INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

H4-SMR 393/55

SPRING COLLEGE ON PLASMA PHYSICS

15 May - 9 June 1989

Symposium on Third World Fusion Programmes
and South-North Collaboration

FUSION PROGRAMMES IN MALAYSIA

S. Lee

Department of Physics
University of Malaya
59100 Kuala Lumpur
Malaysia

Fusion Programmes in Malaysia

S. Lee
Physics Department, University of Malaya
59100 Kuala Lumpur, Malaysia.

Abstract:

Fusion Programmes in Malaysia are briefly reviewed with some attention to historical perspective and to the academic continuity from undergraduate through to doctoral programmes. The research in the areas of glow-discharge, small tokamak, pinch, current-stepped pinch, vacuum spark pinch and the plasma focus is then reviewed. The central research theme threading all this research is identified as a study of the limits and enhancement of compressions. Our work shows that in general density compressions are limited and independent of the absolute magnitude of the compressive force. Enhancement of compression may be achieved through time variation of the force field, e.g. specifically using a force-stepping technique, through a reduction in specific heat ratio and in the case of the pinch through an elongation of pinch length during the compression. These ideas are applicable to magnetic field compressions as well as to radiation-driven compressions and should prove useful to aid in understanding e.g. the plasma focus scaling laws.

This review also reports the experience of the research group in its attempt to share fusion related technology on a South-South basis by the development of specific training packages. One such package the UNU/ICTP Plasma Fusion Facility has already been developed and 8 sets have been sent back to the home institutes of the UNU/ICTP Fellow trainees. A compact torus FRC based on the Rotamak concept is also being developed.

Paper prepared for the Symposium on Third World Fusion Programmes and South-North Collaboration, 8-9th June 1989 Trieste, Italy.

Fusion Programmes in Malaysia
S. Lee
Physics Department, University of Malaya
59100 Kuala Lumpur, Malaysia.

Abstract:

Fusion Programmes in Malaysia are briefly reviewed with some attention to historical perspective and to the academic continuity from undergraduate through to doctoral programmes. The research in the areas of glow-discharge, small tokamak, pinch, current-stepped pinch, vacuum spark pinch and the plasma focus is then reviewed. The central research theme threading all this research is identified as a study of the limits and enhancement of compressions. Our work shows that in general density compressions are limited and independent of the absolute magnitude of the compressive force. Enhancement of compression may be achieved through time variation of the force field, e.g. specifically using a force-stepping technique, through a reduction in specific heat ratio and in the case of the pinch through an elongation of pinch length during the compression. These ideas are applicable to magnetic field compressions as well as to radiation-driven compressions and should prove useful to aid in understanding e.g. the plasma focus scaling laws.

This review also reports the experience of the research group in its attempt to share fusion related technology on a South-South basis by the development of specific training packages. One such package the UNU/ICTP Plasma Fusion Facility has already been developed and 8 sets have been sent back to the home institutes of the UNU/ICTP Fellow trainees. A compact torus FRC based on the Rotamak concept is also being developed.

Introduction

Fusion Research in Malaysia is centered in the Plasma Research Laboratory, University of Malaya. This laboratory was started in the early 1960's by S.P. Thong who at that time was associated in glow discharge work in collaboration with K.G. Emeleus of Queens University, Belfast. Aware of the work already on-going at that time in Britain on controlled fusion research Thong had the foresight to acqire from the British Government through the Colombo Plan 100 pieces of 40kV 0.6 μF fast discharge capacitors. Preliminary work with these and other capacitors resulted in the first Physics M.Sc thesis in Malaysia being produced on the topic of electric and electromagnetic shock waves under the supervision of H.H. Teh[1-3] in 1966.

In 1970 the technical problems of installing these capacitors were solved with a design dividing the 100 capacitors into 4 modules each switched by 2 ignitrons with the help of a voltage division technique proposed earlier by C.P. Lim. In 1972 1.9MA was measured in a full test[4]. This capacitor bank is still operational and will soon be converted to be switched by parallel plate swinging-cascade spark gaps. A plasma focus was designed and in October 1973 D-D nuclear fusion neutrons were measured from the focus by time-of-flight method giving an energy of 2.2 $\pm$ 0.1 MeV in a 'backward' direction.[5]

During this period of development and since then we have planned our research mainly on academic basis resulting in the production of 5 Ph.D [6-10] and 15 M.Sc theses[11-24] in plasma and fusion physics. Continuity between undergraduate and postgraduate work is maintained by undergraduate courses in plasma and fusion physics augmented by undergraduate experiments in glow discharge, electromagnetic shock tube and pulse electronics experiments.[25]

Experimental plasma research in Malaysia is currently carried out on the following devices : glow discharge, small tokamak, current-stepped Z pinch, vacuum spark x-ray source and the plasma focus. Various lasers are being developed for diagnostic work. A transistorised Rotamak which is a compact torus FRC with current drive is being developed at our associated Pulse Technology Laboratory and an elongating Z-pinch is being designed at the Technology University.

