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PLASMA AND FUSION PHYSICS IN EGYPT

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CAIRO - EGYPT

1. INTRODUCTION:

1.1 Nucelar Fusion and Developing Countries:

The energy needs of the world in the future are so great that all sources of energy should be seriously studied. The present understanding is, however, that only nuclear energy - Fission and Fusion - can meet the long term needs of the world. Fusion research has been a growing field of activity for more than 30 years and the advantage of fusion is seen mainly in a comparison with fission. Fusion offers the possibility of several long-term advantages and it seems worthwhile to pursue it vigorously, in spite of some technological difficulties. The main objective has always been the generation of useful and economic power by fusion and during last few years the studies of reactor systems have been undertaken in detail. In fact these studies are complex and expensive and need high technology. Doubtless, fusion is needed, and assuming it will be in due course form the basis of economic reactor, then came the usual question: how developing countries - like Egypt - should respond to these advances in fusion programmes ? The answer, of course, depend mainly on the estimated long term energy requirements, taking into account conservation and estimates of the potential of the different energy sources in these countries. But it is agreeable that the most important objective for a developing country is to be able to make a continuous, reliable and objective assessment of the progress and likely outcome of fusion

research in major centres in advanced countries(*). This objective can be achieved by developing sufficient experience in fusion to make an independent judgment, which can be done by attaching scientists to fusion programmes elsewhere or developing a national programme based on small-scale experiments for plasma physics. Also, by employing experts from advanced centres.

In addition, it is known that fusion research is closely related to the basic science of plasma physics, which in turn related to gas discharge physics and astrophysics. Therefore, in developing countries, these fields have to be a desirable fields of study and research for scientific and trainsing purposes.

Now, it will be of interest to give some light on the research fields and main results obtained by both the experimental and theoretical groups- during the last 10 years - at the plasma physics Units, Nuclear Research Center, Atomic Energy Authority, Cairo, Egypt.

1.2 Plasma Physics Activities at The Atomic Energy Authority in Egypt:

Plasma Physics Research Group Now:

Group Leader: Prof. Dr. T.A. El-Khalafawy.

Head of The Experimental Group: Prof. Dr. M.M. Masoud.

Head of The Theoretical Group: Assist. Prof. Dr. W.H. Amein

Members of Experimental Group:

Dr. Eng. M. Bourham	(Assistant Professor)
Dr. A.B. Beshara	(Lecturer)
Dr. H.M. Soliman	(Lecturer)

(*) H.A.B. BODIN; Int. Conf. on Nuclear Energy Technology in Developing Countries, Grado Conf. Centre, Italy, Oct.,, 1981.

Dr. Z.M. Mostafa	(Lecturer)
Mrs. H.A. El-Gamal	(Assistant Lecturer)
Miss H.A. El-Taib	(Assistant Lecturer)
Mis. A.A. Shagar	(Assistant Lecturer)
Mr. A.M. Mansour	Demonstrator
Mr. F.M. El-Kashif	Demonstrator
Mrs. F.A. Abd-El-Aziz	Demonstrator
Miss F.M. El-Tokhy	Demonstrator
Mr . G.G. El-Herigy	Demonstrator

Members of Theoretical Group:

Dr. Sh. M. Khalil	(Assistant Professor)
Dr. Y.A. Sayed	(Assistant Professor)
Dr. R.N. El-Sherif	(Lecturer)
Mr. B.F. Mohamed	(Assistant Lecturer)
Mr. N.G. Zaki	(Assistant Lecturer)

The plasma physics laboratory was created in Nuclear Physics Department, 1962 after my return from Plasma Physics K.F.A. Jülich. The research program was planned to establish mainly two experiments, magnetic compression theta pinchs, shock tubes, plasma diagnostics such as magnetic and electric probe, rogowski coils, microwave, spectroscopy, high speed photography and X-ray, and theoretical plasma physics. Preparation of needed trained manpower started by giving courses in theoretical and experimental plasma physics, gas discharge and all related topics in co-operation with University Staff Members.

Cooperation between the plasma physics group and International Laboratory started since 1966 with exchange of scientists for long and short period. Scientists from USSR joined us for long period under the umbrilla of bilateral agreement between the Soviet Atomic Energy and The Egyptian Atomic Energy Establishment.

UKAEA, Culham Laboratory U.K. donated the group a 3.5-meter Θ-pinch which is now in operation. The bilateral agreement between International Bero K.F.A. Jülich, W. Germany and A.E.A. Egypt 1981 gave a chance of developing the laser diagnostics training the group as well as supplying with some components to improve and upgrade the

diagnostics and technology of the plasma machines. I.A.E.A. supplied us with parts of data aquisition system and some help in the up to date diagnostics.

Also we have a Federation Agreement with the International Centre for Theoretical Physics (ICTP, TRIESTA, ITALY). According to this agreement, two scientists of the theoretical group visit the Centre every year and participating in the activities held in the centre and related to plasma and fusion research.

The cooperation with advanced countries and internation societies is of great importance for any developing countries to overcome the sofisticated technology and financial problems.

In present the plasma group consists of 16 permanant physicsts, 10 experimentalist and 6 theoreticalists besides 12 technicians, mechanics, electronic, vacuum and optical workshop.

One of main task of the group is to encourage the university staff to go for plasma physics fields. About 25 staff members are attached to the group from different universities, as well as several experiments are running.

High lights on the experiments carried out and the main problem investigated and results obtained by both the experimental and theoretical group follow.

