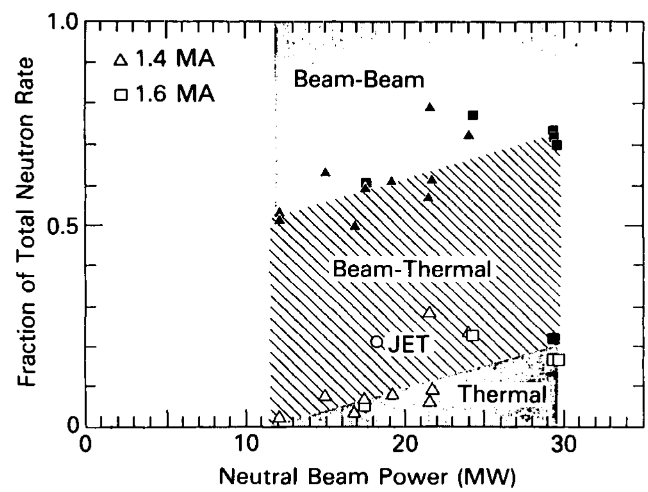

Fig. 2. Fraction of total neutron rate as a function of neutral beam injection power, showing the "two-component" idea of enhanced fusion reactivity.[5]

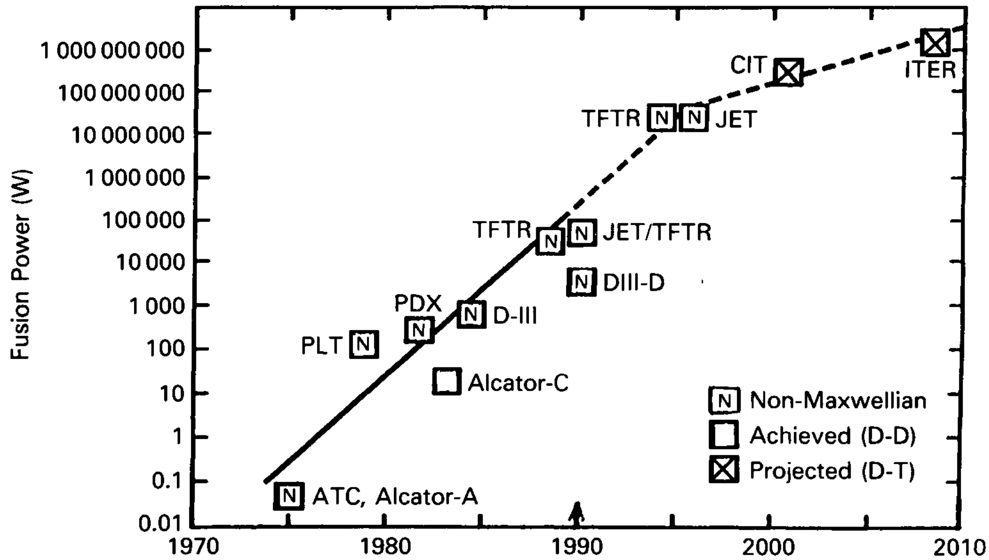

Fig. 3. Progress in magnetic fusion power in recent tokamaks.[5]

from the high-temperature plasma to drive the magnet current.

In spite of Coppi's encounter with Dawson's effort in the early 1980s, Dawson had been working on advanced fuel for many years by then. I can testify to this personally since, as a newly arriving postdoctoral, I was assigned to work on a portion of the advanced fuel reactor research project funded by the Electric Power Research Institute (EPRI) in early 1976. Throughout the 1970s, Dawson was actively working on so-called "alternative concepts" particularly suitable for advanced fuels. His effort during this epoch can be seen by his numerous reports.[6,8,9,12,13] He was also thinking about floating internal rings with small toroidal fields for advanced fuels.[14] As with his idea on beam-enhanced fusion reactivity, Dawson wanted to explore every possible avenue to improve the attainment of fusion, in this case by ion cyclotron wave-enhanced confinement. In his final report to EPRI (unpublished), he explains: "The diffusion of particles into the (mirror) loss cone can be considered . . . through the entropy change $\partial S/\partial t$, (which) is roughly related to ion-ion collision frequency. If an ion cyclotron wave is applied to push the distribution back to the loss cone, mirror losses could be reduced. The minimum amount of power required to do this is $T_i \partial S/\partial t$." I was assigned to study such a prospect by computer simulation at the time, and a summary may be found in Ref. 13.

