SHIFT MEASUREMENTS OF THE STARK-BROADENED IONIZED HELIUM LINES AT 1640 AND 1215 Å

by

James R. Van Zandt

Thesis submitted to the Faculty of the Graduate School
of the University of Maryland in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
1976

ABSTRACT

Title of Dissertation: SHIFT MEASUREMENTS OF THE STARK-BROADENED IONIZED HELIUM LINES AT 1640 AND 1215 Å

James Russell Van Zandt, Doctor of Philosophy, 1976

Dissertation directed by: Hans R. Griem, Professor of Physics

Time-resolved measurements were made of the shifts of the ionized helium lines at 1640 Å ($n = 3 \rightarrow 2$) and 1215 Å ($n = 4 \rightarrow 2$), and of the Stark profile of the λ 1215 Å line. An electromagnetic shock tube was used as a light source. The plasma conditions corresponded to electron temperatures of $\sim$3.5 eV and electron densities of 0.8 to $1.8 \times 10^{17} cm^{-3}$. The measured shifts fell between two previous estimates of plasma polarization shifts. The measured Stark width of the λ 1215 Å line was up to 30% greater than the theoretical width.

DEDICATION

To my wife, Nita, who kept my nose to the grindstone.

ACKNOWLEDGMENTS

I would like to express my gratitude to Prof. H. R. Griem for suggesting the topic of this dissertation and for guidance throughout, to Drs. Larry Jones, Walter W. Jones, and Manfred Neiger for many helpful discussions, to Mr. Elmer Pierpont for his expert advice and assistance in the fabrication of equipment, to Mrs. Clara Rodriguez for her cheerful help in ordering materials and supplies, and to Mrs. Janet Wolfsheimer for typing the manuscript. Without their help, it would not have been possible to finish this work.

This work was supported by funds from the National Aeronautics and Space Administration and the National Science Foundation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Spectroscopy has long been recognized as an important diagnostic tool for both astrophysical plasmas, where it is often the only method available, and in the laboratory where, unlike many methods, it does not disturb the plasma under study.

The considerable theoretical and experimental efforts in this field have resulted in good understanding of the pressure broadening and shifts of spectral lines due to the Stark effect of nearby charged perturbers. Particular attention has been paid to the lines of hydrogen and the hydrogenic ions, for which the quasistatic and impact theories predict considerable broadening but no shifts. However, in 1962, Berg et al reported[1] a blue shift for the He II 4686 line, which they attributed to the reduction of the Coulomb potential of the nucleus by the polarization of the plasma near the radiating ion. Later measurements[2] demonstrated this "shift" had been simulated by some unresolved Si III lines on the blue wing of the helium line. Greig et al. then reported blue shifts of the He II 304 line.[3] Subsequent photographic measurements[4,5] did not verify the shift of the 304 line, but higher series members (256, 243, etc.) had blue shifts which could have been due to plasma polarization. The most recent measurement[6] showed blue shifts for the 256 and 243 lines, with a greater shift for the 304 line, in agreement with Greig's result.

The polarization shift is expected to be important for high-Z ion lines and may limit wavelength accuracies in, for example, laser-produced plasmas. The theoretical treatments of this effect have been unsatisfactory,[7,8] and no attempts have been made to measure shifts of the "Balmer" (or "second Lyman") series lines of ionized helium, at 1640, 1215, 1084 ... Å. The primary aim of this experiment was to look for such shifts, and investigate their possible dependence on plasma conditions. A secondary purpose was to measure the Stark broadening of the higher series members, to check the theoretical calculations.[9,10]

A T-tube was chosen as a source because it produces a fairly homogeneous plasma[6] near local thermal equilibrium (LTE),[11,12] at a density and temperature suitable for the emission of ionized helium lines. The line positions were measured relative to nearby impurity lines. Plasma conditions were determined from photoelectric measurements of the He II 4686 line, and plasma reproducibility was checked by monitoring the total intensities of the 4686 line and the continuum near 4976 Å.

