UNIVERSITY OF HOUSTON
DEPARTMENT OF PHYSICS

PROGRESS REPORT

March 1, 1969 - February 28, 1970

SPACE RELATED TECHNICAL INVESTIGATIONS

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A. F. Hildebrandt

This report covers the period from March 1, 1969, through February 28, 1970. The period from March 1, 1969, through August 30, 1969, was funded at a low level by means of a no cost extension of the previous contract. The work reported in the period from September 1 to now is covered in the proposal submitted in January 1969. Although the proposal was funded at only one third the original level, no area of research has been completely eliminated. Excellent progress has been made on all phases of the proposed work and in two cases the research has been completed. An updated summary of all publications of work performed under the grant is attached.

Questions regarding the work described in this grant may be directed to Dr. Alvin F. Hildebrandt, Professor and Chairman, Department of Physics, University of Houston, Houston, Texas 77004, (713) 748-6600, extension 1932 or 1943. The investigators named in the body of the report may be contacted individually regarding their work at the same address.

Atomic Processes and Solid State Physics Studies

1. Many Body Effects in Metals, R. H. Walker

The atomic scattering problem has been treated by obtaining semi-quantitative interaction potentials for colliding atoms in different spin states. From these the required cross-sections are obtained by directly calculating the scattering phases numerically. To this end both exact and semi-classical schemes were employed which allowed very large angular momenta components to be taken into account. Part of our results were then compared with experimental results which have just become available and excellent agreement was obtained. The results of this work has been submitted for publication and should appear shortly.

2. The Response of Crystals to External Fields, R. H. Walker

The approach to the treatment of Mossbauer line shape was quite novel and lent itself nicely to an exact analytical treatment of diverse phenomenon. The basic idea was to represent the perturbation on the lattice by an impulsive force appropriate for the momentum carried away by the emitted γ-ray. The scattering matrix for the process could then be calculated exactly to infinite order in contrast to the usual first order results. Once the scattering operator for the lattice is known, the line shape of the emitted γ-ray can be calculated for a variety of lattice conditions. In particular, this approach has been applied to γ-emission for the lattice at absolute zero, for a thermal distribution of phonons, for the lattice at absolute zero but carrying either a coherent or incoherent sound wave, and finally for the lattice at a finite temperature in the presence of sound waves. The γ-ray line shape has been calculated for each of these cases and compared with experiment for those cases where experimental results exist. Still other phenomena can be studied with this approach. Of particular interest is the study of the influence of local heating on the Mossbauer effect. This work has resulted in one M.S. thesis.

3. The Interaction of Quantum Fluids with Physical Boundaries

Superfluid Helium Critical Velocities in Wide Channels. A. F. Hildebrandt and H. E. Corke.

Previously measured critical velocities in wide channels ($>10^{-3}$cm) fall into two conflicting ranges, those explained by the Feynman-Onsager vortex model and those with a channel dependence of $d^{-1/4}$.[1] The work completed utilizes quantum mechanical

[1] W. M. van Alphen, G. J. van Haasteren, R. de Bruyn Oubter, and K. W. Taconis, Phys. Letters 20, 474 (1966).

phase coupling of the superfluid in parallel channels to make critical velocity measurements. A sensitive pressure measuring device is located in one flow channel to monitor the velocity and indicate the first sign of flow impedance. The results show that a superfluid critical velocity exists in agreement with the Feynman-Onsager model of vortex generation, with possibly a small temperature dependence. Flow transitions well above critical velocity indicate the onset of superfluid turbulence. This work will be presented at the Dallas meeting of the American Physical Society in March.

Second Sound in Counterflowing Normal and Superfluid Helium II, A. F. Hildebrandt and E. M. Johnson.

In a previous paper by Johnson and Hildebrandt[2] the velocity of second sound was measured as a function of counterflowing normal and superfluid helium. Counterflowing normal and superfluid constitutes a heat flow density in liquid helium. In liquid helium one can relate hydrostatic pressure directly to heat flow density. Employing thermodynamic expressions for second sound velocity an alternate equation for pressure on a disk can be obtained. Second sound provides a direct measurement of the associated radiation pressure. In order to measure the radiation pressure the velocity of second sound as a function of heat flow density should be measured in greater detail. The experimental apparatus for doing this experiment has been designed.

4. Flux Quantization and the Vector Potential in Unipolar Induction. A. F. Hildebrandt and Thomas N. C. Tsien.

Studies of a modified unipolar generator have revealed that an apparently new electromagnetic induction voltage can be observed in the rotational state.[3] The magnitude of the observed voltages does not agree with the conventional computations using the polarization $P = VxM/c^2$ because of the motion of the magnetization M. Neither does it agree with the vector potential calculations in the Lagrangian formulation. Analytic and numerical analysis have shown that the measured voltages can be explained in terms of the time rate of change of magnetic field provided that the motion of the individual molecular magnets are taken into consideration. Such a consideration was previously believed

[2] Phys. Rev., 178, 1, 5 Feb. 1969.

[3] "Electromagnetic Induction of Rotating Magnets", Thomas N.C.Tsien and A. F. Hildebrandt, to be presented at A.P.S. meeting March 23-26, 1970.

only to be significant in quantum phenomena. To confirm our analysis, it would require that the voltage detection circuit be completely shielded with superconducting materials. If the observed voltages are indeed due to $\partial B/\partial t$ of the motion of the elementary magnets, a back e.m.f. would be set up in the shield and a null result should be measured in the circuit. Also the superconducting shield would assure the entire circuit to be in zero magnetic field so that the Lorentz force would not apply to describe any measured voltages. Such an apparatus has been designed and is near completion. Theoretically, a detailed treatment of the forces is still required since only potentials have been measured. Further investigation of the motion of the elementary magnets is in progress.

