



PLASMA PHYSICS GROUP

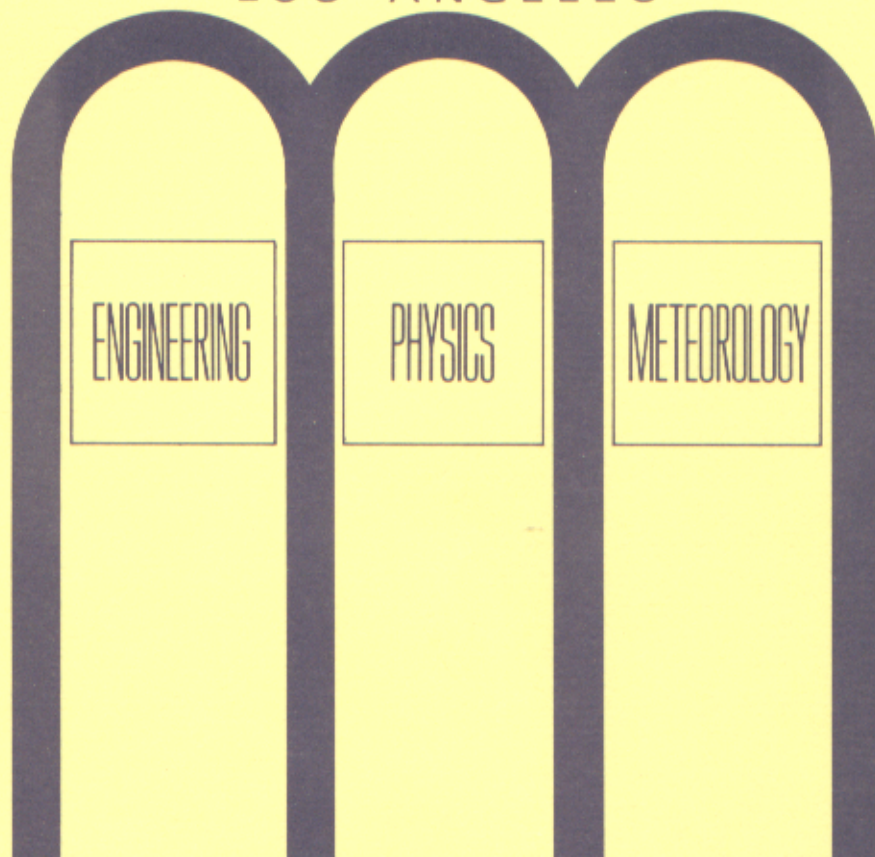
Q Machines, by Robert W. Motley

A Book Review by Francis F. Chen

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UNIVERSITY OF CALIFORNIA
LOS ANGELES



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Advances in physics come in spurts: a new effect or instrument triggers a flurry of activity, which serves to solidify the bases of our intuition on how the world behaves. We have seen this happen with bubble chambers, parity nonconservation, Mössbauer effect, and so on. In plasma physics, nothing comes easily, and the advances are not usually spectacular; but the invention of the Q machine and the subsequent experiments on quiescent plasmas would qualify, if anything does, as a major step in the struggle to understand plasma behavior in magnetic fields. This episode, which had its peak in the 1960's, has now been documented succinctly, accurately, and comprehensively by Robert W. Motley, who, more than anyone else, has devoted the major portion of his scientific career to Q-machine research.

By now everyone knows that matter in the plasma state resists being confined by a magnetic field, to the great dismay of those seeking energy from nuclear fusion. Until the invention of the Q machine, no connection could be made between plasma theory and experiment, simply because the wild thrashing of confined plasmas aborted all attempts at careful measurement. By a fortuitous combination of circumstances, a Q machine was able to produce quiescent (hence, "Q") plasmas devoid of non-thermal fluctuations. For the first time, plasma physicists were able to see what they had read about in fairy tale books: the propagation of ion acoustic waves, the gentle onset of instabilities, the orderly promenade of charged particles across magnetic fields by collisional diffusion, the damping of waves by a collisionless mechanism.