The first chapter of this dissertation has served as an introduction. In Chapter 2 some of the relevant results of plasma spectroscopy are presented. A description of the experimental apparatus and method appears in Chapter 3. The experimental results, with a discussion of them and possible errors, are in Chapter 4.

CHAPTER II

THEORETICAL BACKGROUND

A. Line Intensities

The relative intensities of emission lines depend on the population densities of atoms in the upper state and the probability of radiative transition to the corresponding lower state.

In equilibrium, the density N_z of ions of charge Z is related to the electron density N_e and the density of atoms in the next lower ionization stage according to the Saha equation[13]

$$\frac{N_e N_z}{N_{z-1}} = 2\,\frac{Z_z(T)}{Z_{z-1}(T)}\left(\frac{m_e \kappa T}{2\pi\hbar^2}\right)^{3/2} \exp\left(-\,\frac{E_\infty^{z-1} - \Delta E_\infty^{z-1}}{\kappa T}\right) \quad . \qquad (2\text{-}1)$$

Since nearly all the atoms are in the ground state, the partition function $Z_z(T)$ can usually be replaced by the statistical weight g_z of the ground state. In this case, $\ell=0$, and we have $g_z = 2S+1$ (1 for H^+, He^0, and He^{++}; 2 for H^0 and He^+). The correction ΔE_∞^{z-1} to the ionization energy E_∞^{z-1} due to Coulomb interactions in the plasma is[13]

$$\Delta E_\infty^{z-1} = \frac{Z\,e^2}{4\pi\varepsilon_0 \lambda_D} \ , \qquad (2\text{-}2)$$

where λ_D is the plasma Debye length[14]

$$\lambda_D = \left(4\pi \sum_i \frac{N_i q_i^2}{kT_i}\right)^{-1/2} \ , \qquad (2\text{-}3)$$

where N_i is the density of particles with charge q_i. Plots of helium ionization stage concentrations as functions of temperature appear in Fig. 2-1. Plots of λ_D and other plasma properties appear in Fig. 2-2,