Programme areas

Over the years the research has developed a pattern propelled primarily by the academic needs and perceptions of individuals within a framework of limited infrastructure and financing typical of the university environment of a developing country. Yet a pattern has loosely developed and three broad areas may be identified:

I. Long-lived plasmas, production and diagnostic techniques.
II. Pulsed plasmas, production and properties and techniques for compression enhancement.
III. Development of fusion-related technology for research initiation in developing countries.

I. Long-Lived Plasmas

Work on these plasmas include the Glow Discharge, a Small Tokamak and recently we have started constructing a transistorised compact torus FRC device with current-drive from either a rotating magnetic field or from a transverse oscillating magnetic field. This device called the Rotamak was first developed at Flinders University of South Australia and was transistorised as a specific project to bring the technology of a compact torus FRC within the reach of a developing country.

Glow Discharge

Measurements on glow discharge[26] have been continued. Recent developments include pulsed Langmuir double probe studies[27] in various gases and a computer based data acquisition system[28].

Small Tokamak

A small Tokamak was planned[29] and plasma obtained in June 1983 with the following parameters :

major radius R	0.25m
major radius a	0.05m
R/a	5
toroidal field B	0.5T
plasma current	10 kA
safety factor q	2.5
lifetime (optically observed)	200 μs
operational pressure	10^{-3} torr
T_e	10 eV

Stabilization bank

Capacitance	60 μF
Charging voltage	26 kV
Coil inductance	63 μF
No. of turns	100
Coil current	25 kA
risetime	100 μs

Heating bank

Capacitance	100 μF
Charging voltage	4 kV
Coil inductance	360 μH
No. of turns	20
Coil current	2 kA
risetime	300 μs

The toroidal stabilization field, planned at 2T is severely reduced by induced current effects in the stainless steel wall of the plasma chamber.

Rotamak

In the Rotamak[30] a plasma current is driven around an axial bias field in such a direction that the axial field of the plasma current opposes the axial bias field. When the driven plasma current becomes large enough it reverses the original axial field in the central region. These reversed field lines in the central region join up with the field lines having the original direction in the outer regions to form a compact-torus field-reversed-configuratation with closed field lines. The Rotamak traditionally uses a magnetic field, rotating at a frequency between ω_e (plasma electron frequency) and ω_i (plasma ion frequency), to pull along the electrons, thus producing the current drive in the plasma.

In conventional Rotamak devices the RF generators for the rotating magnetic field require expensive triode valves. In a specific attempt to develop low-cost Rotamak technology suitable for the Third World transistorised RF generators using MOSFETS were developed at Flinders University. Moreover during that exercise it was found that an oscillating magnetic field transverse to the axial bias field was sufficient to produce the Rotamak configuration. This provided a further simplification.[31]

The Rotamak we are building uses a glow-discharge for preionisation and a MOSFET RF generator of 2 kW to power the oscillating transverse magnetic field at 500 kHz. We expect to drive a plasma current of 200 A in a chamber of diameter 25 cm holding an FRC plasma at a temperature[32] of 7eV and an electron density of 10^{12}/c.c with a lifetime of several 10's of ms.

II. Pulsed Plasmas - Studies of Compression Limits and Enhancement

Much of our plasma and fusion-related programmes deal with pulsed plasmas and may be connected by the research theme of compression limits and compression enhancement. From energy and pressure consideration applied to fast compressions it may be shown that generally for a spherical compression driven by piston-like force field with force F, the final compressed radius r_m is related to the initial radius r_o by the compression limit expression.

$$F_m = \frac{f(\gamma)}{f_{rs}} \int_{r_m}^{r_o} F \frac{dr}{r}$$

where $f(\gamma)$ is a function of the specific heat ratio γ and f_{rs} is related to the reflected shock over-pressure as the reflected shock hits the incoming piston force field.

This simple relationship has the following important features, determining compression limits and indicating methods of enhancement. These features are:

1. It determines the radius ratio r_m/r_o and shows that the radius ratio is determined by energy and pressure considerations.