These achievements did not come easily. Fully half of the effort, as reflected by Motley's coverage, involved understanding how the machine worked, how to construct it to operate reliably, and how to make measurements in an alkali-metal environment. The plasma is generated by thermionic emission of electrons and contact ionization of atoms of hot endplates. Theories of end-plate surface recombination and three-body recombination were developed to explain axial losses. Radial losses turned out to be controlled by convection caused by very small temperature gradients in the endplates and had to be eliminated by painstaking measures. Large electric fields from contact potential differences at the radial boundaries had a profound influence on plasma behavior, and sheath conditions at the endplates in single- and double-ended operation had to be kept constantly in mind. Motley covers these fundamental points in the first two chapters and elaborates on them in the body of the text. The treatment of how $T_i > T_e$ is possible is especially welcome. Future generations of students will be astounded at the effort expended by Q-machine experts to establish the validity of their results; and, hopefully, they will be inspired by this book to exercise a similar degree of thoroughness in their own research.

In Chapter 3, Motley gives a brief survey of plasma diagnostic techniques. Since these encompass the entire array of wave, **probe**, **optical**, and particle detectors in the experimentalist's arsenal, the treatment necessarily assumes considerable knowledge on the part of the reader. This chapter is nonetheless essential, because of special requirements peculiar to Q machines and because the field of plasma diagnostics itself benefited from Q-machine research.

Experiments done on Q machines are divided into four chapters

covering instabilities, confinement, waves, and complex magnetic geometries, respectively. The major contribution of Q machines to basic plasma physics is probably the identification of resistive drift waves, a variety of "universal" instability driven only by the density gradient. This is a weak instability which can be seen only in a plasma free from all other instabilities. Motley gives a complete account of drift wave research, including theory, experiment, nonlinear effects, feedback stabilization, and effect on confinement. Derivations of equations are only sketched, but a better summary cannot be found elsewhere because contributions from all quarters (besides Princeton!) have been included. The subject of drift instabilities is not yet closed, because the threshold magnetic field is 50% higher than theory predicts; this discrepancy is mentioned but perhaps not sufficiently emphasized. The other instability discussed by Motley is the Kelvin-Helmholtz instability in a nonuniform transverse electric field. This is an important but relatively unpublished effect. The treatment by Motley is by far the most exhaustive one on the subject. The parallel Kelvin-Helmholtz instability was, for some reason, left unmentioned.

Plasma losses from Q machines are dominated by effects other than classical collisional diffusion--effects such as endplate recombination, probe losses, transport by oscillations, and convection. This complicated picture--even in a uniform magnetic field--is clearly unfolded by Motley; the reader can well imagine what a similarly thorough study of confinement in a torus would involve. The impression one gets from this chapter is the correct one that plasma convection is the primary cross-field loss mechanism in a Q machine, and one would be wise to look for it in other machines.

The chapter on waves emphasizes the ion acoustic wave, which was first seen in a Q machine despite the fact that it is heavily damped when the ion and electron temperatures are nearly equal. This experiment was also the first verification of Landau (collisionless) damping. Motley gives a good account of ion waves; in particular, the statement on collisional damping of ion waves--a more subtle effect than one might expect--is the best there is, despite its brevity. One might have wished for a fuller discussion of pseudowaves and grid-induced effects, on which there is extensive literature. Incidentally, the useful Sessler-Pearson graph of the ion wave dispersion relation is reproduced here more clearly than in the original paper.

The use of alkali-metal plasmas in complex magnetic fields has yielded demonstrations of the effectiveness of shear and short connection length in stabilizing drift waves and reducing convection. Motley does not fail also to give an account of the notorious Wendelstein controversy, in which a Q-stellarator group in Garching, Germany, dared to lock horns with the redoubtable C-Stellarator team at Princeton--and got away with it.

Finally, the reader is made privy to the details of constructing a Q-machine, in case he is well-funded and so inclined. Here the relevant data on ionization potentials, work functions, etc. are given. Graphs of tungsten resistivity, emissivity, and thermionic emission would have been a welcome addition.

As can be seen from the foregoing, Q-machine research cuts across all of plasma physics. It would have been easy to write a book twice this length. We owe the author a vote of thanks for exercising great restraint and unerring editorial judgment, underplaying results that are uncertain and emphasizing those that are important. Succinctness,

however, has its price; the reader would have benefited from more poignant discussions, for instance, of why a radial electric field exists, why contact potentials cause the jump in plasma potential at the limiter, and how a bar of iron allows upper-hybrid radiation to escape. In discussing collisionless drift waves, no mention was made of the experiment at Fontenay-aux-Roses by Deschamps et al. True, this was not done in a Q machine, but it nonetheless has to be mentioned in that context. Otherwise, the book is very complete, particularly in its 341 references. Above all, Motley has given fair treatment to all who have worked in the field. If anything, he is guilty of excessive modesty regarding his own substantial contributions.