2. EXPERIMENTAL RESEARCH:

The plasma physics research work in N.R.C. of Egyptian A.E.A. started 1962 with two major experiments. The first was theta-pinch, the second was shock waves. During the 25 years of research some experiments were shotdown, others build up according to scientific personnel presence, apparatus avaiable, scientific and technological development, financial support and cooperation with international laboratory interest.

Current plasma experiments consist of three main experiments, small linear Θ-Pinch 4KJ, 10 KJ Plasma Focus, and 3.5 meter Θ-Pinch 60 KJ.

The 4 K.J. Θ-Pinch is in operation since 1973 and continue. The Plasma Focus experiment started with 3 KJ system and developed in 1983 to 10 KJ bank. A new focus device is under construction with bank energy of 40 KJ.

The 3.5 meter Θ-Pinch can be used as Θ-Pinch, screw pinch, or Z-Pinch. It is in operation since 1985 with main Θ-Pinch bank of 60 K.J.

The developments of the diagnostics tools started with laser. A home made nitrogen pumped dye laser is in operation successfully, some modification in the N_2 laser and mode selection is in progress. H.C.N. laser and flash lamp pumped dye laser are in the testing phase.

In present year the program are concentrated on several plasma diagnostics and data aquisition system for 3,5 meter Θ-Pinch, and 40 KJ Plasma Focus and Plasma wall interaction. Also it is undertaken to achieve a spheromak configuration by using the coaxial discharge with toroidal and poloidal magnetic field.

Our ultimate goal for the future plan after that will be a small toroidal system with all additional control and diagnostics similar to the existing tokamak system.

2.1 <u>Shot Down Experiments and Its Main Results</u>:

The development of these experiments; configuration, parameters, diagnostics, main problem studied are shown in tables.

2.1.1 Development of Θ-Pinch 1965-1976 (Table I).

2.1.2 Development of shock tubes 1965- (Table II).

2.1.3 Development of Plasma Focus 1974- (Table III).

2.2 <u>Current Experiments</u>:

2.2.1 <u>The Straight Θ-Pinch (Thetatron) Discharge 1984 Till Now</u>:

This work is mainly concerned with the investigation

of heating mechanism and its relation to plasma dynamics and magnetic stability.

<u>Experimental Set-Up</u>:

The thetation discharge arrangement consists of a condenser bank 9µF, producing 129 KA at charging voltage of 16 KV. The compression coils used consists of 14 parts paralelly connected ledngth 50 cm around the ceramic tube of inner diameter 7 cm, its length 100 cm, filled with hydrogen press ranging between 10^{-1} to 10^{-3} torr. The gas was preionized by glow discharge, has a maximum value of electron temperature 55 eV at tube radius 1.25 cm and density 1.6×10^{11} cm^{-3}.

Diagnostic methods used are electric probe (double floating probe) Rogowski coil, magnetic probes and microwave probe.

<u>Experimental Results</u>:

Radial election temperature distribution shows its maximum value near tube axis R-0.5 cm and drop to lower values at R - 1 cm. The increase of the electron temperature near the axis may be due to energetic particles diffused from plasma sheath and shock waves approaching the axis. But radial density distribution reaches its maximum value at R - 1 cm where $n = 13 \times 10^{12}$ Cm^{-3} and lower value near the tube axes. This can be attributed to the existence of the trapped magnetic field at the axis of the discharge tube.

Study of the microwave radiation emission indicates that it originates from electron oscillations depending on charging voltage for $\lambda \leq 4$ mm $\lambda \leq 8$ mm according to $\sigma_{rad} \simeq A \lambda^{1/4} I_{dis}$ σ = radiation density, A is a constant, I discharge current, also it was found that the peak value of emitted radiation occurs at $Po \simeq 8 \times 10^{-3}$ torr for $\lambda \leq$ 4mm and for 4mm $\leq \lambda \leq$ 8 mm radiation intensity increase linearly with increasing initial pressure to $Po = 8 \times 10^{-2}$ torr.

Also it propagate at right angle to the direction of axial magnetic field, predicting that it is due to longitudinal oscillation which leads to the generation of electromagnetic radiation. The microwave radiation frequency for 8 and 4 mm was 4.7×10^{11} sec^{-1} 2.36×10^{11} sec^{-1} and corresponding value for cyclotron frequency $W_{ce} \approx 4.93 \times 10^{10}$ sec^{-1} and 2.92×10^{10} sec^{-1} and calculated value for W_{Pe} is 7.98×10^{10} sec. This result show that:

$$W_r = nW_{ce} < W_{Pe}$$

Where n = 8 in case of λ = 8 mm, n = 10 in case of λ = 4 mm, Fig. 4.17, 4.18.

The electromagnetic radiation has also relation to the upper hyprid frequency as:

$$W_r = nW_{nl}$$

Where n = 3 in case 8 mm, n = 5 for 4 mm indicating the possibility of longitudinal oscillation to be transformed into electromagnetic radiation.

Magnetic Field distribution in both axial and radial directions show trapped magnetic field depending on initial gas pressure and has peak value at Po = 8×10^{-3} torr which coincide with maximum of microwave radiation $\lambda \leq 4$ mm. This predicts that the change of magnetic flux during the tearing and reconnection will cause an accelerating electron beam. This electron beam will give rise to the excitation and emission of microwave radiation.