I still remember Dawson's face radiant with his heightened curiosity and excitement when he found that one of the most important fuel ingredients for advanced fuel fusion, ^{3}He, which is rare in natural abundance, seemed to be abnormally abundant in Hawaiian volcanic gases.[15] Later, the Apollo space mission discovered that the lunar soil contains an abnormally high concentration of ^{3}He on the surface (~50 cm) that has been deposited by the solar wind.[16] This abnormally high concentration may be related to the equally abnormally high ^{3}He content in solar winds due to impulsive solar flares.[17] Wittenberg et al.[18] argued that mining and transportation of ^{3}He to the earth for fusion fuel could be cost-effective. It should also be noted that abnormally high isotopic concentrations of ^{3}He in many commercial metals have been reported.[19]

Dawson's curiosity knows no bounds. Even when he is thinking about a magnetic fusion reactor, his mind may wander to Hawaiian volcanoes, or an X-ray bimental boiler,[6] or to the surface of the moon. It also surprised me one day in 1976 that he was painstakingly collecting nuclear fusion rates for various elementary processes,[20-22] as I assumed at the time such data were well established and, on top of it, Dawson was doing that chore himself.

LASER FUSION

As early as 1963 (published[23] in 1964), just a few years after the first laser was constructed and immediately after Basov and Krokhin,[24] Dawson suggested the creation of a thermonuclear fusion plasma driven by lasers. He has often come back to this topic.[25,26] Appropriate to his pioneering work, foresight, and interest, several speakers talked about topics of related interest.

W. Kruer discussed generation of suprathermal electrons as a result of the resonant laser/plasma interaction and nonlinear behavior of ion waves. The hot electron production leads to preheating of the target, thus making it more difficult to compress for thermonuclear conditions. In the short-pulse irradiation of an exploding pusher target (i.e., a pulse duration <100 ps), the electromagnetic fields of the laser cause a strong enough ponderomotive force on the plasma to create a steep density profile, at the middle of which the density n of the plasma becomes equal to the critical density n_c ($n = n_c \equiv m\omega^2/4\pi e^2$, where ω is the laser frequency). At this resonant point in space, strong laser light absorption takes place, yielding a heated plasma (see Fig. 4 and Ref. 27). On the other hand, in a long-pulse irradiation of an ablatively driven compression, there appears a large skirt of an underdense plasma, in which the laser/plasma interaction gives rise to a variety of plasma parametric instabilities. In these large underdense plasmas, the stimulated Raman instability produces hot electrons with a modest bulk temperature. The amount of the hot electron fraction that correlates with Raman scattering is shown in Fig. 5 (Ref. 27). In these plasmas, the reflectivity due to a stimulated Raman process can be >10% (see Fig. 6 and Ref. 27).

Kruer went on to explain laser/plasma interaction through nonlinear ion waves.[28] Kruer and Dawson, along with Rosen, showed[28] that when the beat of two electromagnetic waves equals the ion wave frequency, ion waves are nonlinearly driven and can play an important role in the laser/plasma interaction. In particular, the ion nonlinearity tends to saturate the growth of the ion density perturbation δn around 4% of the total density n_0, regardless of the intensity of the laser