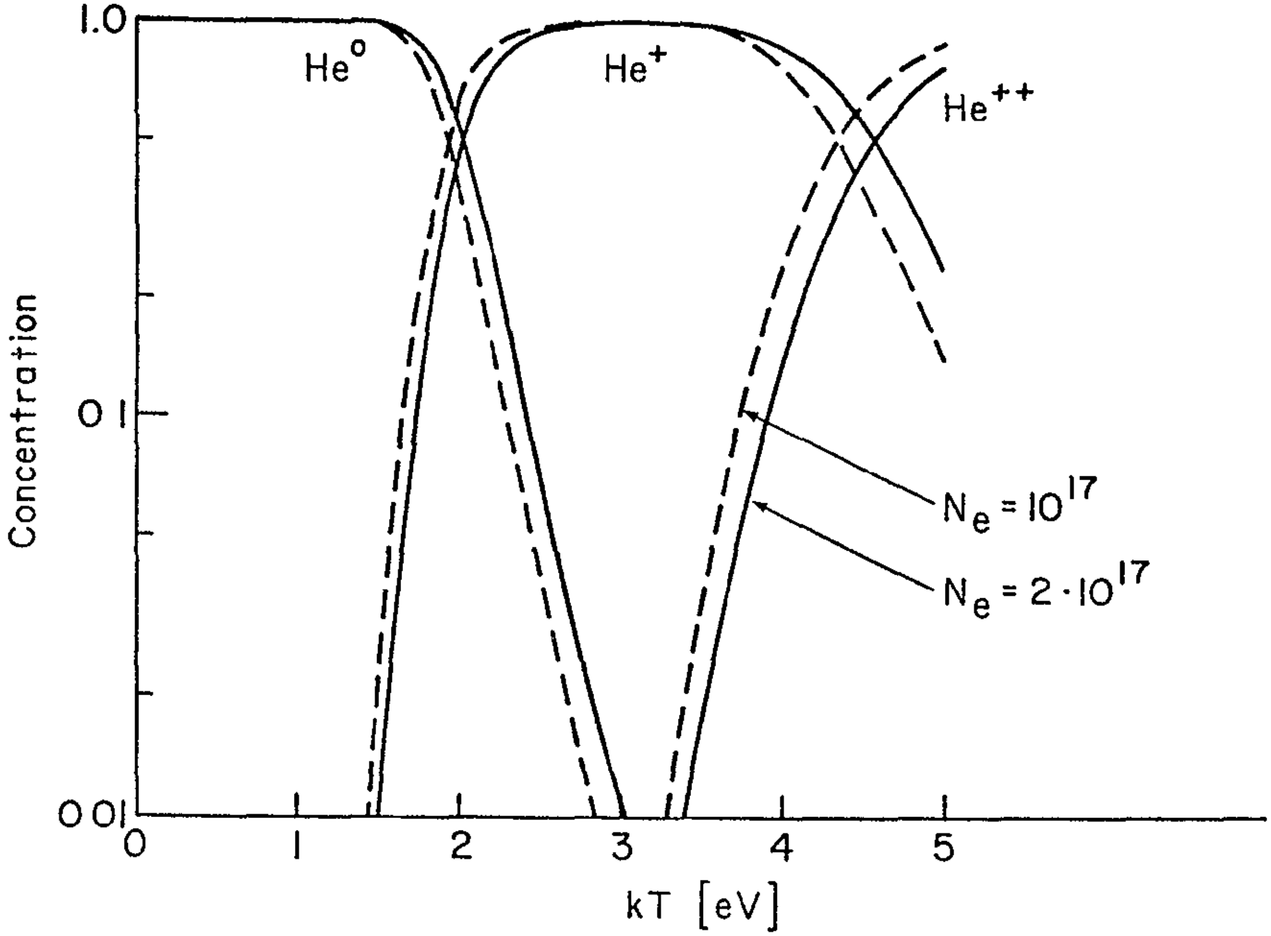


Fig. 2-1 Calculated helium ionization stage concentrations

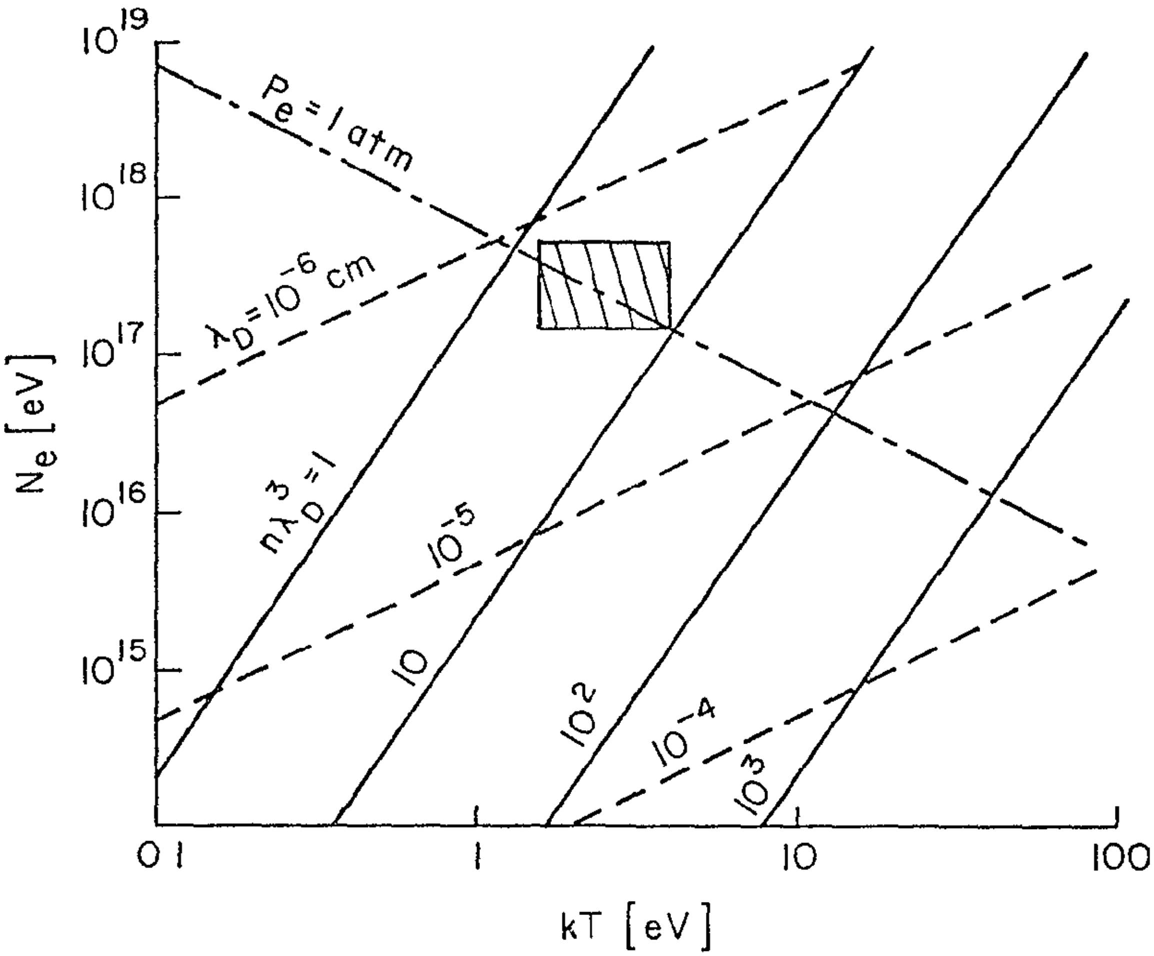


Fig. 2-2 Calculated conditions for a pure helium plasma

where the shaded region is typical of T-tubes. Note that the plasma approximation $N_e\lambda_D^3 >> 1$ (indicating many particles in a Debye sphere) is only marginally satisfied.

The population densities N_{nLS} of the state (n,L,S) of a given ionization stage is given by the corresponding Boltzmann factor[13]

$$N_{nLS} \propto g_{nLS} \exp\left(-\frac{E_{nLS}}{\kappa T}\right), \tag{2-4}$$

together with the normalization condition. The exponential term is nearly always much less than one for excited states, justifying the earlier statement that most atoms are in the ground state. Note that an isolated atom has an infinite number of bound states, whose energies tend to the ionization energy E_∞^z. When the atom is embedded in a plasma, however, the ionization energy is reduced as described above, and only a finite number of bound states remain.

Treating an atom as an electric dipole radiator, the transition probability per unit time for spontaneous emission is[13]

$$A_{\ell u} = \frac{4e^2\omega^3}{3\hbar c^3[4\pi\varepsilon_0]} g_\ell \sum_i |\langle\ell|x_i|u\rangle|^2_{av} \quad , \tag{2-5}$$

which is tabulated for many spectral lines.[15] The sum is over the components of the coordinate vector of the radiating electron, and the average is over possible final states. Multiplying by the energy $\hbar\omega$ of the photon, and using (2-4) to relate the upper state population density to the ground state population density N_g (with statistical weight g_g) we find the total power per unit volume spontaneously radiated in the given line to be[13]

$$P_{\ell u} = 2\pi\hbar c \frac{N_g A_{\ell u}}{\lambda} \frac{g_u}{g_g} \exp\left(-\frac{E_u}{\kappa T}\right) . \tag{2-6}$$

Since the line intensities are proportional to the concentration of atoms in the appropriate ionization stage, the intensity ratio of lines of different ionization states is an extremely sensitive function of temperature (see Fig. 2-3), and can be used to measure the temperature. Note, however, that this measurement depends strongly on the assumption of local thermal equilibrium, which can require a long time and considerable distance to establish between states with very different energies.