5. Applications of Exterior Differential Forms, R. M. Kiehn

Following the successful effort on applying the theory of differential forms to transport phenomena[4], further work on this topic during the period Feb. 1, 1969, to Sept. 1, 1969, is not directly attributable to this grant, for the work was not funded during that period by NASA. However, during the summer of 1969, a number of seminars were held at the Los Alamos Scientific Laboratory on applications of the theory to hydrodynamic problems. Following the reinstatement of differential forms portion of the grant in September, 1969, the LASL seminars will serve as the foundation for a two week study (commeasurate with the level of funding) in the summer of 1970 at the University of Houston. During this period an attempt will be made to generalize the transport theorems of Kochin, Kibel and Roze[5] by use of differential form theory.

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[4] R. M. Kiehn and J. F. Pierce "Intrinsic Transport Theorem", Phys. of Fluids, 12, 9, 1941 (1969).

[5] N. E. Kochin, I. A. Kobel, and N. V. Roze, "Theoretical Hydro-Mechanics", Interscience, New York, (1965).

Plasma Studies, Dr. Melvin Eisner

Introduction

This progress report describes the objectives and results obtained in the program of the analysis and detection of low energy neutrals.

Initial results on the evaluation of the dense plasma focus device as a pulsed ionization are encouraging in that a well defined ionization peak of short duration has been calculated and the dependence of this peak on the heavy ion load of the accelerator has been demonstrated. Further studies should reveal the conditions for optimization of the design and the limitations and potential applicability of the scheme for low energy neutral analysis.

The program of determining the efficiency of the stripping process for neutral detection has progressed and estimates of the cross sections involved have been obtained. Further work to analyze the low energy region of the cross sections is in progress.

Low Energy Neutral Detection

Present Status of the Problem:

A basic problem in experimental plasma physics is determining the energy distribution of the ions in a given plasma. This is especially important in fusion experiments where ion heating is a major concern.

Positively biased probes have been used to measure the number of positive ions which have enough energy to reach it. The current to the probe is proportional to the number of ions that strike it with energies above its positive bias. However, the biased probe has several disadvantages. First, since the ions which strike the probe may be of several types and only a current is being measured, the different species are not distinguishable. Another disadvantage is that the probe attracts electrons which partially cancel the current due to the ions. A final major disadvantage is that the probe strongly perturbs the internal fields of the plasma.

A more feasible means of detecting the energetic ions is by analyzing the energetic neutral component escaping from the magnetic confinement system. These neutrals originate primarily in charge exchange collisions between energetic ions and thermal neutrals in the background. In this process, an ion becomes neutralized by picking up an electron through a collision with a thermal neutral. The neutral formed is unaffected by the magnetic field and leaves the plasma region. Since the momentum of the original ion is only slightly altered when colliding with a slow neutral, the energies of the ions are represented accurately by the energies of the neutrals produced. The energy distribution of the ions may be found from the energy distribution of the neutrals if the cross section for the charge exchange is known as a function of energy.

The problem now involves detecting the neutral outflux. Because a neutral is only slightly effected by electric or magnetic fields, it is difficult to detect. Neutrals may be detected by allowing the particles to strike a polished metal surface and measuring the current of ejected electrons at a nearby probe. The number of electrons ejected from the surface of a particular metal per incident atom or ion is called the secondary electron emission coefficient, gamma (γ). Gamma has been measured for various neutrals[1] and ions[2] incident upon metals such as aluminum, copper, and copper-beryllium alloy for a wide range of energies. However, since the surface properties of the target metal are important at energies below 500 ev, and monolayers of gas coat the metal surfaces even under the best vacuum conditions, the measured value of γ may vary appreciably under different experimental conditions. In some instances, the above method offers an even greater limitation. Since the neutrals are not being examined directly, the electron current from the metal target folds together information concerning particle flux, their energy, and identity (mass). Knowledge of two of these factors is necessary in order to get the third.

A more direct method for neutral detection is to ionize a portion of the neutrals and then use conventional methods[3] to analyze the ions produced. Ionization has been accomplished by passing the neutrals through a thin foil[4] but it is difficult to make foils thin enough so the beam is not completely attenuated for low energies. Foils are generally used only at energies above 10 kev. A different method, which has been used at energies as low as 200 ev[5], allows the neutrals to strike a metal surface with small angle incidence producing ions in a range of small exit angles. Because the ions produced at the metal surface are spread in energy relative to the incident neutrals and are divergent in exit angle, it is difficult to focus the ions into a detector and retain accurate information concerning the energy of the original neutral beam. This difficulty, along with the low conversion efficiency of the process, makes it less deisrable than the methods to be discussed next.

Electron ionization of neutral atoms and molecules has been studied for many years and the cross section values are well known for targets such as atomic or molecular hydrogen.[6] The ions formed by passing neutrals through an electron beam are produced with very little momentum exchange due to the small electron to proton mass ratio. Although the ionization efficiency increases with lower neutral velocity due to the longer transit time through the electron beam, the slower ions suffer greater deflection from the electric fields associated with the space charge of the electron beam and the acceleration voltages on the gun. Above 50 ev and with optimum electron gun design, the effect of the stray electric fields may be reduced so that the ionization efficiency can be accurately calculated. The only major disadvantage is that the total ionization efficiency is low.