Recent Published Papers

1. Bourham M.A., El-Gamal H.A., and abu El-Nasr T.Z., "Radiation in plasma" Proc. of Tropical Conf., Trieste, Italy, (1983) editted by B. Machnamara, World Sc. Pub. Co. P. 1018, (1984).

2. Bourham M.A., El-Gamal H.A., and Abu El-Nasr T.Z., Bull. Phys. M. Sia P. 161 (1983).

3. Bourham M.A., International Conf. on Plasma Physics ICPP, P. 1-7, Lausanne, Switzerland, Jon 27 - Jully 3, P. 8 (1984).

4. Bourham M.A., Masoud M.M., Sharkawy W.A., and Eissa M.A., Arab Jour. of Nuclear Sciences and Applications, Vol. 20, (1987).

5. Bourham M.A., XVT int. on. phenomena in ionized Gasses (1984).

6. Bourham M.A., El-Gamal H.A., El-Sherief R.N., and Shagar A.M., 14th European Conf. on Controlled Fusion and Plasma Physics, Vol. 11D, Part II, P. 562, Madrid 26-29 June (1987), published by European Phys. Soc.

7. Eissa M.A., and Bourham M.A., Sign. J. Phys. Vol. 3, No. 1, P. 83 (1986).

8. Masoud M.M., Bourham M.A., Sharkawy W., Eissa M.A., Journal Fzik Malayzia, Vol. 7, No. 1, P. 25 (1986).

2.2.2 3.5 Meter Θ-Pinch (1985 - Now):

The machine is the ex-culham 3.5 M Θ-Pinch which is re-installed at the plasma laboratory and modified to suit the rearrangement conditions. Capacitor bank of 60 KJ stored energy is allowed to discharge through 7 turns Θ-coils in order to deliver 400 KA discharge current of 7 μsec rise time. Bias magnetic field is created by the discharge of a 4.8 KJ condenser bank triggered before the main bank by means of a delay system. A z-pinch discharge is used for preionization and preheating before applying the main bank. The discharge takes place between two metallic electrodes placed at the ends of the discharge chamber (4.2 m separation). The z-pinch bank has an energy of ≈ 1 KJ with rise time of 1.9 μs.

Main Problems Studied and Results:

The plasma dynamics for both z-pinch and θ-pinch was investigated. The effect of the bias magnetic field on the stability of the sheath was obtained. The density and temperature of the plasma sheath was estimated. Trapped magnetic field and microwave radiation was measured. A compelte analysis of the results is in progress. 3 Reports about the pinch behaviour were published.

Future Plan:

Since the machine banks is triggered by air switches which are noisy, a pressurized switches where designed and under construction to be fixed to the machine. Heating mechanisms and instabilities of the plasma sheath and pinch will be the main course of study in the coming year as will as wake excitation in the microwave region.

Published Works:

1. ARE AEE/Int. Rep. 114 (1985).
2. ARE AEE/Int. Rep. 116 (1986).
3. ARE AEE/Int. Rep. 128 (1987).

M.Sc. Thesis of A. Mansour (to be published).

2.2.3 Coaxial Plasma Focus:

The plasma focus devices, consist of a coaxial electrodes of Mather geometry have been used. The first one has an outer and inner electrodes radii of 3.3 and 1.6 cm respectively and a length of 31.5 cm, and the second one has an outer and inner electrodes radii of 0.5 cm and 5 cm respectively and length of 7 cm.

The experiments were conducted with a 150 KA peak discharge current, with rise time of 10 μ sec, which delivered from a 10 KJ capacitor bank for charging voltage of 15 K.V.

The investigations are carried out in Hydrogen gas with base pressure ranging from 0.2 to 1 mm_{Hg}. The discharge was triggered by a two pressurized three electrodes spark gap triggation type.

Diagnostics used are, miniature rogawiski coil, magnetic and electric probes, high speed camera spectroscopy, X-ray detector, gridded faraday cup, retarding field analyzer.

Experimental Results:

a. For the first device (a = 1.6 cm, b = 3.3 cm, z = 31,5 cm).

The most important results are; the current sheath is formed near the breech of the coaxial electrodes and move with velocity $V \propto \rho^{-0.5} Z^{0.4}$, where ρ is the gas density and Z is the distance from breech. It rotates around the central electrode at Z = 15 and the rotating current increases with sheath motion as $I_Q \propto Z^{3.4}$ until it reaches a value of 20% of the radial current. Applying a magnetic field 0,6 T along the coaxial electrodes, the sheath current rotates near the breech and increases as $I_Q \propto Z^4$ until it approaches the value of radial current. Increasing the discharge current up to 150 KA results of an emission of intensive X-ray accompanied by a low divergence energetic electron beam at one side on the axis and energetic ions brust the other side. Plasma focus density and temperature was estimated to be 10^{19} cm^{-3} and $\approx$ 3 Kev. Applying a transverse magnetic field 280 G in the expansion chamber, the radial velocity of the expanded plasm shell is restricted and plasma temperature decreased while its density increased.

b. Second device (a = 0.5 cm, b = 5 cm, z = 7 cm).

The most important results obtained are:

- A pulse of energetic electron beam ejected from the pinch region of the focussed plasma was detected and estimated to be 0.32 KeV measured by retarding field analyzer.
- Electron temperature of the plasma focus was determined by measuring X-ray intensity to be 2.8 KeV.