It is problematical whether Q machines will continue to be used in the future. They are expensive and difficult to operate. There are now other quiescent plasmas, such as the Double Plasma devices developed at UCLA, which are easier to build and have higher electron-ion temperature ratio. But the example of meticulous measurement and thorough analysis set by the Q-persons of the '60's will probably be unequalled in the annals of plasma physics. Bob Motley has captured the spirit of this epoch magnificently in his short monograph. Now if someone would only do the same for multipoles. . .

Suggested Illustration

Figure 7-5, p. 147

Caption: Equipotential contours in a Q machine, showing the symmetization of plasma convective patterns by magnetic shear.

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- PPG-126 "Amplification of Electromagnetic Waves in Overdense Plasmas," F.F. Chen and R.B. White (September 1972, revised August 1973). J. Plasma Physics 16, 565 (1974).
- PPG-127 "Abstracts presented at the American Physical Society Division of Plasma Physics Annual Meeting, Monterey, November 13-16, 1972".
- PPG-128 "Can the Ionosphere Regulate Magnetospheric Convection?" F.V. Coroniti and C.F. Kennel (October 1972). J. Geophys. Res. 78, 2837 (1973).
- PPG-129 "Nonlinear Stabilization of Oscillating Two-Stream Instability," K. Nishikawa, Y.C. Lee and P.K. Kaw (October 1972). Physics of Fluids 16, 1380 (1973).
- PPG-130 "Drift Waves in Finite Beta Plasmas," Morrell S. Chance (October 1972). Thesis.
- PPG-131 "Wave Packet Formulation of Nonlinear Plasma Wave Kinetics," K. Nishikawa and B.D. Fried (October 1972). Physics of Fluids 16, 1321 (1973).
- PPG-132 "Electron Cyclotron Drift Instability Experiment," B.H. Ripin and R.L. Stenzel (October 1972). Phys. Rev. Letters 30, 45 (1973).
- PPG-133 "Resonant Excitation of Electrostatic Modes with Electromagnetic Waves," G. Schmidt (October 1973). Physics of Fluids 16, 1676 (1973).
- PPG-134 "Energetic Ion Beam Source and Free-Stream Beam Diagnostic Techniques," R.L. Stenzel and B.H. Ripin (November 1972). Rev. Sci. Instr. 44, 617 (1973).
- PPG-135 "Electron Plasma Waves in an Unbounded Uniform Magnetoplasma," R.L. Stenzel (November 1972). Physics of Fluids 16, 565 (1973).
- PPG-136 "Convective Amplification of Type I Irregularities in the Equatorial Electrojet," K. Lee and C.F. Kennel (November 1972), J. Geophys. Res. 78, 4619 (1973).
- PPG-137 "Effects of Propagation Parallel to the Magnetic Field on the Type I Electrojet Irregularity Instability," K. Lee and C.F. Kennel (November 1972). Planetary and Space Sciences 21, 1339 (1973).
- PPG-138 "Analog Computer Simulation of Parametric Instabilities," R.L. Stenzel (November 1972).
- PPG-139 "Theory of Double Resonance Parametric Excitation in Plasmas," D. Arnush, B.D. Fried, C.F. Kennel, K. Nishikawa and A.Y. Wong (November 1972). Physics of Fluids 16, 2270 (1973).
- PPG-140 "Filamentation and Trapping of Electromagnetic Radiation in Plasmas," P. Kaw, G. Schmidt and T. Wilcox (December 1972). Physics of Fluids 16, 1522 (1973).
- PPG-141 "Finite Beta Drift Alfvén Instability," M.S. Chance, F.V. Coroniti and C.F. Kennel (January 1973). J. Geophys. Res. 78, 7521 (1973).
- PPG-142 "The Formation of Ion Acoustic Shocks," R.B. White, B.D. Fried and F.V. Coroniti (January 1973). Physics of Fluids 17, 211, 1974.
- PPG-143 "Experiments on Parametric Instabilities," A.Y. Wong (March 1973).
- PPG-144 "On Cosmic Ray Generation by Pulsars," C.F. Kennel, G. Schmidt and T. Wilcox (March 1973). Phys. Rev. Letters 31, 1364 (1973).
- PPG-145 "On the Marginally Stable Saturation Spectrum of Unstable Type I Equatorial Electrojet Irregularities," K. Lee, C.F. Kennel and F.V. Coroniti (April 1973). J. Geophys. Research 79, 249, 1974.