Another method, which is to be studied in this research, is stripping in a neutral gas cell. Stripping offers a higher efficiency over the methods discussed above and has been used for neutral detection at energies down to about 50 ev even though the cross sections for the process were not well known.[7] Stier and Barnett[8,9] along with Allison[10] have measured the cross sections for stripping hydrogen in the 4-200 kev range. Much of the recent work at high energies has been reviewed by Fite.[11] Although much study has been devoted to collisions at high energies, very little has been done at energies below 500 ev.[12] V. V. Afrosimov and his group[13] measured the cross section for stripping atomic hydrogen in nitrogen gas at energies from 300 ev to 4 kev. Fleischmann and Tuckfield[14] extended the measurements for atomic hydrogen on various target gases down to 50 ev. Since the angular spread of the ions produced in the stripping process becomes greater with lower energy, there is some question as to what error is present in the previous cross section measurements due to the small solid angle subtended by the ion detectors used. No work has been published on stripping molecular hydrogen at low energies.

Objectives and Procedures:

The object of this research is to calibrate a detector for atomic and molecular hydrogen in the 50 to 500 ev range. An effort will be made to measure the cross section for stripping both atomic and molecular hydrogen in various gases and vapors. Because common gases leak through the entrance and exit apertures of the stripping cell and thus require differential pumping, other vapors which freeze at room temperature will be used as a stripping target. The stripping efficiency of metal vapors such as titanium and aluminum will be measured relative to that of common gases. The cross sections of primary interest which will be measured are:

$$\underline{H} + H_2 \qquad \underline{H}^+ + H_2 + e^-$$

$$\underline{H_2} + H_2 \qquad \underline{H_2^+} + H_2 + e^-$$

$$\underline{H} + M \qquad H^+ + M + e^-$$

$$\underline{H_2} + M \qquad \underline{H_2^+} + M + e^-$$

An underlined symbol designates the projectile (energetic) particle; M designates a metallic atom or molecule.

The first step toward measuring the cross section for neutral stripping involves building and calibrating a source of low energy neutrals. Some investigators have used the neutral flux from a pulsed plasma gun[15,16] as a source. This method produces an intense flux of neutrals for a short length of time but the composition of the flux cannot be accurately determined or controlled. The most direct approach is to form neutrals by passing ions from a low energy source through a gas charge exchange cell. This simulates the process by which energetic neutrals are liberated from a magnetically confined plasma as discussed in the beginning portion of this paper. The relevant charge exchange reactions to be considered are:

$$\underline{H}^+ + X \qquad H + X^+$$

$$\underline{H_2^+} + X \qquad \underline{H_2} + X^+$$

X represents the target molecule. The cross sections for these reactions are known and are rather large for target gases such as oxygen and hydrogen. Ion to neutral conversion efficiencies of up to ten per cent may be easily obtained. The ions and neutrals emerging from the charge exchange cell are sent through a region of high electric or magnetic field to sweep out the unconverted ions, leaving a pure neutral beam. Because the stripping cross section decreases rapidly at energies below 500 ev, the major experimental problem is producing a sufficiently intense neutral source so that the ion signal produced by stripping is large enough for detection. Since the number of neutrals produced in the charge exchange reaction is proportional to the number of ions entering the cell, the ultimate problem is the strength of the ion source. Afrosimov (Ref. 13) used a charge exchange neutral source and due to a limited ion beam current of around 10^{-9} amperes, stripping was not seen below 300 ev. Fleischmann (Rev. 14) used a pulsed plasma source to see stripping down to 50 ev but his results are uncertain.

A duoplasmatron similar in construction to that originally designed by Von Ardenne[17] in 1956 has been used in this laboratory as a source of low energy ions. This device makes use of a high current arc inside a chamber containing neutral gas to form a plasma bubble from which positive ions are extracted. Currents of up to 10^{-5} amperes of 200 ev hydrogen ions have been generated. Mass analysis of the ion output showed the presence of almost equal amounts of H^+, H_2^+, and H_3^+ along with a variable amount of electrons. This four component beam was passed directly into a hydrogen charge exchange cell and after deflecting the unconverted ions, the neutral component was used to observe stripping at energies as low as 100 ev. The total current from the duoplasmatron was monitored by measuring the current to a transparent copper mesh inserted in the path of the beam. The ions produced in the stripping process were momentum analyzed with a 90 degree magnet sector and then counted. With this arrangement, the cross sections for stripping atomic hydrogen could not be made to correlate with Afrosimov's values above 300 ev. The difficulty was traced to several sources. First, the relative amount of each of the three ion species from the plasmatron varies with its mode of operation. Since the current at the monitor grid does not distinguish the ion species, the intensity of each group was uncertain. It was also found that the electron component of the beam was at times considerable, partially canceling the ion current to the monitor grid. The path lengths between source, reaction regions, and detector system were excessively long and much signal may have been lost due to the angular spread of the ion and neutral beams. Finally, the effective solid angle of the detector system was severely limited by the bending magnet.

An improved arrangement, which is under construction, involves selecting one of the ion components with the bending magnet prior to its entry into the charge exchange cell. This will eliminate the unwanted ions and electrons in the region of the monitor grid; only the ions being bent through the magnet will be monitored. A large aperture detector will be placed directly following the stripping chamber and path lengths throughout the system will be minimized. In order to reduce ion loss through the bending magnet, the ions will be formed at a high energy, mass analyzed, and then de-accelerated to the desired energy before entering the charge exchange cell. Analyzed ion beams of at least 10^{-7} amperes are expected.