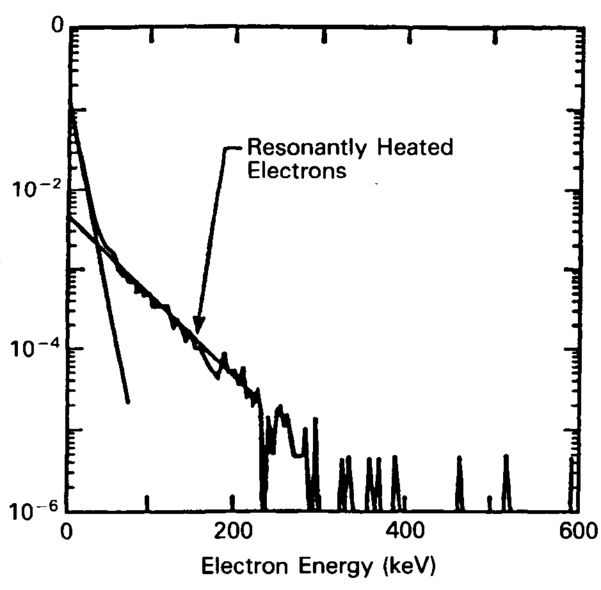

Fig. 4. Superthermal electron generation in short scale length laser/plasma interaction: the electron distribution function. The density modification is important for resonance absorption and suprathermal electron formation.[27]

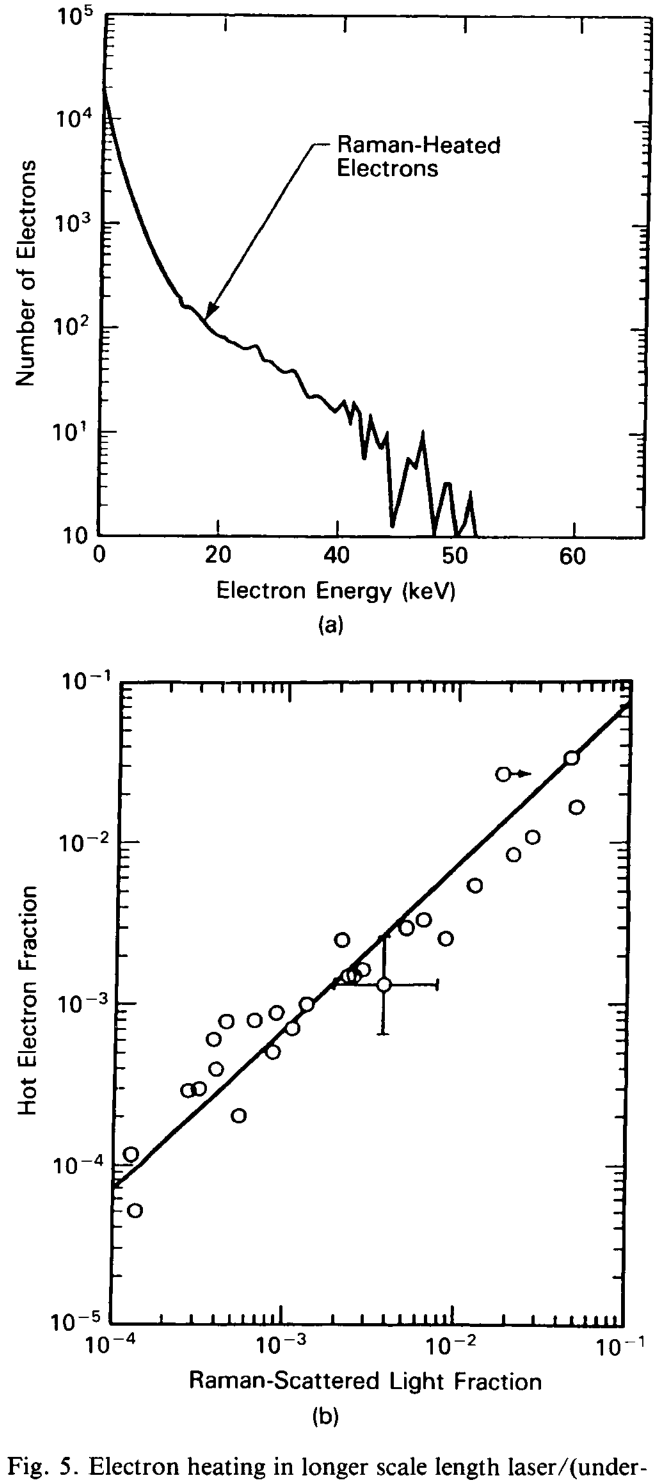

Fig. 5. Electron heating in longer scale length laser/(underdense) plasma interaction (heating of the underdense plasma happens due to the Raman instability): (a) the electron distribution function and (b) the hot electron fraction of the irradiated plasma versus the Raman scattered light fraction, indicating the Raman instability nature of the plasma heating in this case. Target gold disk with 0.53-μm Novette experiments of 0.5 to 4 kJ, 1-ns pulses at 10^{14} to 2×10^{16} W/cm^2 power density.