2. The radius ratio (hence density compression) is independent of the absolute peak magnitude of the force F.

3. The density compression depends on the space - or time - variation of the force field.

4. It depends on the specific heat ratio.

5. It depends on the reflected shock over-pressure factor factor f_{rs}.

For a radiation-driven compression in a spherical geometry[33] the corresponding energy balance equation is :

$$R_m = \frac{3(\gamma - 1)}{f_{rs}\, r_m} \int_{r_m}^{r_o} R\,dr$$

where R is the radiation power.

This expression may be used[33] to show that a square power pulse radiation piston will produce a density compression of only 27 for a $\gamma = 5/3$ fully ionised plasma whereas a sequenced double pulse each with linearly rising power may increase the compression limit to 1750 greatly increasing the fusion energy gain factor for a given absorbed energy in a spherical D - T target.

For a pinch the compression limit expression takes the form:

$$\iota_m^2 = \frac{2(\gamma - 1)}{f_{rs}\, \ell_m} \int_{\kappa_m}^{1} \iota^2 \ell \frac{d\kappa}{\kappa}$$

where ι, κ and ℓ are the normalised current, radius and length respectively and m indicates the quantity at time of maximum compression. From this expression several methods of compression enhancement are proposed :

1. Pinch elongation, as in the elongating pinch or plasma focus.[34]
2. Reduction[35] of γ, e.g. as $\gamma \to 1$ $\kappa_m = \frac{r_m}{r_o} \to 0$,

   This applies particularly to high - Z plasmas which remains freely ionizing even at high temperatures e.g. argon or xenon in pinches, hollow pinches or plasma focus or high-Z plasmas in vacuum-spark pinches.[36, 37]
3. Current-stepped compressions.[38]

Effects of radiation cooling[20] have also been considered.

Vacuum Spark Pinch

In this experiment a cloud of high-Z material is injected into a vacuum gap by irradiating a pointed stainless-steel cathode with a 60MW ruby laser pulse. This high Z-material is then compressed using the current from a fast 22μF capacitor charged to 20kV. From x-ray emission experiments hot spots, possibly radiation collapsed, with electron temperatures up to 10 keV have been measured.[37]

Recently a miniature vacuum spark device using nF capacitors is being developed as an x-ray source.

Current-Stepped Pinch

In preliminary work a low performance linear Z-pinch with $\alpha = 15$, where α = electrical characteristic time/ pinch characteristic time, has been built for laser scattering diagnostics in a joint project with the Laser Group[@]. This pinch produces a plasma with $T_e \sim 30{,}000$ K estimated from observed converging shock waves.

Modelling of pinch has been carried out using circuit-coupled snow-plow model with energy balance limit[39-40]. A generalised slug model was also developed for general pinch computation including radiation cooling effects [20, 41].

Another pinch with $\alpha = 0.8$, $\beta = 0.9$ has been designed to give a hotter plasma with the aim of connecting to two sequenced capacitor banks for testing the current-stepped pinch compression enhancement effect.[42]

In preliminary work the design was constrained by existing conventional capacitor banks. It was decided to operate the 15cm diameter pinch at average collapse speed of 2.5 cm/μs increasing to 6cm/μs before the current step. However no increase in compression was observed since at this speed range the expected increase in compression may be cancelled by an increase in γ at 6cm/μs and beyond.

To remove this γ -compensation effect the current-stepped pinch needs to be run at a higher speed so that the γ remains at constant high value and does not change substantially during the current-step. The design considerations require a 150kV 0.6μF Marx generator to provide a 70kA pulse to be current-stepped by means of a 150kV water-line pulsed-charged by a 0.1 μF, 150kV Marx. These are at present being constructed.

Plasma Focus

A Mather's type plasma focus, the UMDPF1[43], has been operated in the laboratory for a number of years. The following are the typical operating conditions:

inner electrode radius	1.3cm (hollow copper tube)
outer electrode radius	4.3cm (six copper rods)
length	16 cm
Capacitance	60μF (ignitron switched)
current	550kA at 20 kV
Current risetime	3¼μs
pressure (D_2)	8 torr
neutron yield	10^9 per discharge

The device has also been operated in argon.

Measurements made on this device include device characterisation[43-45] soft X-ray pinhole photography and temperature measurement[46], shadowgraphs[47,48], holographic interferometry[19], neutron time of flight[5], neutron counting[16,49], neutron half-life measurements[50] and dynamic modelling[25,51]. We have also started work on charged particle measurements using emulsions and mass spectrometers.