Future Experimental Program:

A modified energy source for new design of plasma focus device (inner diameter = 4 cm, outer diameter = 11 cm, its length = 8 cm), bank stored energy up to 40 KJ has been constructed. It is planned to study creation mechanism of the induced axial magnetic field, magnetic field tearing within the plasma sheath as well as its distribution, rotation ... etc. Effect of the applied axial magnetic field along the coaxial electrodes on the plasma sheath dynamics as well as viscosity effect.

Developed diagnostic techniques will be used for measurements processes such as laser and high speed photography.

Recent Published Papers

1. Coaxial electrodes gun characteristics.
   M.M. Masoud, H.M. Soliman.
   ARE-AEE Rep. 268 (1981).

2. Plasma focusing in coaxial gun.
   H.M. Soliman,M.M. Masoud and T.A. El-Khalafawy.
   Arab J. of Nuclear Science and Applications, Accepted for publication (13/85), (1985).

3. Plasma Rotation in Coaxial Discharge.
   M.M. Masoud,H.M. Soliman and T.A. El-Khalafawy.
   ARE-AEE Rep. (289), (1985).

4. Plasma Sheath and Focus Dynamics.
   M.M. Masoud,H.M. Soliman and T.A. El-Khalafawy.
   XVII International Conf. on Phenomena in Ionized Gases Vol. (2), P. 963 (1985).

5. 10 Kilo Joule Plasma Focus.
   H.M. Soliman,M.M. Masoud and T.A. El-Khalafawy.
   Arab J. of Nucl. Sci. and Applications.
   Accepted for Publication, (41/85), (1985).

6. Viscosity effect on plasma sheath dynamic in plasma focus.
   M.M. Masoud,H.M. Soliman and T.A. El-Khalafawy.
   ARE-AEE Rep. (294), (1986).

7. Influence of longitudenal magnetic field on current sheath in coaxial discharge.
   H.M. Soliman,M.M. Masoud and T.A. El-Khalafawy.
   XVIII International Conf. on Phenomena in Ionized Gases, Vol. 2, P. 432 (1987).

8. Heating and Acceleration Mechanism in Plasma Focus.
   T.A. El-Khalafawy,M.M. Masoud and H.M. Soliman.
   Energy Independence Conference on Fusion. Energy and Plasma Physics, P. 584 (1987).

9. Investigation of energetic electron beam and X-ray generated in a plasma focus.
   H.M. Soliman,M.M. Masoud and T.A. El-Khalafawy.
   The 4th Conf. of Nucl. Sci. and Applications, Vol. 2, P. 749 (1988).

10. Magnetic Reconnection and Instabilities in Coaxial Discharge.
    M.M. Masoud,H.M. Soliman and T.A. El-Khalafawy.
    15th European Conf. on Controlled Fusion and Plasma Heating, Vol. (1), P. 1275 (1988).

11. Plasma focus matching conditions.
    H.M. Soliman,M.M. Masoud and T.A. El-Khalafawy.
    ARE-AEE Rep. 297 (1988).

12. Plasma Sheath Current Density, Ion Beam and X-ray in Plasma Focus.
    H.M. Soliman,M.M. Masoud and T.A. El-Khalafawy.
    Arab. J. of Nucl. Sci. and Applications.
    Accepted for Publication (3/88), (1988).

2.2.4 Glow Discharge:

The objective of that experiment is to introduce up to date technology in plasma and laser diagnostics. Glow discharge which is a linear electrode in a vessel of 30 cm length and 10 cm diameter represents the basic experiment for such diagnostics.

Main Problems Studied and Results:

A double electric probes was used to investigate the plasma density and temperature and their radial and axial distribution. The results are in progress and the analysis of the different discharge power parameter will continue till the end of this year. The main interest is the glow discharge fundamental processes. A tunable dye laser is used to confirm the probe results as well as to study the electrodes material effects on the discharge.

Future Plan:

An ion beam injector is designed and is under construction to study beam-plasma interaction as a diagnostic tool.

A data aquisition system has been installed and the meassurement will be linked with it, with the proper program. The scientific group are working in the data aquisition system to use it properly as soon as they complete their progress.

3. THEORETICAL RESEARCH:

The theoretical studies in plasma physics are mainly directed during last ten years to study and investigate following topics:

3.1 Plasma Intabilities and Equilibrium:

These studies are of great interest from the confinement point of view, specially in the thermonuclear fusion reactors. In addition, in investigating some of the plasma phenomena as the mechanism of collisionless plasma heating, the nonlinearity and turbulence in plasmas, and MHD generators. The following problems are considered:

3.1.1 Drift Waves and Instabilities in Inhomogeneous Plasma:

The nonlinear dispersion and the kinetic wave equations for drift potential oscillations of weakly inhomogeneous plasma with fixed phases are obtained. The drift kinetic is derived with accuracy to within the terms $W_{c\alpha}^{-2}$ ($W_{c\alpha}$ is the cyclotron frequency of type $\alpha = e, i$). This equation makes it possible to take into account not only the density and temperature gradients, but also the current velocity inhomogenity. Coulomb collisions are considered and helped to remove divergences in the matrix elements, describing the nonlinear wave interactions. The derived kinetic wave equation enables to investigate the nonlinear dynamics of drift oscillation saturation, hazardous for plasma confinement, as well as the wide range of homogeneous collisional plasma.

On the basis of weak turbulence theory, the drift instability excited by longitudinal current in isothermal plasma (current-convective instability), and electron-acoustic instability excited in hot ion rotating, are investigated analytically.