After completing measurements of the gas stripping cross sections, the gas cell will be replaced by a chamber containing metal vapor from a heated filament. The stripping efficiency of the metal will be compared to that of the gas.

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The Bremsstrahlung Spectra Emitted from a DPF (Dense Plasma Focus) Mode of a Plasma Accelerator and Its Application to the Ionization of Neutral Atoms

1. Objectives

A. To apply snowplow model to the plasma pinch in a DPF.

B. To study thermalization of various three-component plasmas during the pinch.

C. To find out the favorable conditions of the three-component plasma which would yield a Bremsstrahlung spectrum with a maximum ionization power for hydrogen atoms.

2. Present Status of the Question.

The Process of a DPF in a plasma accelerator can be viewed dynamically as composed of three successive stages. In the first stage, a $\vec{J}\times\vec{B}$ force accelerated the plasma sheath axially down to the end of the central cylindrical electrode. In the following stage, a small portion of the accumulated gas are radially pinched at the end of the inner electrode. The snowplow model has been applied separately to the axial motion and to the radial compression.[1,2] The radial motion equation is

$$\frac{d}{dt}\{[m_o + \pi\rho_o(R_c^2 - R^2)\frac{dR}{dt}\} = -2\pi R \frac{\mu_o}{2} (\frac{I}{2\pi R})^2$$

in which the initial value of radius R is R_c, the inner electrode radius. This non-linear equation can be solved numerically to obtain the radius R and velocity R (=dR/dt) as a function of time. As a typical experiment result with a 15 KJ energy input, a plasma will be pinched radially from 3 cm down to less than 1 mm in a period of 50 n.s. During this time its density increases from $10^{15}cm^{-3}$ to $1.5x10^{18}cm^{-3}$ and its velocity increases from essentially zero to about $6.5x10^{7}$ cm/sec corresponding to an electron energy of 0.5 ev and an ion energy of 1 Kev approximately. While the particles are accelerates, thermalization occurs and a considerable amount of Bremsstrahlung radiation is emitted. In the third stage, the high density electrons and ions collide with each other in the DPF without any input power. Now the thermalization is very fast due to the high density of particles. A high intensity of radiation will be emitted before the instability sets in and destroys the focus of the plasma.

The rate of thermalization between two components in a static plasma has been measured[3] and is given theoretically in the following equation[4]

$$\frac{dT_1}{dt} = \frac{T_2 - T_1}{\tau_{12}} \tag{1}$$

where $\tau_{12} = \frac{3m_1 m_2}{8\sqrt{2\pi}\, nL(Z_1 Z_2 e^2)^2} \left(\frac{T_1}{m_1} + \frac{T_2}{m_2}\right)^{3/2}$ is the temperature equalization time and L is the Coulomb logarithm of the plasma. For electron-ion collision this equation may be reduced by taking

$$\frac{T_e}{m_e} >> \frac{T_i}{m_i}\text{, giving}^5$$

$$\frac{dT_e}{dt} = \frac{8\sqrt{2\pi}\, nL(Z_e Z_i e^2)^2}{3m_i} \frac{T_i - T_e}{T_e^{3/2}}$$

This rate decreases as m_i increases. Equation (1) can be modified for a three-component plasma by adding a term $T_3 - T_1/\tau_{13}$ on the right hand side of the equation. Then for a given set of initial temperatures, three such coupled together need to be solved in order to obtain the rates of thermalization.

Since the intensity of Bremsstrahlung radiation rate is proportional to Z, the intrinsic radiation rate per atom from high Z impurity content can be many orders of magnitude greater than the Bremsstrahlung radiation from ionized hydrogen. Even a small fractional impurity content can greatly increase the total escaping radiation flux from the plasma.[6]

The ionization cross section of hydrogen atom due to Bremsstrahlung radiation increases with the wavelength of the photon up to a cut-off limit whose corresponding photon energy equals to the ionization potential in the ground state.[7] Therefore the conditions at which electrons and the light ions in a three-component plasma stay longer at low energies will yield Bremsstrahlung spectra which are more favorable for optimum ionization cross section for hydrogen atoms.

With a constant input energy and low energy impurity particles at the end of the central electrode, the more the amount of the impurity the slower the rate of thermalization. The longer the electron stays at low temperature, the more relatively low frequency it radiates. But the total radiation power is lower on account of low electron energy. The ionization percentage is dependent on the product of the ionization cross section and the spectral intensity. By a proper selection of the mass number and the amount of the high Z impurity in the DPF, the spectrum which would yield the highest percentage of ionization can be obtained.

We propose in this work to develop a flash light source with a sharp peak radiation power from the DPF so that it is most efficient in ionizing neutral particles at their course of flight.

3. Procedure

In the first stage, the motion is purely axial and for one annulus of radius r_o, the equation needs to be solved is

$$\frac{d}{dt}\left[2\pi\gamma_o\rho_o z\frac{dz}{dt}\right] = 2\pi\gamma_o \frac{\mu_o}{2}\left(\frac{I}{2\pi\gamma_o}\right)^2$$

in which ρ_o is the gas density.

The rate of increasing energy of individual particle due to the radial acceleration in the pinch process can be obtained by solving the radial motion equation. The screening effect due to electrons on the high Z ion is important to Bremsstrahlung radiation. Considering the Thomas-Fermi potential

$$V(\gamma) = \frac{zZe^2}{\gamma} \exp\left(-\frac{\gamma}{\alpha}\right),$$

we assume the minimum impact parameter due to screening by the atomic electrons to be

$$b^{(5)}_{max} \approx a \sim 1.4 \frac{a_o}{Z^{1/3}} .$$

Beyond $b^{(5)}_{max}$ the potential is considered as of a single or double charged ion and is cut off completely at the Debye radius.