The objectives of the plasma focus research are shifting more and more to the following :

development of diagnostics[53] and modelling of dynamics[57]
development of applications e.g. as neutron[50] or soft x-ray sources
development of fusion neutron scaling laws
development as a cost-effective training package for international cooperation[49, 52,58].

The latest development include a target technique[23] for determination of fusion neutron source structure in the plasma focus and more efficient nitrogen lasers [54,55] for focus diagnostics with shadowgraphy, Schlieren system and M-Z interferometry [56].

On the question of neutron scaling the plasma focus seems to be unduly restricted to a fusion neutron yield ~ (current)^4 law due to an observed restriction of axial speed to 10cm per microsecond. We are studying the possibility of increasing this speed. Preliminary studies[58] seem to indicate that increasing the axial speed leads to a decoupling of the magnetic piston and shock front during the end of the axial phase - a natural consequence of the rise of γ towards 5/3. If this problem can be solved, by geometry, by seeding with small amounts of high-Z material, by gas puffing or current-stepping; this might lead to a yield- ~ (current)^7 scaling with great consequence to the plasma focus as a fusion device.

Elongating Pinch

An elongating pinch[59] is being designed at the Plasma Research Laboratory of the University of Technology. This is a linear Z-pinch with a hole (radius ~ $0.5r_o$) in the centre of each of the cathode and anode. To each hole is attached a straight side arm . When the plasma column pinches to the size of the hole any further compression by the pinch current causes the plasma pinch to elongate into the side arms. This elongation will enhance compression and stability.

III. Development of Fusion-related Technology for research initiation in Developing Countries

In view of our relatively extensive experience in experimental plasma physics the Plasma research group has pioneered the concept [49,52] of sharing of fusion-related technology in developing countries. We have developed the concept of packaging cost-effectively an integrated facility consisting of well defined sub-systems which together make up a complete facility for research and training.

For example we have identified that the following sub-systems are necessary to start experimental research in a developing country on the plasma focus :

- simple vacuum system
- focus electrode system with vacuum feed-through and proper insulation
- small capacitor bank (3kJ) and high current switch
- control and triggering electronics
- power supplies
- simple diagnostics for current, voltage, magnetic field, x-ray, neutron and laser shadowgraphy
- plasma dynamic model with structure and chemistry suitable for use on a microcomputer.

These ideas expounded at the ICTP in Trieste[52] have been further developed with the help of the First[25], Second and Third Tropical Colleges[64] and has received full tests in the 6-months UNU Training Programme in Plasma and Laser Technology (1985/86) and a subsequent (UNU) ICTP Training Programme (1988). For these Training Programmes twelve UNU/ICTP Fellows (from Indonesia, India, Pakistan, Egypt, Nigeria, Sierra Leone and Thailand) have worked together with us to develop research packages for the plasma focus, glow discharge and nitrogen laser. The work has produced a number of research reports and papers[49,50,60-64].

During this Training Programme was developed a complete Fusion Facility[49] now designated as the UNU/ICTP PFF (Plasma Fusion Facility).

In the First Training Programme five complete sets of the device were tested over a period of two months, and each was found to work reliably producing well-defined dynamics and reproducible fusion neutron bursts. On 20th January 1986 ICTP Director Professor Abdus Salam honoured us with a visit to the training programme when he witnessed a fusion discharge.

As a result of the training programmes plasma focus fusion facilities are in various stages of development in Pakistan, Nigeria, Indonesia, Thailand, India, Sierra Leone and at Al Azhar University of Cairo. The first experimental plasma physics Ph.D has been produced in Pakistan and several M.Sc's in Nigeria.

The momentum generated by these results has led to the formation of the Asian African Association for Plasma Training (AAAPT) with the aim of extending the concept of effective hands-on training at progressively higher levels by making available resources in plasma physics of countries like China, Egypt and India. It is felt that our training resources in experimental plasma/fusion physics will become more comprehensive when we have developed a simple cost-effective package in a Tokamak-type plasma or a compact torus FRC plasma.

Conclusion

It may be seen that after some 28 years of plasma/fusion research in Malaysia our programmes are still physics-based aimed primarily at academic production and the development of practical methods for the sharing of plasma/fusion technology among the smaller Third World Countries. We feel that the time is not ripe for us in Malaysia to have a large programme, or a programme involving a 'large' or 'national-sized' machine. We see ourselves playing a useful role in fusion-related technology in the community of smaller Third World Countries. We hope to continue fulfilling this useful role, with the help of ICTP and TWAS, using small but high quality machines in the area of long-lived and pulsed plasmas.