For drift instability, the nonlinear Landau damping is the mainly nonlinear mechanism limiting the oscillation amplitude and that the nonlinear instability saturation takes place at high noise level.

The linear stage of the current-convective instability is also investigated for nonisothermal magnetized plasma, where the temperature ratio T_e/T_i play an essential role, i.e., increasing T_i over T_e leads to decreasing the growth rate of the instability in the linear stage.

3.1.2 Kinetic Theory of Buneman's Instability:

The development of Buneman kinetic instability is investigated under different plasma conditions. Expressions for the frequency, growth rate, threshold values, and conditions of excitation of such instability are obtained at current velocity slightly exceeds the instability threshold velocity.

In quasilinear approximation, the major effect was the slowing down of resonance electrons, and connected with it, a reduction of residual electron terms in the dispersion equation for waves with hot ion plasma. This effect leads to a gradual increase of the oscillation growth rate and to the transformation of weak instability-as in the linear stage - into a strong one.

In isothermal collisional plasma, the existance of a critical value of the external applied electric field (E_{C2}) is found to divide the quesilinear effect into: amplification of instability at $E < E_{C2}$ and saturation at $E > E_{C2}$ with low noise level.

Weak turbulence theory of a homogeneous magnetized plasma with allowance for Coulomb collision is also developed for potential plasma ascillations with random phases. Based on this theory, the nonlinear stage of Buneman's instability excited in hot ion plasma by longitudinal current is investigated. In this case, the nonlinear treatment of the instability is not essential, while the major effect due to quasilinear theory.

In addition, this instability is investigated for hot electron plasma both in linear and quasi-linear stages. The linear growth rate in this case found to be much less than for hot ion and isothermal plasmas, and quasilinear effect leads to neglecting the contribution of the electrons in the dispersion equation.

3.1.3 Instabilities and Turbulence in Plasma with Transverse Current:

The effect of plasma ions upon the process of nonlinear scattering of instability excited by transverse current is investigated. In the case of excitation of 3-dimensional wave pockets, nonlinear scattering of the waves on ions is small so that the oscillation scattering on plasma electrons play the main role in the stability qsaturation. The case of 2-dimensional wave packets requires a new approach, and a new model of weak turbulence theory allowing for the broadening of resonant denominators at the expense of the wave growth increments. Therefore, a theory of weak turbulence in a homogeneous collisional plasma without magnetic field and in strong magnetic field is developed.

Based upon the above theory, two types of instabilities are studied:

i. The excitation of oscillations by a cold electron beam in hot free plasma.

ii. The excitation of ion-cyclotron waves by axial current.

The developed theory is especially suitable for analysis of nonlinear saturation of instabilities with a threshold character if plasma parameters correspond to a slight surpassing of instability excitation threshold.

3.1.4 Relaxed States of Toroidal Plasmas:

The problem of calculating the lowest eigen values which connected with the maximum current for the relaxed (force-free) toroidal plasmas "Taylor States" is investigated for axisymmetric case. These eigenvalues (zero-flux and zero-field eigenvalues) have been calculated exactly for toroidal plasmas for both arbitrary aspect ratio and arbitrary cross sections as circle, ellipse, multi-pinch corss section described by a cassini curves, and D-shape of the JET.

For more details concerning plasma instabilities and equilibrium, see references [1-13], (recent publications of the theoretical group).

3.2 Nonlinear Interaction and Wave Generation in Plasmas:

These studies are of prime importance from the practical applications point of view, e.g., in plasma diagnostic technique and in studying the interaction of intensive electromagnetic waves with matter (laser-fusion reaction). Besides, it is of great interest in studying the propagation of electromagnetic waves in ionosphere and using the strong generated waves as a tool for plasma heating. The following main results are obtained:

3.2.1 Isotropic Plasma:

In case of nonlinear interaction of P-polarized incident electromagnetic waves on a semi-bounded isotropic plasma, the tangential electric field components of the waves at combination frequencies are found to be discontinuous at the plasma boundary. This is a new result differs from that of earlier work in which the tangential electric field is assumed to be continuous at the boundary.

The amplitudes and phases of the wave radiated from a transition layer at combination frequencies are found to be depend neither on the width of the transition layer nor on the plasma density distribution through the TL but only on the plasma density in the homogeneous region of the medium. The above work is generalized later for two interacting waves of different polarization (S and P).

In the case the amplitudes of the generated waves with combination frequencies are equally radiated from transition layer into plasma vacuum. Besides,

the amplitudes of S-radiated second harmonic waves into plasma and vacuum are not equal, while amplitudes of P-radiated second harmonic waves are equal.

When one of the interacting waves is a surface wave, the second harmonic is radiated only in the direction of the reflected wave at the basic frequency.

3.2.2 Anisotropic Plasma:

Above studies are considered in case of applied static magnetic field where two plasma geometries are considered:

i. Semi-bounded plasma.

ii. Plasma layer.

The external magnetic field has no effect on the fundamental s-polarized waves only, while it strongly affects the generated waves. The generated amplitudes are found to be sharply increases at frequencies approaches the electron cyclotron frequency. The resonance in the amplitudes of these waves occur for values of the static magnetic field in the neighbourhood of plasma resonance for the waves at the fundamental and combination frequencies.

In case of normal incidence of electromagnetic waves on unmagnetized plasma, waves are not emitted. On the other hand, existance of static magnetic field causes a second harmonic generation for normal incidence.

When the electrons in the plasma layer are relativistic, the amplitudes of the generated waves are found to be sharply increases.