B. Continuum Intensities

Plasmas emit continuum radiation due to radiative recombination (inverse photoionization), bremsstrahlung, and the formation of negative ions. A pseudo-continuum results when the Stark profiles of nearby lines overlap.

The extremely weak bremsstrahlung radiation due to ion-ion and nonrelativistic electron-electron collisions can be neglected. That due to electron collisions with ions of charge z is given by[16]

$$\varepsilon_\omega^{ei} = \frac{16\pi e^6}{3c^2\sqrt{6\pi m_e^3}} \frac{N_e N_z}{\sqrt{\kappa T_e}} z^2 G_z(\omega,T_e) \ , \qquad (2\text{-}7)$$

where G_z is the free-free Gaunt factor, which is usually of order one.[17]

The radiation from electron-neutral collisions (approximated by elastic, billiard-ball type interactions) is given by[16]

$$\varepsilon_\omega^{e0} = \frac{32e^2}{3c^3(2\pi m)^{3/2}} N_e N_0 (\kappa T_e)^{3/2} G_0(\omega,T) \ . \qquad (2\text{-}8)$$

When an ion captures a free electron, the binding energy and the electron's kinetic energy are given to a photon. For recombination into a given orbital (n,L,S), the photon then has the minimum energy

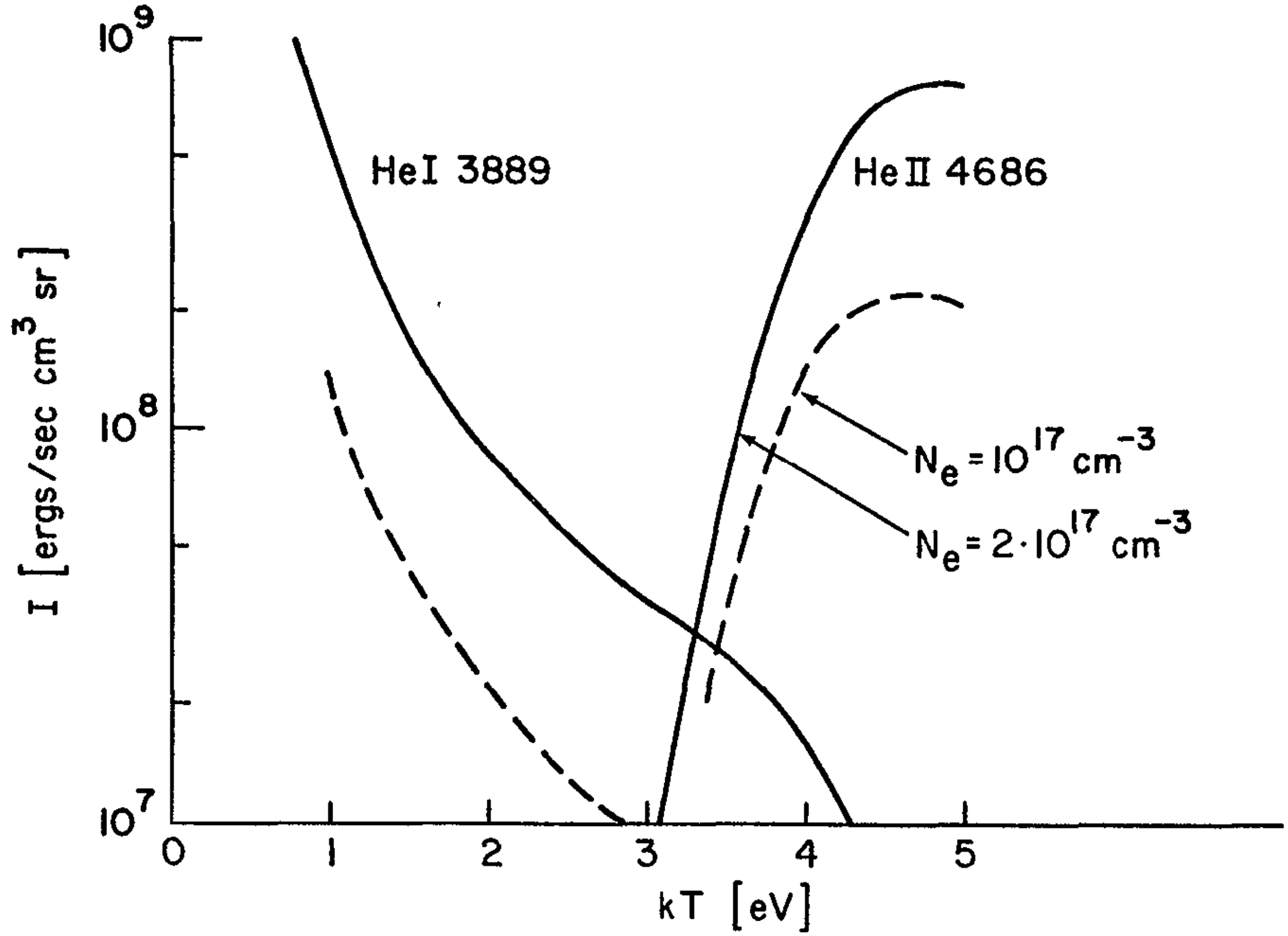


Fig. 2-3 Calculated helium line intensities

$$\hbar\omega = E_{z-1,\infty} - E_{z-1,n} \quad . \qquad (2\text{-}9)$$

Viewed another way, this restricts the possible final states for the electron for a contribution to the continuum at a given frequency. The recombination continuum is then, by detailed balancing,[16]

$$\varepsilon_\omega^R = \frac{2\pi\hbar^4}{c^2} \frac{N_e N_{z,1} \omega^3}{(2\pi m \kappa T_e)^{3/2}} \exp\left(-\frac{\hbar\omega}{\kappa T_e}\right) \sum_n \frac{g_{z-1,n}}{g_{z,1}} \sigma_{z-1,n} \ , \qquad (2\text{-}10)$$