Acknowledgement

The fusion research programmes in Malaysia are sponsored mainly by the Ministry of Science, Technology and the Environment under the Intensification of Research Priority Areas (IRPA) mechanisms through grants number 04-07-04-40, 02-07-04-33 and by the University of Malaya. The South-South fusion technology transfer programme is sponsored by the ICTP in Trieste, Italy under its OEA and ICAC programmes. We also acknowledge the help of the Third World Academy of Science, the United Nations University, the Alexander von Humboldt Foundation and the British Government Colombo Plan.

Reference

1. S.Lee, Some shock wave phenomena in a ring-electrode system, (M.Sc. Thesis UM 1966)
2. H.H.Teh and S.Lee Int. J. Electron. 22, 193 (1967)
3. H.H.Teh and C.K.Pang Int. J. Electron. 23, (1968)
4. S.P. Thong and S.Lee, Malaysian J. of Science 2(B) 157 (1973)
5. S.Lee and Y.H.Chen, Malsyaian J. of Science 3(B), 159 (1975)
6. Y.H.Chen, Parametric study of focus optimization (Ph.D Thesis UM 1978)
7. C.S.Wong, Experimental and numerical studies of a Laser-initiated vacuum spark, (Ph.D Thesis UM 1983)
8. S.M.Low, An investigation of a linear hydrogen plasma pinch using a low power dye laser, (Ph.D Thesis UM 1986)
9. T.Y. Tou, Pinch radius ratio of the plasma focus (Ph.D Thesis UM 1987)
10. K.H.Kwek; Pinch Structure in a Plasma Focus (Ph.D Thesis UM 1989)
11. C.K. Pang, Shock wave studies in a ring-electrode shock tube, (M.Sc Thesis UM 1969)
12. Y.H.Chen, Study of Coaxial plasma gun in mode 1 operation, (M.Sc Thesis UM 1972)
13. S.P.Chow, Current sheath studies in a coaxial plasma focus gun, (M.Sc Thesis UM 1972)
14. K.W.Lee, Current oscillations in glow discharge, (M.Sc Thesis UM 1972)
15. A.C.Chew, Plasma focus in an axial magnetic field, (M.Sc Thesis UM 1974)
16. C.S. Wong, Some neutron measurements of the plasma focus, (M.Sc Thesis UM 1978)
17. Y.C.Yong, Multiple ionization in an argon plasma focus, (M.Sc Thesis UM 1978)
18. Y.H.Chin, shadowgraphic studies of a plasma focus, (M.Sc Thesis UM 1981)
19. K.H.Kwek, Holographic interferometric measurements of electron densities in a dense plasma focus (M.Sc Thesis UM 1982)
20. Jalil B. Ali, The enhancement of pinch compression - A numerical study, (M.Sc Thesis UM 1986).
21. C.X.Ong, Exprimental Studies of a Toroidal Plasma (M.Sc Thesis UM 1987)
22. O.H.Chin, Construction and Characterisation of a Helium Glow Discharge (M.Sc Thesis UM 1988)
23. C.K.Chakrabarty, Plasma Focus neutrons - some measurements and applications (M.Sc Thesis UM 1989)
24. H.W.Lee, Construction and Operation of a ruby laser amplifier (M.Sc Thesis, UM 1989)
25. Laser and Plasma Technology Ed. S.Lee et al. (World Scientific Co. 1985)
26. H.H.Teh, Int.J.Electronics 22 (1967)
27. C.S.Wong, J. Fiz.Mal.5, 121 (1984)
28. C.S.Wong. S.H.Saw and O.H.Chin, J.Fiz.Mal.6, 115 (1985)
29. S.Lee, Fusion Energy -1981 IAEA-SMR-82, p.289-295, Procs. Symposium on plasma research, theory and experiment, ICTP, Trieste, Italy, June 1981.
30. I.R. Jones, Comments Plasma Phys and Controlled Fusion 10, 115 (1986)
31. S.Lee, S.Xu, I.R.Jones, to be published
32. I.R. Jones, Fusion Research in 'Small' Countries, Paper presented at plenary session 3rd Asia Pacific Physics Conference June 1988 Hong Kong, Procs. Vol. 1 pg. 162. World Scientific Ed. Y.W. Chan et al (1988).