Since the temperatures of the ions and electrons depend on the conditions in the pinch, the rate of thermalization and the radiation loss, three coupled differential equations of the following type need to be solved numerically to obtain the temperatures and the spectrum of radiation.

$$\frac{dT_e}{dt} = -\frac{2}{3}(Q_{e1} + Q_{e2}) - (R_{e1} + R_{e2}) + \frac{1}{2} m_e \frac{d\dot{R}^2}{dt}$$

$$\frac{dT_1}{dt} = -\frac{2}{3}(Q_{12} + Q_{1e}) + \frac{1}{2} m_1 \frac{d\dot{R}^2}{dt}$$

$$\frac{dT_2}{dt} = -\frac{2}{3}(Q_{21} + Q_{2e}) + \frac{1}{2} m_2 \frac{d\dot{R}^2}{dt}$$

where $Q_{e1} = \frac{3}{2}\frac{T_e - T_1}{\tau_{e1}}$ is the collisional energy transfer from electron to ion type one, and

$$R_{e1} = \frac{16\pi^{7/2} z^4 Z_i^2 e^6}{3 m_e c^3 h} n_1 \left[\frac{2}{\sqrt{\frac{m_e}{2T_e}}} + \frac{\sqrt{\frac{m_e}{2T_e}}}{\frac{m_1}{2T_1}}\right]$$

$$R_{e2} = \frac{16e^2 c}{3}\left(\frac{z^2 e^2}{m_e c^2}\right)^2 n_2 \iint \Big[\frac{Z_2^2 \gamma^2}{a} \ln\left(\frac{2aMu}{\hbar}\right) + \frac{Mu}{\hbar}\left(\ln \frac{2\gamma^2}{\hbar} + 1\right)$$

$$- \frac{\gamma^2}{a}\left(\ln\frac{2MDa}{\hbar} + 1\right)\Big] \left(\frac{b_e}{\sqrt{\pi}}\right)^3 \left(\frac{b_2}{\sqrt{\pi}}\right)^3 e^{-b_e^2 v_e^2} e^{-b_2^2 v_2^2} d^3v_e d^3v_2$$

with $b = \sqrt{\frac{m}{2T}}$, $u = |\vec{v}_e - \vec{v}_2|$, and $\gamma = 1/(1 - \frac{u^2}{c^2})^{1/2}$ are the electron radiation loses due to the interactions with the two species of ions respectively.

For a 15 KJ energy input, the total Bremsstrahlung radiation power at the end of the pinch is of the order of 10^9 watts for a plasma composed of 90% H and 10% Xe whose initial filling pressure is 3 torr. The maximum spectral intensity is shifting gradually to higher frequency as the electron temperature increased with time as seen in figure 1.

The optimum ionization coefficient of hydrogen atom is expected to be calculated from a suitable Bremsstrahlung spectrum using the following equation.[8,9]

$$\alpha = \frac{n_e}{n_o + n_e} = \int_0^T dt \int_{\nu_G}^{\infty} d\nu \{\sigma_{ion} s(t,\nu) e^{-n_o \sigma_{ion} d}\}/d^2 h\nu$$

where ν_G is the frequency limit for photoionization, and d is the distance from the light source.

After the plasma is focused, it continues thermalizing and radiating in a quiescent state without any input power. In this quiescent state, the total radiation power stays almost the same as the focus, but the ionization power decreases as the high spectrum intensity shifts toward the high frequency which is unfavorable for ionization due to its low photoionization cross section.

With a constant input energy, the temperatures, the total radiation power and ionization coefficients for two different impurities are shown in figure 3 and 4 separately. The corresponding quantities for the case without impurity is shown in figure 2.

As seen in figure 2, 3 and 4 the higher the z number of the impurity, the better the ionization power. Most of the intensity of the radiation comes from the intense interaction between the electrons and the heavy ions. The high Z ions also slow down the thermalization to keep the electrons in low temperature. This also will increase the ionization power. The peak of dN/dt in figure 4 is very effective in ionizing neutral hydrogen in a very short time period.

Without considering the self-absorption, the total radiation power with impurity after focus is of the order of 10^9 watts which is one order higher than that of Hofmann.[9] The integrated ionization coefficient over the DPF is much lower than that of Hofmann since his intense radiation pulse is in the order of us. which is much longer than the DPF case. The sharp pulse from the DPF yields a peak in ionizing neutral particles. This characterizes the different feature and application from the light source of Hofmann.

Both the rate of thermalization and total radiation intensity increase as the density of the plasma increases. But the ionization power may not become larger since more high frequency radiation is emitted from higher temperature electrons due to the fast thermalization. For this same reason, an increase of input energy may result in higher electron temperature which is not favorable for photoionization. These are the properties of the plasma that can be studied in the future in order to elucidate the proposed optimumization problem.