where $\sigma_{z-1,n}$ is the photoionization cross section[18,19], $g_{z-1,n}$ and $g_{z,1}$ are statistical weights, and the sum runs from the lowest allowed state to the highest bound state (i.e., with energy less than the reduced ionization energy calculated from (2-2)).

Some electronegative atoms (H, N, O, C, etc.) can capture a free electron and form a negative ion, while emitting a continuum as in recombination. The spectral emission coefficient is, similarly,[16]

$$\varepsilon_\omega^- = \frac{2\pi\hbar^4 \ \omega^3}{c^2 (2\pi m \kappa T_e)^{3/2}} N_a N_e \frac{g^-}{Z_0(T_e)} \sigma^-(\omega) \exp\left(\frac{E_a - \hbar\omega}{\kappa T_e}\right) \ , \qquad (2\text{-}11)$$

where g^- is the statistical weight of the negative ion (which usually has only one bound state), Z_0 is the partition function of the neutral atom, E_a is the binding energy of the new electron (generally less than 2 eV), and σ^- is the cross section for the inverse process of photodetachment.[20] This process is unimportant in hot plasmas, where the density N_a of neutral atoms is low.

The pseudo-continuum of lines is generally important only for hydrogenic atoms, which are subject to the linear Stark effect, and then only near a series limit. The last clearly distinguishable line of a series is then given by the Inglis-Teller limit.[21]

Since both line and continuum intensities increase with electron density, but scale differently with temperature, the ratio of the line intensity to that of the nearby continuum can be used to measure the temperature.