- PPG-146 "Spatial Growth Properties of Parametric and Backscattering Plasma Instabilities," B.D. Fried, R. Gould and G. Schmidt (April 1973). Submitted to Phys. Rev. Letters.
- PPG-147 "Evolution of BGK-Like Modes with Trapped Electrons," A.Y. Wong, B.H. Quon and B. Ripin (April 1973). Phys. Rev. Letters 30, 1299 (1973).
- PPG-148 "Stabilization of Ion Acoustic Waves by Electron Trapping," N. Albright (April 1973). Physics of Fluids 17, 206, 1974.
- PPG-149 "Turbulence in Electrostatic Ion Acoustic Shocks," R.W. Means, F.V. Coroniti, A.Y. Wong and R.B. White (May 1973). Physics of Fluids 16, 2304, 1973.
- PPG-150 "Theory of Dielectric Function in a Magnetized Plasma," Y.C. Lee and C.S. Liu (June 1973). Submitted to Physics of Fluids.
- PPG-151 "Physical Interpretation of the Oscillatory Two-Stream Instability," A.Y. Wong and G. Schmidt (June 1973). Submitted to Physics of Fluids.
- PPG-152 "Relativistic Particle Motion in Nonuniform Electromagnetic Waves," G. Schmidt and T. Wilcox (June 1973). Phys. Rev. Letters 31, 1380, 1973.
- PPG-153 "The Ring Current and Magnetic Storms," F.V. Coroniti (July 1973). Radio Science 8, 1007, 1973.
- PPG-154 "Energetic Electrons in Jupiter's Magnetosphere," F.V. Coroniti (July 1973). Astrophysical Journal 27, 261, 1974.
- PPG-155 "Stably Trapped Proton Fluxes in the Jovian Magnetosphere," F.V. Coroniti, C.F. Kennel and R.M. Thorne (July 1973). Astrophysical Journal 189, 383, 1974.
- PPG-156 "Absolute Raman Scattering Instabilities in an Inhomogeneous Plasma," J.F. Drake and Y.C. Lee (July 1973). Physical Review Letters 31, 1197 (1973).
- PPG-157 "Growth and Saturation of the Absolute Electron Cyclotron Drift Instability," R.L. Stenzel and B.H. Ripin (July 1973). Phys. Rev. Letters 31, 1545 (1973).
- PPG-158 "Parametric Instabilities of Electromagnetic Waves in Plasmas," J. Drake, P.K. Kaw, Y.C. Lee, G. Schmidt, C.S. Liu and M.N. Rosenbluth (July 1973). Physics of Fluids 17, 778, (1974).
- PPG-159 "Nonlinear Optics of Plasmas," F.F. Chen (August 1973). Survey Lectures. International Congress on Waves and Instabilities in Plasmas, Innsbruck, Austria, 1973 (Institute for Theoretical Physics, Innsbruck) pp. C1 - C19.
- PPG-160 "Physical Mechanisms for Laser and Plasma Heating - Parametric Instabilities," F.F. Chen (August 1973). In Laser Interaction and Related Plasma Phenomena, ed. H.J. Schwartz and H. Hora, Vol. 3A p. 291 - 313 (Plenum Press 1974).
- PPG-161 "Trip Report on the Sixth European Conference on Controlled Fusion and Plasma Physics, July 30 - August 4, 1973, Moscow," B.D. Fried (August 1973).
- PPG-162 "Abstracts presented at the Philadelphia Meeting of the American Physical Society, Division of Plasma Physics, October 31 - November 3, 1973".
- PPG-163 "Enhancement of Plasma DC Currents by Intense AC Fields," A.T. Lin and J.M. Dawson, October 1973. Physics of Fluids 17, 987, 1974.
- PPG-164 "Temporal Electrostatic Instabilities in Inhomogeneous Plasmas," Y.C. Lee and P.K. Kaw, November, 1973. Physical Review Letters 32, 135 (1974).
- PPG-165 "Nonlinear Schrodinger Equation Model of the Oscillating Two-Stream Instability," G.J. Morales, Y.C. Lee and R.B. White, December 1973. Phys. Rev. Letters 32, 457 (1974).
- PPG-166 "Backscattering Decay Processes in Electron Beam-Plasma Interactions Including Ion Dynamics," B.H. Quon, A.Y. Wong and B.H. Ripin, December 1973. Phys. Rev. Letters 32, 406, 1974.
- PPG-167 "Conversion of Electromagnetic Waves to Electrostatic Waves in Inhomogeneous Plasmas," R. Stenzel, A.Y. Wong and H.C. Kim, December 1973. Phys. Rev. Letters 32, 654, 1974.