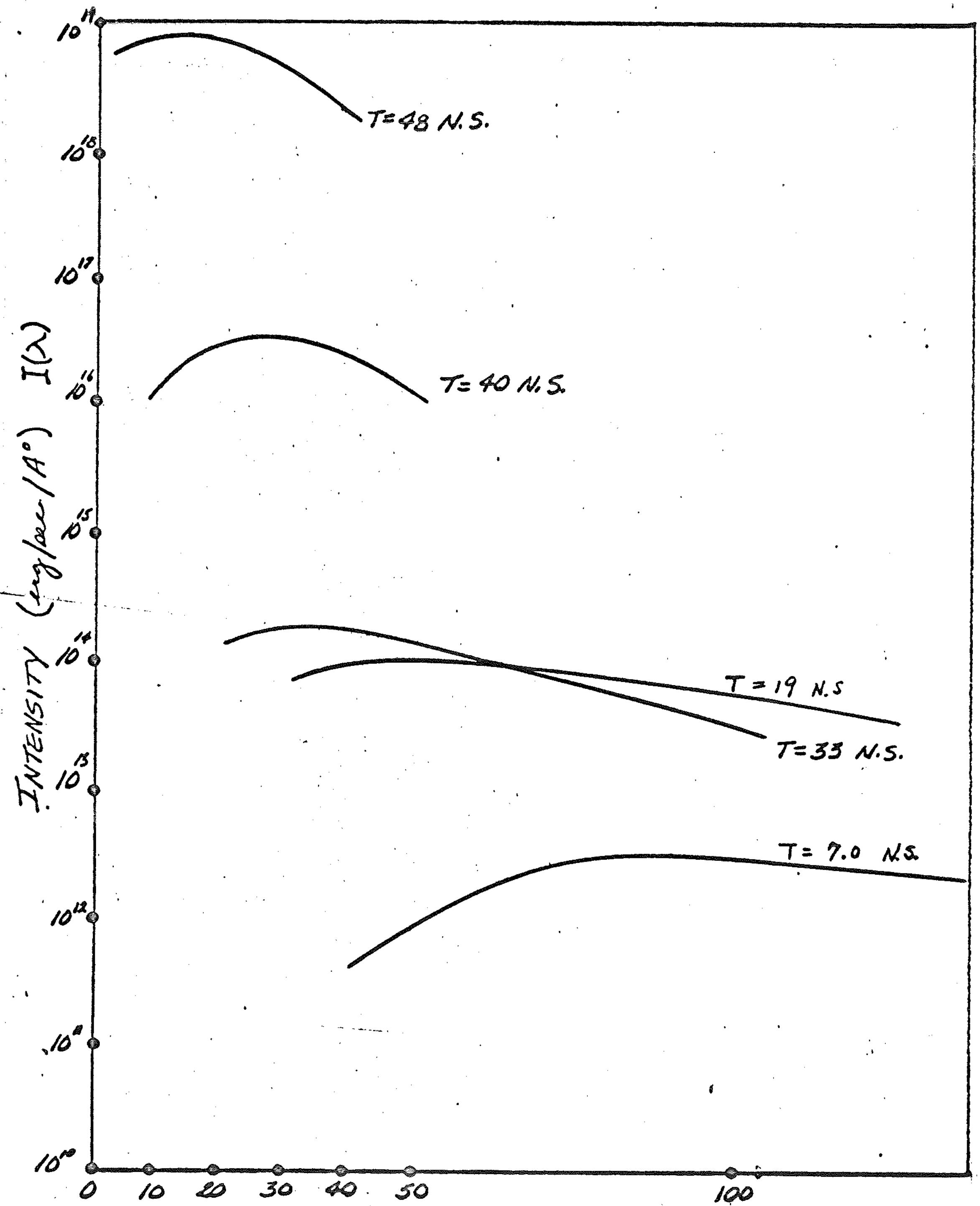
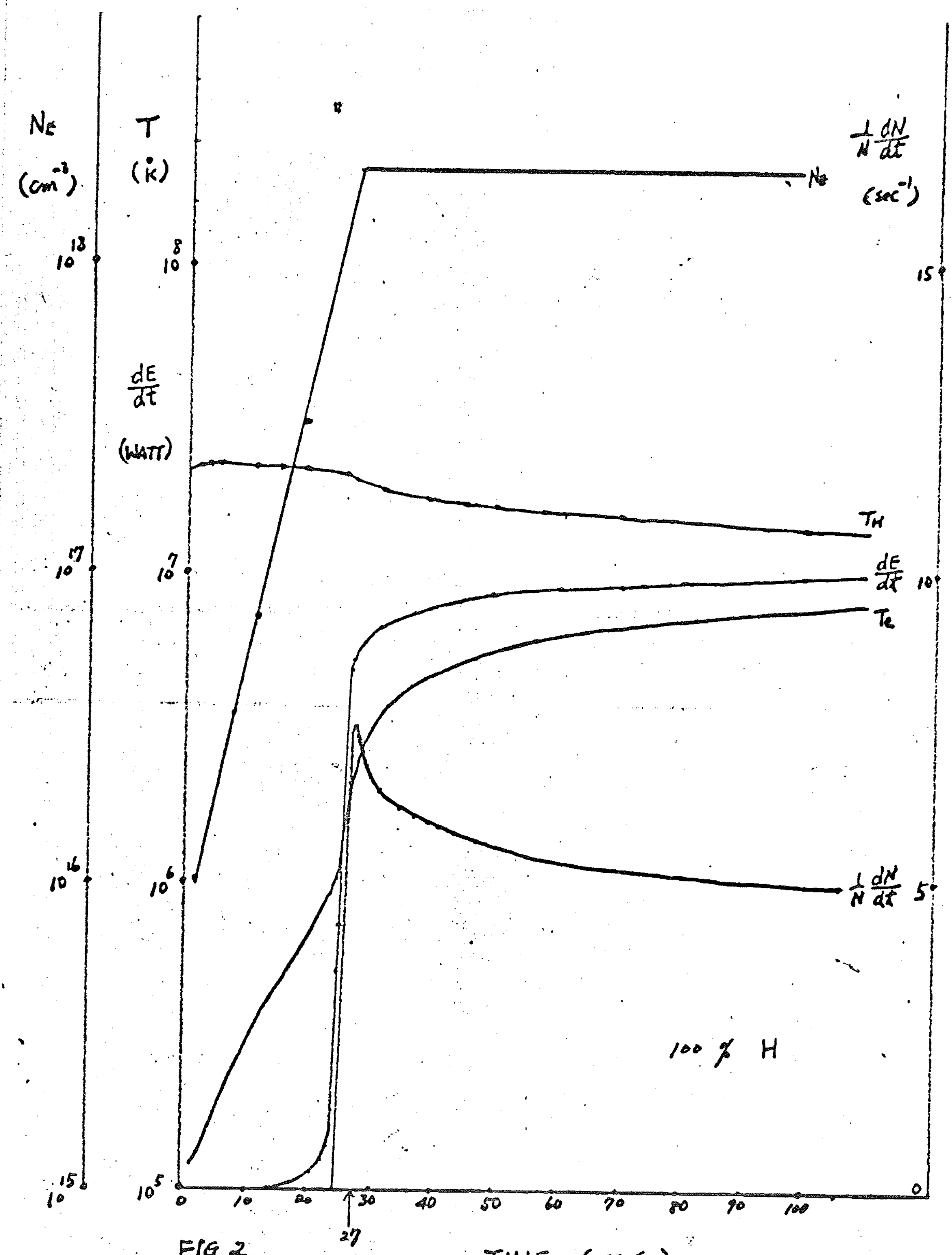