C. Radiation Transfer

In previous sections we have discussed the spectral emission coefficient ε_ω of the plasma, expressed as power radiated per unit solid angle, frequency interval, and volume. The experimentally measurable quantity is I_ω, the power radiated per unit solid angle, frequency interval, and surface area of plasma observed. In the simplest situation, i.e., neglecting scattering, it obeys the differential equation[13]

$$\frac{d}{dx} I_\omega = \varepsilon_\omega - k'_\omega I_\omega \ , \qquad (2\text{-}12)$$

where k'_ω is the effective absorption constant, equal to the actual absorption constant minus the induced emission. ε_ω includes only the spontaneous emission. If the plasma is in LTE, the emission follows Kirchoff's law[13]

$$\varepsilon_\omega = k'_\omega B_\omega(T) \ , \qquad (2\text{-}13)$$

where B_ω is the Planck function. If we further assume the plasma to be homogeneous, the solution of (2-12) is

$$I_\omega(\ell) = B_\omega(T)[1 - \exp(-k'_\omega \ell)] \ . \qquad (2\text{-}14)$$

The quantity $k'_\omega \ell$ is the "optical depth", and if $k'_\omega \ell << 1$, the equation reduces to

$$I_\omega(\ell) = B_\omega(T) k'_\omega \ell = \varepsilon_\omega \ell \ , \qquad (2\text{-}15)$$

as expected. In the opposite limit, $k'_{\omega}\ell >> 1$, the plasma radiates as a blackbody. Stellar atmospheres have great optical depth at almost all wavelengths, while laboratory plasmas are normally optically thin except possibly near the centers of some resonance lines.

D. Line Broadening

Spectral line broadening in a plasma is a complex phenomenon, and no attempt is made here to discuss all the results of investigations in atomic spectroscopy,[22] astrophysics[23], and plasma spectroscopy.[10,13]. Only a physical picture of the various effects is presented.

Let the (frequency-space) spectral line profile $I(\omega)$ be proportional to the light intensity between ω and $\omega + d\omega$, subject to the normalization condition

$$\int_{-\infty}^{\infty} I(\omega)d\omega = 1 \ . \tag{2-16}$$

These spectral intensities are the squares of the corresponding Fourier components $C(\omega)$:

$$I(\omega) = |C(\omega)|^2 \ , \tag{2-17}$$

where $C(\omega)$ is the Fourier transform of the amplitude $f(t)$

$$C(\omega) = \sqrt{\frac{1}{2\pi}} \int_{-\infty}^{\infty} e^{i\omega t} f(t)dt \ . \tag{2-18}$$

Since each atom emits light for only a short time, the light from an ensemble is not monochromatic. It is physically reasonable to assume that $f(t)$ for one atom has the exponentially decaying form[24]

$$f(t) = \begin{cases} 0 & t<0 \\ \sqrt{2\gamma}\, e^{i\omega_0 t}\, e^{-\gamma t} & t>0 \end{cases} \ , \tag{2-19}$$

which satisfies the normalization condition

$$\int_{-\infty}^{\infty} |f(t)|^2 dt = 1 \ , \tag{2-20}$$

and has the Fourier components

$$C(\omega) = \sqrt{\frac{\gamma}{\pi}} \frac{-i}{\omega_0-\omega+i\gamma} \ , \tag{2-21}$$

leading to the Lorentz or dispersion profile

$$I(\omega) = |C(\omega)|^2 = \frac{\gamma}{\pi} \frac{1}{(\omega_0-\omega)^2+\gamma^2} \ . \tag{2-22}$$

The half-half width γ, the frequency separation at which the intensity is half the maximum, is given by the sum of the transition rates for transitions originating from either the upper or lower state of the line[13]

$$\gamma_{\ell u} = \sum_{u'} A_{u'u} + \sum_{\ell'} A_{\ell'\ell} \ . \tag{2-23}$$

Since atomic excited states have relatively long lifetimes ($A_{\ell u} < 10^9 \text{sec}^{-1}$), this natural broadening is almost always smaller ($\Delta\lambda < 10^{-4}$Å) than the other effects we will discuss. It can of course be derived rigorously from the quantum theory of radiation.[25]