3.2.3 Beam-Plasma Interaction:

The effect of external static magnetic field on the interaction of relativistic beam with an inhomogeneous bounded cold plasma and plasma heating is investigated in one-dimensional. In this case, more power is absorbed by the plasma, and the relativistic beam, due to the resonant increase of the electric field in the interval where $W = W_p$, acts as a source for feeding the plasma with power and not only for amplification of waves, especially when second harmonic waves are generated.

For more details concerning section 3.2, see references [14-25], (recent publications by the theoretical group).

3.2 Future Plan:

The following programme is supposed for the future plan. It is assumed to continue the theoretical research work of above mentioned topics under the following considerations:

3.2.1 Plasma Instabilities and Equilibrium:

1. To study some of current electrostatic micro-instabilities (Buneman, current-convective, electron-sounds) under the effect of inhomageneous fields and to find the possibility in this case for instability saturation.
2. To create a complete picture of the plasma-sound instability.
3. To use the derived kinetic wave equations (for magnetized and nonmagnetized plasma) to study and investigate the nonlinear dynamics of current-convective instability in inhomogeneous plasma.
4. To investigate turbulent heating as result of Bunemanl and electron-sound instabilities and the effect of these instabilities on the plasma parameters.
5. To study the case of nonaxisymmetric relaxed force-free toroidal plasma.
6. To study plasma current instability due to two ions streams.

3.2.2 Nonlinear Interaction and Wave Generation in Plasmas:

1. To study the effect of external applied weakly inhomogeneous magnetic field on the wave generation and amplification in plasmas. This consideration is important from the practical stand point, when the electron displacement from the equilibrium position is considerably less than the characteristic scale of magnetic field inhomogeneity.
2. Relativistic incident radiation on the plasma, which of great interest in connexion with higher energy deposition in various devices for intense electromagnetic radiation generation.
3. The effect of different parameters on the generated waves:
   - Dense or rarefied plasma.
   - Normal or oblique incidence.
   - Plasma shape (more realistic geometry), either flat inhomogeneous plasma layer, or thin inhomogeneous plasma cylinder.
   - Warm plasma.
4. The role of surfaces in the interaction of radiation with plasmas.

3.3 **Recent Published Papers:**

3.3.1 Plasma Instabilities and Equilibrium:

1. On Nonlinear Scattering of The Electron-Sound Oscillations of Plasma on Ions.
W.H. Amein, I.A. El-Naggar, and V.L. Sizonenko; Plasma Physics, 19, 651 (1977).
2. On The Theory of Buneman's Instability in Hot Ion Plasm.
I.A. El-Nadggar, Sh. M. Khalil, and V.L. Sizonenko : J. Plasma Physics, 20, 75 (1978).

3. On The Theory of Magneto-Active Plasma Weak Turbulence.
A.M. Hussein, Sh.M. Khalil, and V.L. Sizonenko : Plasma Physics, 20, 545 (1978).

4. Collisionless Quasilinear Current Instability in Field-Free Plasma.
Sh.M. Khalil, W.H. Amein, I.A. El-Naggar, and N.M. El-Siragy; 1982 Int. Conf. on Plasma Physics, June 9-15, Göteborg, Sweden, 15P-1-25, 424 (1982).

5. Turbulent Ion Heating in Rotating Plasma.
N.M. El-Siragy, Y.A. Sayed, and V.L. Sizonenko: Physica, 122C, 113 (1983).

6. Electron-Sound Instability Based on Weak Turbulence Theory.
W.H. Amein, Sh.M. Khalil, Y.A. Sayed, and B.F. Mohamed : XVI Int. Conf. on Phenomena in Ionized Gases, 29 Aug. - 2 Sept.,Düsseldorf, 5, 714 (1983).

7. Buneman Instability in Inhomogeneous Magnetized Plasma.
Sh. M. Khalil, lY.A. Sayed, and W.H. Amein: College on Plasma Physics (Radiation in Plasmas), 15 May - 17 June, ICTP, Trieste - Italy, 2, 864 (1983).

8. Kinetic Wave Equation for Inhomogeneous Collisionless Field-Free Plasma.
Y.A. Sayewd, Sh.M. Khalil, and W.H. Amein: J. Fiz. Mal., 6, 7 (1985).

9. Current Instability in Hot Electron Anisotropic Plasma.
Sh.M. Khalil, Y.A. Sayed, and R.A. Sayed: Int. Rep. IC 186/186 - ICTP, Trieste-Italy (1986).
Accepted for publication at: Arab J. Nuclear Sciences and Applications (1988).

10. Current-Convective Instability in Inhomogeneous Hot Electron Plasma.
Sh.M. Khalil, Y.A. Sayed, and N.G. Zaki : Int. Conf. on Phenomena in Ionized Gases, 13 - 17 July, Swansea, U.K., 2/C, 336 (1987). Accepted for publication at: Beitrage Aus Der Plasmaphysik (1989).

11. Electron-Ion Two-Stream Instability in Anisotropic Isothermal Plasma.
Sh.M. Khalil, and B.F. Mohamed:
J. Phys. France, 49, 451 (1988).

12. Eigenvalues of Relaxed Toroidal Plasmas.
F. Cap, and Sh.M. Khalil:
15th European Conference on Controlled Fusion and Plasma Heating, 16-20 May, Dubrovnik, Yugoslavia, 12B, 425 (1988).