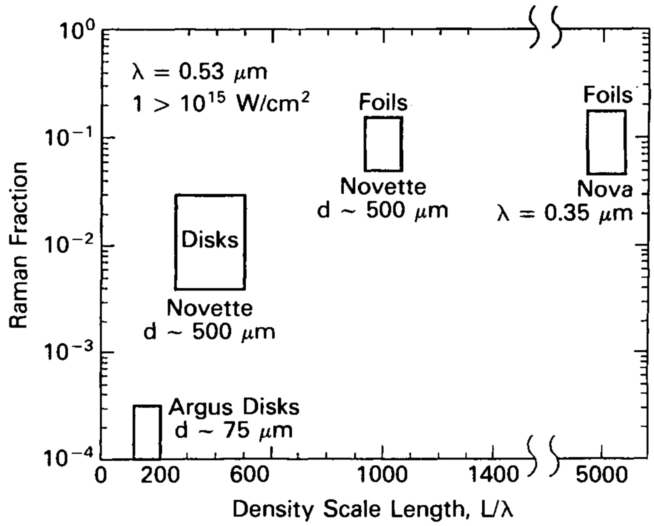

Fig. 6. Raman-scattered light fraction versus the density scale length of the plasma L (normalized to the laser wavelength λ). Stimulated Raman reflectivities >10% have been observed in large-scale plasma irradiation in accordance with theoretical and computational expectation (a detrimental effect that should be avoided for laser fusion).[22]

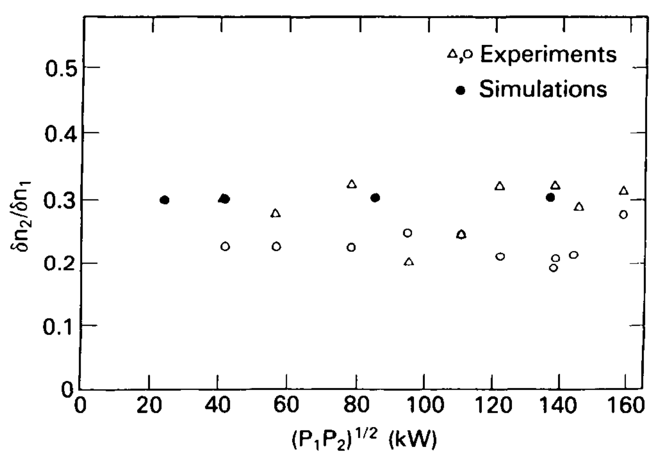

Fig. 7. Ion wave density fluctuations driven by beat of lasers: The ratio of the second-harmonic fluctuation divided by the fundamental as a function of the geometrical mean of two laser powers. Experiments by Pawley et al. and particle simulation are compared favorably.[27] The saturation is due to ion nonlinearity, as explained by Dawson and Kruer.

above a certain threshold. The experiment by Pawley et al.[29] and computer simulations (Kruer) both agree reasonably well, as shown in Fig. 7, but the value of $\delta n/n$ can reach as large as 0.3.

Both J. Lindl and J. Kindel touched upon the topic of laser fusion and laser/plasma interaction. K. Nishikawa discussed the high-frequency conductivity of a plasma due to Dawson and Oberman[25] and related to the parametric instabilities[30] and anomalous absorption. P. K. Kaw spoke about driving current by the ponderomotive force of electromagnetic waves.

In addition to the microimplosion of the fusion fuel by lasers, Dawson thought about the use of intense lasers in initiating fusion reactions in smaller densities. He introduced[31] the simplest possible magnetic confinement system, a long solenoid plasma heated by one or more laser beams, whose length is >1 km for the end loss confinement time requirement (Lawson criterion). In spite of its length, it has several advantages, including guaranteed plasma stability and simple reactor configuration. Its length is no more than the SLAC linear accelerator and far smaller than the Superconducting Super Collider (SSC). In fact, a hundred gigawatt reactors could be placed at each corner of the SSC, were it a ring of the long solenoid reactors.