- PPG-168 "Langmuir Wave Turbulence - Condensation and Collapse," Y.C. Lee, C.S. Liu and K. Nishikawa, January 1974. To appear in Comments on Plasma Physics and Controlled Fusion.
- PPG-169 "The Consequences of Micropulsations on Geomagnetically Trapped Particles," R.M. Thorne, January 1974. Reviews of Space Science 16, 443, 1974.
- PPG-170 "Linear Wave Conversion in Inhomogeneous Plasmas," D.L. Kelly and A. Baños, Jr., March, 1974.
- PPG-171 "The Cause of Storm After Effects in the Middle Latitude D-Region Ionosphere," W.N. Spjeldvik and R.M. Thorne, March 1974. Accepted by J. of Atmospheric and Terrestrial Physics.
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- OOG-174 "What we have Learned from the Magnetosphere," C.F. Kennel, April 1974. Submitted to Comments on Astrophysics and Space Science.
- PPG-175 "Observation of the Ponderomotive Force and Oscillating Two-Stream Instability," H.C. Kim, R. Stenzel and A.Y. Wong, April 1974.
- PPG-176 "Electron Beam Plasma Interaction Including Ion Dynamic," B.H. Quon, June 1974. Thesis.
- PPG-177 "Linear Conversion and Parametric Instabilities in a Non-Uniform Plasma," H.C. Kim, R. Stenzel and A.Y. Wong, June 1974. Thesis.
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- PPG-179 "Equatorial Spread F: Low Frequency Modes in a Collisional Plasma," M.K. Hudson, July 1974 (Dissertation).
- PPG-180 "Effect of the Ponderomotive Force in the Interaction of a Capacitor RF Field with a Nonuniform Plasma," G.J. Morales and Y.C. Lee, July 1974. Phys. Rev. Letters 33, 1016, 1974.
- PPG-181 "Deduction of Ionospheric Tidal Winds by Dynamo Simulation," J.P. Schieldge and S.V. Venkataswaran, August, 1974. Submitted to J. of Atmospheric and Terrestrial Physics.
- PPG-182 "Response of the Middle Latitude D-Region to Geomagnetic Storms," W. Spjeldvik and R.M. Thorne, August 1974. Accepted by J. of Atmospheric and Terrestrial Physics.
- PPG-183 "Production of Negative Ions and Generation of Intense Neutral Beams," A.Y. Wong, J.M. Dawson and W. Gekelman, August 1974.
- PPG-184 "Development of Cavitons and Trapping of RF Fields," H.C. Kim, R. Stenzel and A.Y. Wong, August 1974. Phys. Rev. Letters 33, 886 (1974).
- PPG-185 "Albuquerque Abstracts: Papers presented at Albuquerque Meeting of the American Physical Society Division of Plasma Physics, October 28-31, 1974."
- PPG-186 "Localized Quasi-Stationary Plasma Modes in One, Two and Three Dimensions," J. Zitkova Wilcox and T.J. Wilcox, September 1974. Accepted by Physical Review Letters.
- PPG-187 "Denouement of Jovian Radiation Belt Theory," F.V. Coroniti, September 1974. Proceedings of Conference on Magnetospheres of the Earth and Jupiter, Frascati, Italy, May 28 - June 1, 1974.
- PPG-188 "Is Jupiter's Magnetosphere Like a Pulsar's or Earth's?" C.F. Kennel and F.V. Coroniti, September 1974. Ibid.
- PPG-189 "Parametric Instability of the Sheath Plasma Resonance," R. Stenzel, H.C. Kim and A.Y. Wong, September 1974. Bull. Am. Phys. Soc., October 1974.
- PPG-190 "Effect of Localized Electric Fields on the Evolution of the Velocity Distribution Function," G.J. Morales and Y.C. Lee, September 1974. Phys. Rev. Letters 33, 1534 (1974).
- PPG-191 "Parametric Instabilities in Plasma," J.M. Dawson and A.T. Lin, September 1974.