33. S.Lee, Laser and Particle Beams 6, 597 (1988)
34. S.Lee, J. Appl. Phys. 54, 3603 (1983)
35. S.Lee, Australian J. Physics 36, 891 (1983)
36. S.Lee and H. Conrads, Phys. Lett. 57A, 233 (1976)
37. C.S. Wong and S.Lee, Rev. Sci. Instru. 55(7), 1125 (1984)
38. S. Lee, J. Phys. D: Applied Physics 17, 733 (1984)
39. S. Lee, Plasma Physics 25, 571 (1983)
40. S. Lee, J. Phys. D: Applied Physics 16, 2463 (1983)
41. Jalil B. Ali, S. Lee, T.Y.Tou and Y.C. Yong, J. Fiz. Mal. 5, 153 (1984)
42. S.H. Saw, C.S. Wong, S.Lee in "Small Plasma Physics Experiments" Ed. S. Lee and P.H. Sakanaka pg. 116 World Scientific (1988)
43. S. Lee, and Y.H.Chen, Fusion Energy - 1981, IAEA-SMR-82, p.296 - 303, Proc. Symposium on plasma research, theory and experiment, ICTP, Trieste, Italy, June 1981.
44. S.P. Chow, S. Lee and B.C. Tan, J. of Plasma Physics 8, 21 (1972)
45. S. Lee, Y.H.Chen, S.P. Chow, B.C. Tan, H.H.Teh and S.P.Thong, Int. J. Electronics 33, 85 (1972)
46. Y.H.Chen and S. Lee, Int. J. Electronics 35, 341 (1973)
47. S. Lee and Y.H.Chin, Bull. Phys. M'sia 2, 105 (1981)
48. S.Lee, Harith Ahmad, T.Y. Tou, K.H.Kwek and C.S. Wong, J. Fiz. Mal. 6, 23 (1985)
49. S. Lee, T.Y.Tou, S.P. Moo, M.A.Eissa , A.V.Gholap, K.H.Kwek, S. Mulyodrono, A.J.Smith, Suryadi, W.Usada, and M. Zakaullah, A simple facility for the teaching of plasma dynamics and plasma nuclear fusion, American J. Physics 56, 62 (1988)
50. S.P. Moo and S.Lee, Singapore J. Phys. 4,131 (1987)
51. S.Lee, A plasma focus model yielding trajectory and structure, Spring College on radiation in plasma, Trieste, May 1983; Published in "Radiation in Plasmas, p. 978-987, World Scientific Pub. Co. (1984)
52. S.Lee, Regional Centres for research transfer within South-east Asia Countries - Invited paper presented at the International Conf. on Physics & Development 1984, ICTP, Trieste, Italy.

53. T.Y.Tou and S.Lee Rev. Sci.Instru. 59, 2370 (1988)
54. K.H.Kwek, T.Y.Tou and S.Lee, IEEE Transactions IM-38, 103 (1989)
55. S.Lee, K.H.Kwek et al "Sequenced Nitrogen Lasers" Accepted. J. Appl. Phys. for May 1989
56. K.H.Kwek, T.Y.Tou and S. Lee J. Fiz. Mal. 9, 36 (1988)
57. T.Y.Tou, S.Lee and K.H.Kwek, Accepted IEEE Trans. Plasma Science
58. S.Lee "The sharing of fusion related technology among developing countries" in "Fusion Energy and Plasma Physics" Ed. P.H. Sakanaka, pg. 754, World Scientific (1988)
59. Jalil Ali et al "Dynamics of an elongating pinch", Third Tropical College May/June 1988, to appear in Procs.
60. A.J. Smith, K.H.Kwek, T.Y.Tou, A.V. Gholap and S.Lee, IEEE J. Quantum Electronics QE-23, 283 (1987)
61. K.H.Kwek, A.J. Smith, T.Y.Tou, A.V.Gholap and S.Lee, J. Fiz. Mal. 7, 125 (1986)
62. S.Lee, A.V.Gholap. A.J. Smith, K.H.Kwek, A.C.Chew, T.Y.Tou and S.Sapru, J. Fiz. Mal. 6, 165 (1985)
63. C.S. Wong, O.H.Chin, M.A. Eissa, A.V. Gholap, S. Mulyodrono, C.X. Ong, S. Sapru, S.H.Saw, A.J. Smith, Suryadi and W. Usada, J.Fiz. Mal. 7, 45 (1986)
64. Laser and Plasma Technology Ed. S. Lee et al (World Scientific Co. 1988)