When I was a graduate student, my PhD advisor, Prof. N. Rostoker, suggested that I consider as my thesis topic heating methods (by lasers or electron beams) of the plasma in Dawson's long solenoid reactor. As discussed by Kruer and others, the long-pulsed laser irradiation of plasmas induces stimulated scattering, a highly nonlinear process. Heating by electron beams turns out to be again highly nonlinear. It may have been fate that while working on Dawson's reactor concept, I felt the limited power of the traditional analytical approach for highly nonlinear plasma problems and was compelled to believe the only way was the computer simulation approach, which once again Dawson championed. I somehow naturally ended up on his postdoctoral staff.

ALLIED FIELDS OF SCIENCE AND TECHNOLOGY

Dawson's contributions to science and technology go far beyond those in magnetic and laser fusion. On one hand, his adventures are intimately related to fusion research, either for the purpose of making fusion work or as a spinoff of fusion research. On the other hand, they are due to his adventurous pioneering spirit, which knows no boundary of disciplines. He often finds himself exploring new ideas in an entirely new field he boldly created a moment ago.

One of his most famous contributions in the method of plasma physics is his pioneering effort in the particle approach of plasma simulation.[31,32] It is in this endeavor that he interacted with perhaps the greatest number of younger scientists, including J. Boris, W. Kruer, J. Lindl, A. B. Langdon, H. Okuda, A. T. Lin, T. Kamimura, V. Decyk, J. N. Leboeuf, and myself. It was the vintage Dawson who started this endeavor, as he foresaw the tremendous growth of the computer and the very complex and nonlinear nature of plasma physics. Reflecting on his contributions in the field, R. Sudan discussed subgrid modeling and V. Decyk the future directions of simulation. Besides these talks, Kruer, Kindel, Bingham, Lindl, and Johnston talked about the various physics based on the simulational approach.

Dawson was always interested in concrete applications of science and technology for the betterment of humankind. One of his many inventions was his isotope separation process[33] discussed by F. Chen and by J. Maniscalco of TRW. Dawson's method of preferential spin-up of the desired isotopic element and the associated large body of techniques has been implemented and perfected at TRW. TRW's capability of separating the isotope of ^{102}Pd turned out to be crucial in destroying malignant cancer cells of the prostate, as the Dawson method is inexpensive in collecting a significant amount of rare elements. Another technique is the coil configuration called the Nagoya Type III, which Dawson encountered at Nagoya University's Institute of Plasma Physics (IPP) on one of his many trips to Japan and was later analyzed in detail.[34] This is a coil configuration that is effective in penetrating radio-frequency electric fields into the plasma. This may represent a good example of one idea coming to fruition on a different tree, i.e., in a different country. Of course, Dawson has brought a large number of his own ideas across the Pacific, shaping some of IPP's programs and other Japanese fusion and plasma programs, as K. Husimi, the first director of IPP, testified.

Another allied area in which Dawson has been interested for many decades is particle accelerators and radiation sources, or to put it another way, the interaction of radiation and plasmas. Although his interest in this field is deeply rooted from earlier years,[35] the topic is presently quite hot and many lively talks have been devoted to this. T. Johnston and R. Bingham talked about the laser beat/wake acceleration of electrons[36] and subsequent developments, and C. Joshi talked about the latest development in photon frequency up-conversion in a plasma.[37] Johnston during his talk dedicated a very fitting poem to Dawson:

A plasma magician named Dawson
Is fertile with ideas that blossom,
  Though his concepts are wild,
  Each latest brainchild
Is backed by code runs that are awesome!

Breaking waves he found was so fine,
Near a surf beach he never would pine,
  "Surf's up in the hypercube,
  Comes John in a supertube.
Riding waves till the end of the line!"

Catalina's the place to say, "John,
Though phase-space is maybe a con,
  And flows and vortexes
  Just sent to perplex us,
May you always find waves to ride on!"