13. Quasilinear Theory of Buneman's Instability in Hot Electron Plasma.
Sh.M. Khalil, and B.F. Mohamed:
16th European Conference on Controlled Fusion and Plasma Physics, 13-17 March, Vience, Italy, P4G1 (1989).

3.3.2 <u>Nonlinear Interaction and Wave Generation in in Plasmas:</u>

14. Wave Generation at Combination Frequencies.
A.R. Barakat, V.V. Dolgopolov, and N.M. El-Siragy:
Plasma Physics, 17, 89 (1975).

15. Nonlinear Interaction of Surface Waves with Incident Radiation at A Narrow Inhomogeneous Plasma Layer.
A.M. Hussein:
Physics Letters, 78A, 249 (1980).

16. Waves Generation Due to Nonlinear Interaction of S-Surface Waves at The Plasma Boundary.
N.M. El-Siragy, Sh.M. Khalil, W.H. Amein, O.Z. Nagy:
Plasma Physics, 23, 1189 (1981).

17. Mode-Mode Coupling of S- and P-Polarized Surface Waves at The Plasma Boundary.
N.M. El-Siragy, Sh.M. Khalil, Y.A. Sayed and O.Z. Nagy:
Arab J. Nuclear Sciences and Applications, 16, 195 (1983).

18. Harmonic Generation in Magneto-Active Plasma.
N.M. El-Siragy, Sh.M. Khalil, W.H. Amein, and W.A. El-Feky:
Egypt J. Physics, 15, 213 (1984).

19. Wave Generation in Relativistic Plasma Layer.
Sh.M. Khalil, N.M. El-Siragy, Y.A. Sayed, and R.N. El-Sherif:
Physica Scripta, 30, 357 (1984).

20. Nonlinear Interaction of The Surface Waves at A Narrow Inhomogeneous Layer.
A.M. Hussein:
J. Plasma Physics, 33, 151 (1985).

21. Nonlinear Interaction of S-Plarized Incident Radiation and Surface Waves in Magnetized Plasma.
N.M. El-Siragy, Sh.M. Khalil, Y.A. Sayed, and R.N. El-Sherif:
Beiträge Aus Der Plasmaphysik, 25, 227 (1985).

22. Effect of Magnetic Field on Nonlinear Interaction of Electromagnetic and Surface Waves in Plasma Layer.
Sh.M. Khalil, N.M. El-Siragy, I.A. El-Naggar, and R.N. El-Sherif.
International J. Theoretical Physics, 24, 1001 (1985).

23. Nonlinear Interaction of Relativistic Radiation with Surface Waves in Anisotropic Plasma Layer.
Sh.M. Khalil:
Energy Independence Conference: Fusion Energy and Plasma Physics, Augest 17-21, Rio de Janeiro, Brazil, 20C-9-4 (1987).

24. Second Harmonic Generation in Inhomogeneous Anisotropic Plasma Due to Beam-Plasma Interaction.
Sh.M. Khalil, and R.N. El-Sherif.
16th European Conference on Controlled Fusion and Plasma Physics, 13-17 March, Venice, Italy, P9G9 (1989).

25. Relativistic Electron Beam Heating of Inhomogeneous Anisotropic Plasma.
Sh.M. Khalil, and N.G. Zaki.
Int. Conference on Phenomena in Ionized Gases, 10-14 July, Belgrade, Yugoslavia, No. 110 (1989).

The plasma group during 30 years has accomplish 53 M.Sc., 41 Ph.D. and approximately 400 published papers. We usually participate by research papers in most of the International Conferences related to plasma physics and fusion energy, such as Conferences on Phenomena in ionized Gases, European Conference on Controlled Fusion and Plasma Physics, Conference on Plasma Physics, IAEA Conference on Plasma Phys. and Fusion and ICTP Collegue on Plasma Phys. Triesta.

4. Other Plasma Activities in The Egyptian Universities:

4.1 Al-Azhar University, Physics Department, Nasr City, Cairo, Egypt:

Plasma Group

Group Leader	Prof. Dr. A.A. Garamoon
Members	Dr. W. Sharkawy
	Dr. A. Nosair
	Dr. M.A. Eissa
	Dr. A.H. Saudy
Research Student	Mr. A. Seragy
	Mr. Gammal
	Mr. A. Shahin

The laboratory was establish after return Dr. A. Garamon from U.K. 1968. The laboratory was formed on two branches of research Townsed discharge and high temperature plasma. Research was carried mainly on shock wave tube T-type and investigate plasma parameters such as, plasma temperature with and without magnetic field, after glow discharge and second Townsed effect. Later a UNU ICTP PFF was estasblished in the lab. as well as a Hollow Cathode Experiment and a small Z-Pinch Device.

4.2 Zagazig University, Faculty of Engineering, El-Zagazig, Egypt:

Group Leader Dr. Mohamed El-Shaer.

2 Post Graduate Students (B.Sc.).

The Main item in the work performed is the development of small experiments dedicated to research as well as educational purposes. The main experiments performed are glow discharge and microwave discharge. Since 1987 the lab. was prepared with its peripheries of electricity, water, etc. In the end of 1988 the components was installed and we are now in the phase of experiment building and experimental phase will be in the summer 1989.

The physical program is mainly the investigation of the discharge parameter with suitable diagnostics like probes and optical spectroscopy. There are also educational part for postgraduate students in plasma physics. Visiting professor from other institutions are also involved.

The main equipments are provided as gifts from the KFA in Jülich (FRG) and Max Plank Institut für Plasma Physik in Garching (FRG).