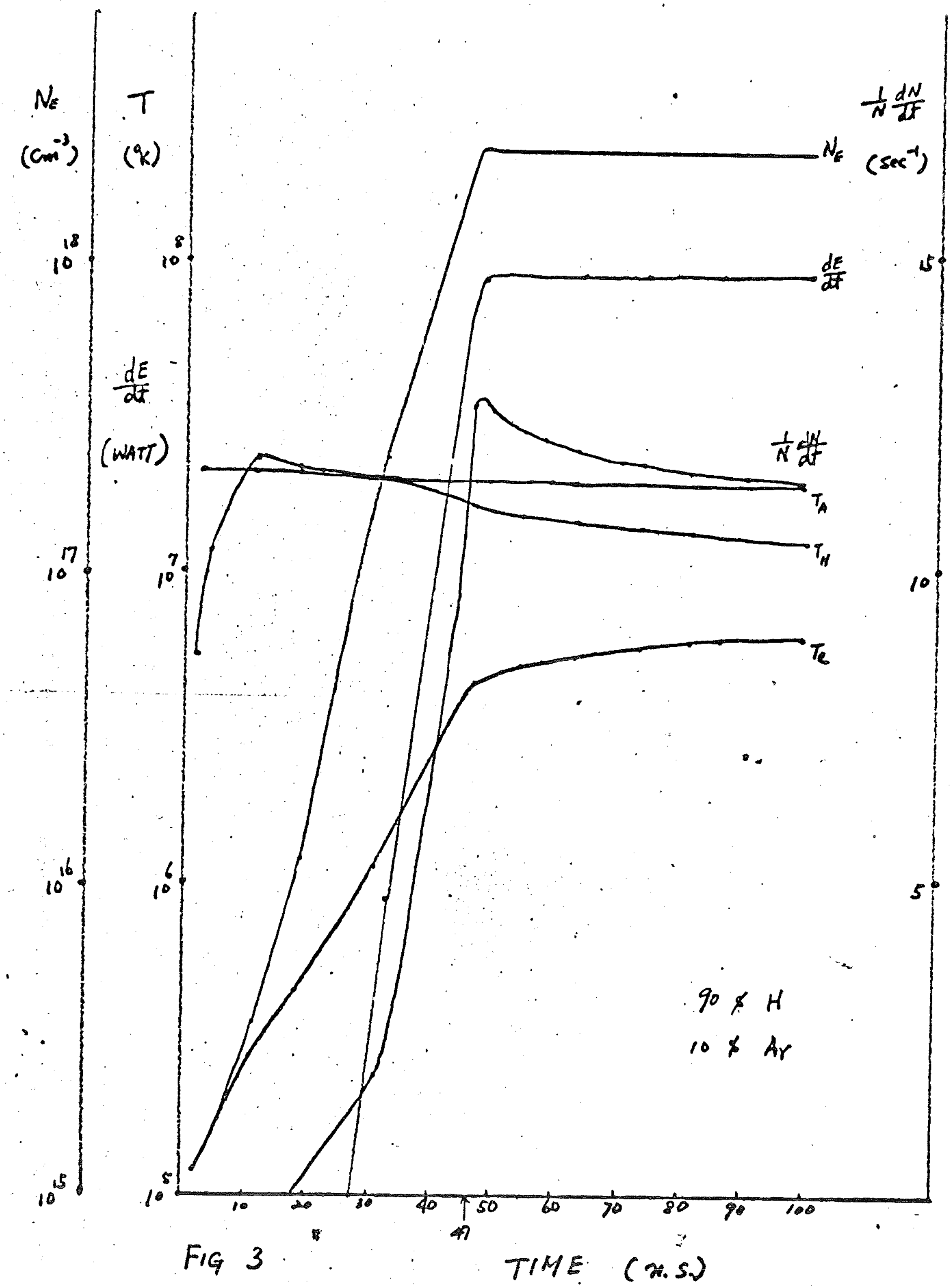