DAWSON AS SCIENTIST AND MAN

A great scientist, as John Dawson surely is, teaches more by example than in any other way. While students, postdoctoral students, and colleagues work with a great man, they have opportunities to learn just what his style of working is and can make educated guesses at some of the secrets of his success when papers are published and lectures are given; however, these are too profound, too organized, and too remote. Only a glimpse into his inner working and feelings can be obtained in the informal, private hours given a student. Perhaps one of the main purposes this meeting report can serve is to shed light on such intimacy so that some of the experiences with John Dawson may be shared with the reader, as I was privileged to share some of the most eventful five years of my career. Dawson, the great thinker, has many outstanding traits we underlings can emulate. Instead of listing all these traits, I would like to mention some occasions for illustration.

It was probably the summer of 1977 when Charlie Kennel, from our department at UCLA, just returned from a trip to the USSR. Charlie entered excitedly into Dawson's office with his typical contagious enthusiasm, saying that he witnessed a wonderful simulation experiment[38] of a magnetosphere by Podgorny of Moscow. It was a crude experiment with temperatures, densities, etc., different from a real magnetosphere, but it showed a global magnetic field structure and magnetic activities. When Charlie reported his findings on the experiments, Dawson, Leboeuf, and I were in the office discussing the computer code development called magnetohydrodynamic (MHD) particle code, Dawson's invention to extend a particle simulation method to MHD (Ref. 39). As a young and still brash scientist, I remember I said something like, "Oh, it is easy for our code to simulate such." Such a statement can be made when a young scientist knows nothing of what others have done; otherwise, he would be afraid that such a simple thought would be too simplistic or, worse, wrong. As a result, one tries to hold back, thinking something does not fit, or someone must have already done it, etc. Now, Dawson is not like that. One may say that he is a rah-rah guy, or more accurately, loves new things and is not afraid of what others might think or might not think. He immediately got excited at the prospect of doing (probably the first – we did not know it then, but it turned out to be that way) global MHD simulation of the magnetosphere. So we did just that.[40] Lesser visionaries may have argued that we did not have enough resolution, a large enough magnetic Reynolds number, etc., so it was not worth the effort. Quite the contrary, Dawson is the guy, himself, who was excited by the idea, just like a child gets excited by his own little thought, pursuing it until resolution. If I am not mistaken, this was Dawson's first serious engagement with space physics research. In the symposium, R. Bingham elaborated more on simulations of space plasmas.

The second example is more personal. It must have been a day in May 1976 several months after I graduated and took a position at UCLA under Dawson when he came back ill from the Anomalous Absorption Conference held in Canada. It turned out that his illness was due to a malignancy. He went through immediate surgery followed by many months of intense chemotherapy. The medicines must have been extremely strong, as he invariably became very sick and lost most of his blonde hair. What was most awesome and inspirational to me was his courageous attitude. In spite of the major life-threatening illness and the equally severe medication, he never stopped working on physics! Dawson used to be a chubby man, but after the surgery and medication he became quite thin. When he was too sick to come to the office, we were summoned to his Pacific Palisades home to discuss our results. Without fail, he fully discussed the subject at hand when I visited him. A more surprising thing was that he was even more creative, or at least it seemed to me, during this serious period than the previous time. Charlie Kennel jokingly said that because he was free from all the daily chores, he was more creative. Charlie was right. During this period, he worked on advanced fuel fusion, various ideas on fusion reactors, MHD particle codes, isotope separation, free electron lasers, initiation of space plasma simulation, and laser acceleration, among other topics, in addition to the more "mundane" duties of teaching students. This, I believe, more than anything else is the testimony of what kind of man John Dawson is.

Nancy Dawson made an emotional speech on his contribution of isotope separation, which produced the ^{102}Pd isotope used to help therapy of prostate cancer. It was such an ironical coincidence that Dawson's inspiration and handiwork while fighting his own cancer helped many other patients.

ACKNOWLEDGMENTS

My thanks to T. Katsouleas for reading my preliminary manuscript and correcting some of my factual recollection of the symposium.

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