4.3 Suez Canal University, Physics Dept., Faculty of Science, Ismailia, Egypt:

Head of the theoretical group is Dr.M.Y. El-Ashry.

The main work is directed to investigate and study theoretically some problems related to parametric instabilities and beam-plasma interaction.

There are some plasma activities in theoretical plasma physics in Tanta University, Alexandria University and Assyout University.

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TABLE I Development of θ-Pinch

1965 - 1985

Experiment & Authors	Machine Parameters and Dimensions tube radius cm.	tube length cm.	coil length cm.	bank energ. KJ	charg volt. kv	max. mag.f. T	τ μ.s.	Diagnostics	Main Study & Results
1- Fast Thetatron T.A. El-Khalafawy L.G. El-Hak A.M. Youssef M.A. Bourham L.A. Hafiz 1964 - 1968	3.6 Quartz	50	12	4	22	2.2	4	- Mag. probe - Elect. probe - Rogowiski coil - Micowave - Spectroscopy - X-ray	-Plasma parameters T_e-T_i -Electron heating mechanism - Plasma turbulence micro-instabilities - Radiation from plasma - Drift wave instability - Application of some modified techniques
2-Hard Core θ-Pinch Core T.A. El-Khalafawy A.M. Youssef M.A. Bourham A.M. Gabr main L.G. El-Hak 1967 - 1972	1 10-4	40 40	16 16	5.4 4.5	3 25	--- ---	120 29	-Mag. probe -Electric probe -Hard X-ray	-Mag. F., elect. F. configuration -Hard X-ray -Hydrodynamic current developed instability lead to turblization plasma heating

TABLE I CONT.

Experiment	Machine Parameters and Dimensions tube radius	tube length	coil length	bank energ	charg. volt.	max. mag.F.	τ	Diagnostics	Main Study & Results
3-Helicoidal core θ - Pinch T.A. El-Khalafawy A.M. Youssef A.M. Gabr M.S. Hanafy H.A. Ahmed 1972 - 1975	Same as previous one Parameter the same except the conductor is helicoidal to form zero zone magnetic field to simulate those of the Tokamak acceleration process.							The same as previous one no (2)	-Field distribution, Formation of zero zone mag. F.
4-Straight Homogeneous θ - Pinch T.A. El-Khalafawy M.A. Bourham 1968 - 1976	4.3	100	14	4.2	30	1.5	18	-X-ray probe Double probe -Microwave - Mag. probe	-Heating mechanism -Ion cyclotron instabilities -Electron excitation & Thermalization
5-Straight Homogeneous θ-pinch with preionization M.A. EL-GAMMAL M.A. Bourham M.A. Lissa M.M. Masoud 1976 - 1985 preionization	4.3 ---	100 ---	80 ---	12 4	40 20	2.2 ---	10 28	- Mag. probe -Double probe -Soft X-ray -Microwave	- Electron heating of turbulent plasma due to microinstabilities of collisionless mechanism due to both ion cyclotron and ion sound instabilities

TABLE III Devlopment of Coaxial Electrodes Gun

1974 - 1984

Experimental Apparatus & Authors .	Machine Parameters						Diagnostics	Main Studies & Results .
	inner electr R(a) cm.	outer electr R(b) cm.	length z cm.	Bank energy KJ	charg. volt. Kv	disch. current K amp		
1- Coaxial plasma gun with dynamic gas injection H.M. Saad M.A. Abdlaal 1974 - 1977	1.6	3.2	25	1	7	40	Diamagnetic loops , Electrostatic analyser	- Plasmoid velocity enjected from the gun = 1.2 x10^7 cm/s. - High energy component of the plasmoid has 10^7 particles with energy ≈ 0.8 kev.
2- Coaxial electrode discharge T.A. El-Khalafawy M.M. Masoud H.M. Soliman 1977 - 1984	1.6	3.2	31.5	1	7	40	Rogowiski coils , Potential dividers, Double electric probe , magnetic probes	-Characterstics of coaxial discharge. -Alocation of the second plasma focus . -Rotating current in the azimuthal direction .

TABLE II Devlopment of Shock Tubes

1965 - 1977

Experiments & Authors	Source Dimensions			Machine Parameters				Diagnostics	Main Studies
	Electrode dim. mm.	Electrode sepr. mm.	tube diam. mm.	charg. vol. Kv.	bank E(KJ)	τ µS.	ext.mag. T		
1- Electrodless conic shock tube T.A.El-Khalafawy M.M. Masoud A.B. Beshara 1965 - 1970	40	50	40	25	3.9	2.8	——	Electric & Magn. probes, X-ray, High speed photography.	- Shock wave interaction with rest gas & walls - Shock structure. - Collisional processes .
2- Coaxial electrode shock tube . T.A. El-Khalafawy M.M. Masoud M.S. El-Gwaily M.A. El-Masry E.E. Nofal 1970 - 1974	34 major 14 minor	80	40	18	5	10	0.6	Electric & Magn. probes, X-ray , Spectroscopy , diamagnetic loops , High speed photography.	- Shock wave interaction with external magnetic field - Energetic particle production.
3- Coaxial shock tube. T.A. El-Khalafawy M.M. El-Nicklawy A.B. Beshara M.B. Eteiba 1974 - 1977	10 minor		100	50	3.75	6	0.1	Electric & Magn. probes, Diamagnetic loops, high speed photography	- Switch on condition . - Collisionless shock structure in magnetic field.