- PPG-192 "Surmac - a Large Surface Magnetic Confinement Device," A. Y. Wong, September 1974.
- PPG-193 "Extraction of Energy From High Intensity Ion Beams," A. T. Forrester, September 1974. Presented at the IInd Symposium on Ion Sources and Formation of Ion Beams, Berkeley, Calif. 22-25 October, 1974. Instr.
- PPG-194 "A Large Quiescent Magnetized Plasma for Wave Studies," W. Gekelman and R. L. Stenzel, December 1974 Accepted Rev. Sci. Instr.
- PPG-195 "Electrostatic Waves Near the Lower Hybrid Frequency," R. Stenzel and W. Gekelman, October 1974. Accepted Phys. Rev. A
- PPG-196 "A Corrugated Mirror-Cyclotron Frequency Direct Conversion System (Comi-Cyfer)," A.T. Forrester, J. Busnardo-Neto and J.T. Crow, October 1974. IEEE Transactions on Plasma Science.
- PPG-197 "The Study of Comparative Magnetospheres: The Future of Space Physics," F.V. Coroniti and C.F. Kennel, October 1974. Presented to the NASA Study Group On "Outlook for Space", Goddard Space Flight Center, September 10, 1974.
- PPG-198 "Application of the Fokker-Planck Numerical Method to Anisotropic and Energy-Dependent Electron Precipitation," W. Spjeldvik, October 1974.
- PPG-199 "Self-focusing and Filamentation of Laser Light in Plasmas," Y.C. Lee, C.S. Liu, H.H. Chen and K. Nishikawa, October 1974. To appear in Proceedings of IAEA Sixth Conference on Plasma Physics, held in Tokyo, Nov. 1974.
- PPG-200 "Stimulated Brillouin Backscatter in the Equatorial Electrojet," D. D. Barbosa and C.F. Kennel, November 1974. Submitted to Planetary and Space Sciences.
- PPG-201 "The Electromagnetic Interchange Mode in a Partially Ionized Collisional Plasma," M. K. Hudson and C. F. Kennel, December 1974. Submitted to J. of Plasma Physics.
- PPG-202 "The Collisional Drift Mode in a Partially Ionized Plasma," M. K. Hudson and C. F. Kennel, December 1974. Submitted to J. of Plasma Physics.
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- PPG-205 "A Recursive Numerical Method to Solve the Pure Pitch Angle Diffusion Equation, A Technical Report," W. N. Spjeldvik, December 1974.
- PPG-206 "The Equilibrium Radiation Belt Electron Pitch Angle Distribution and its Dependence on the Radial Diffusive Source," W.N. Spjeldvik, January 1975. Submitted to Geophys. Res. Letters.
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- PPG-209 "Plasma Confinement by a Picket-Fence", K. N. Leung, N. Hershkowitz and T. Romesser, January 1975. Submitted to Physics Letters.
- PPG-210 "Secular Mode Coupling and Anomalous Drag: A Theory of Plasma Turbulence with Application to the Electron Beam-Plasma Instability," J. F. Drake, February 1975. Dissertation.
- PPG-211 "Nonlinear Generation of Intense Localized Electric Fields in Plasmas," G. J. Morales and Y. C. Lee, February 1975.
- PPG-212 "Plasma Electron Heating by Injection of Low Energy Electrons," N. Hershkowitz and K. N. Leung, February 1975.
- PPG-213 "Ion Confinement by Electrostatic Potential Well in Magnetic Multiple Device," Y. Nakamura, B. Quon and A.Y. Wong, February 1975. Submitted to Physics Letters A.
- PPG-214 "Scattering of Electromagnetic Waves into Plasma Oscillations via Plasma Particles," A.T. Lin and J.M. Dawson, March 1975. Submitted to Physics of Fluids.