INTENSITY (erg/sec/A°) I(λ)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
10^12
10^11
10^10
T=48 N.S.
T=40 N.S.
T=19 N.S
T=33 N.S.
T= 7.0 N.S.
0
10
20
30
40
50
100
WAVELENGTH (Å)

FIG. 1



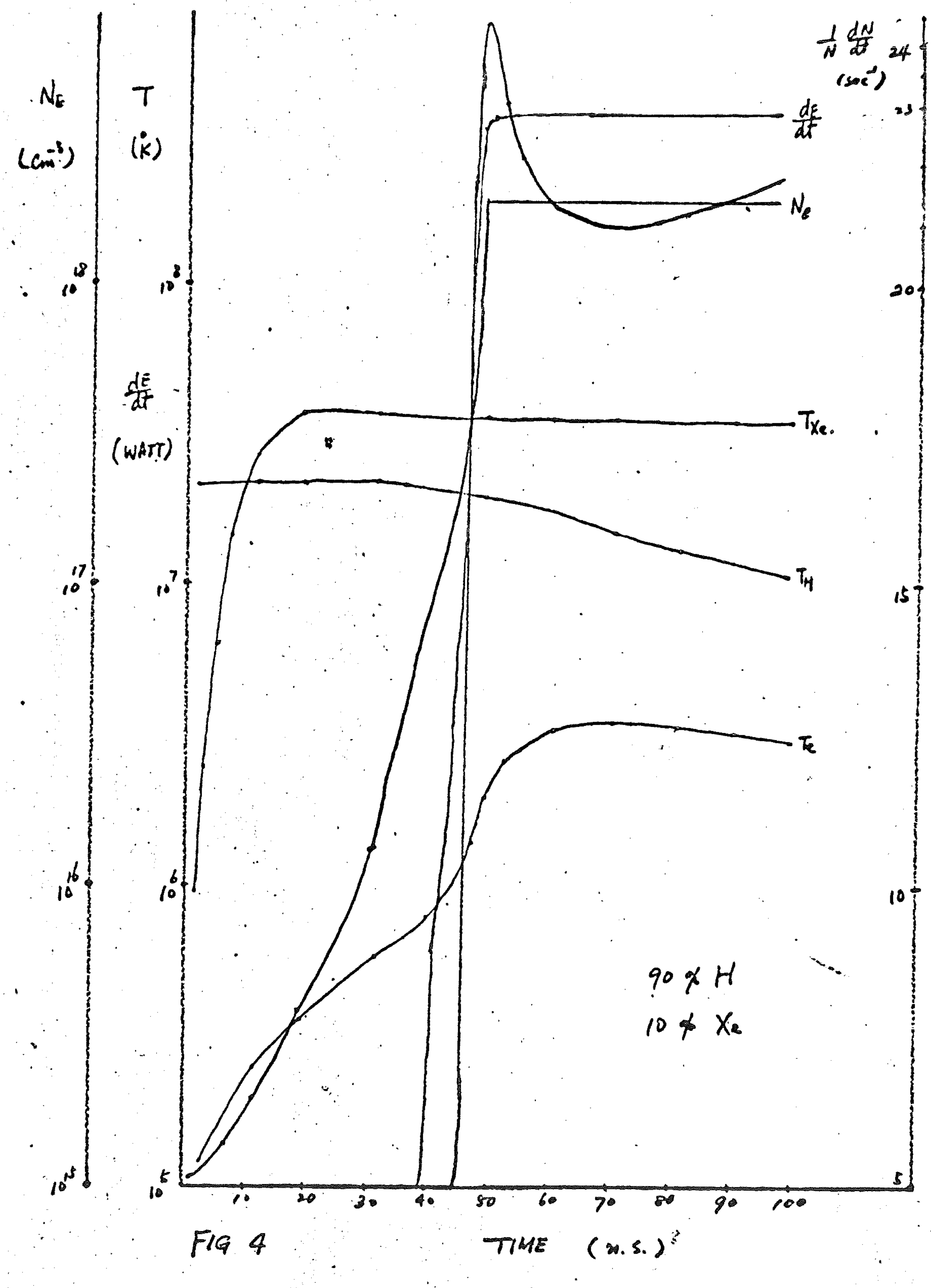
Ne
(cm⁻³)
T
(°K)
dE/dt
(WATT)
1/N dN/dt
(sec⁻¹)
10^18
10^17
10^16
10^15
10^8
10^7
10^6
10^5
15
10
5
0
Ne
TH
dE/dt
Te
1/N dN/dt
100 % H
0
10
20
30
40
50
60
70
80
90
100
27
TIME (n.s.)

FIG 2.



N_E
(cm^{-3})
T
(°K)
$\frac{1}{N}\frac{dN}{dt}$
(sec^{-1})
$\frac{dE}{dt}$
(WATT)
10^{18}
10^{17}
10^{16}
10^{15}
10^{8}
10^{7}
10^{6}
10^{5}
15
10
5
N_E
$\frac{dE}{dt}$
$\frac{1}{N}\frac{dN}{dt}$
T_A
T_H
T_e
90 % H
10 % Ar
10
20
30
40
50
60
70
80
90
100
47
TIME (n.s.)

FIG 3



N_E
(cm^{-3})
T
(°K)
$\frac{dE}{dt}$
(WATT)
$\frac{1}{N}\frac{dN}{dt}$
(sec⁻¹)
$\frac{dE}{dt}$
N_e
T_{Xe}
T_H
T_e
90 % H
10 % Xe
TIME (n.s.)

FIG 4

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