When the energy levels of the radiating atoms are well separated, compared to mean thermal energies, electron collisions rarely exchange energy with the radiator, but change the polarization or phase of the emitted light. Although this approximation does not hold, for example, for neutral helium[7,13] (where there are nearby perturbing levels with the same n but different L), it is well satisfied for hydrogenic atoms. Assuming the light to be monochromatic between collisions, we have a sinusoidal wave train of duration τ, with the Fourier components

$$C_T(\omega) = \sqrt{\frac{1}{2\pi}} \int_0^\tau e^{i\omega_0 t} e^{-i\omega t} dt = \frac{e^{i(\omega_0-\omega)\tau} - 1}{i(\omega_0-\omega)\sqrt{2\pi}} , \tag{2-24}$$

producing the intensity

$$I_\tau(\omega) = \frac{\sin^2\left(\frac{1}{2} (\omega_0-\omega)\tau\right)}{2\pi\left(\frac{1}{2} (\omega_0-\omega)^-\right)^2} . \tag{2-25}$$

If the probability per unit time γ_c of a collision is constant, the intervals between collisions have the Poisson distribution

$$P(\tau)d\tau = \gamma_c e^{-\gamma_c \tau} d\tau . \tag{2-26}$$

Weighting the intensities (2-25) by the corresponding probabilities, we again arrive at the dispersion profile (2-22), now with width γ_c.

The frequency of light emitted by a moving atom is Doppler-shifted according to

$$\omega = \omega_0 \frac{1 - \frac{v_\parallel}{c}}{\sqrt{1 - \frac{v^2}{c^2}}} \doteq \omega_0 \left(1 - \frac{v_\parallel}{c}\right) . \tag{2-27}$$

Assuming the atoms have a Maxwellian distribution of velocities,

$$f_M(\underset{\sim}{v})d^3v = \left(\frac{m_i}{2\pi\kappa T_i}\right)^{3/2} \exp\left(- \frac{m_i v^2}{2\kappa T_i}\right) d^3v , \tag{2-28}$$

the collection will emit light with the Doppler or Gaussian line profile[13,26]

$$I_D(\omega) = \frac{1}{\Delta\omega_D} \sqrt{\frac{1}{2\pi}} \exp\left(- \frac{(\omega_0-\omega)^2}{2\Delta\omega_D^2}\right), \tag{2-29}$$

where the characteristic width is

$$\Delta\omega_D = \sqrt{\frac{\kappa T_i}{m_i c^2}} , \tag{2-30}$$

and the Doppler half-half width is $\sqrt{\ln 4}\, \Delta\omega_D$.

In contrast to the fast electron impacts, nearby ions can usually be considered stationary, and supply only perturbing electric fields. These fields perturb the energy levels (each labeled by n, L, S, and J) of the radiating atom and usually split them into several sublevels, each a linear combination of states of different magnetic quantum number m_j.[16] Transitions between such sublevels of different principal quantum number give rise to the Stark components of a line. Since the operator $-q_e \underset{\sim}{r}_e \cdot \underset{\sim}{F}$, expressing the interaction of the electric field and a given electron, has odd parity (therefore no diagonal elements), there is usually no first-order interaction, and second-order perturbation theory is used. In the hydrogenic case, however, the terms (labeled only by n) are degenerate, and a linear effect is found. This problem is most conveniently solved in the parabolic coordinates (ξ,η,ϕ):

$$\begin{aligned} \xi &= r+z \\ \eta &= r-z \\ \tan\phi &= y/x \\ (r^2 &= x^2 + y^2 + z^2) \ , \end{aligned} \tag{2-31}$$

where the unperturbed wavefunction is[27]

$$\begin{aligned} \Psi(n_1 n_2 m|\xi\eta\phi) &= e^{-\frac{\xi+\eta}{2n}} \xi^{m/2}\eta^{m/2} U_{n_1}(\xi) V_{n_2}(\eta) \frac{e^{im\phi}}{\sqrt{2\pi}} \\ n &\equiv n_1 + n_2 + |m| + 1 = 1,2,\ldots \\ m &= 0, \pm 1, \ldots, \pm(n-1) \ , \end{aligned} \tag{2-32}$$

and the energy, correct to second order in field strength, is[27] (in units of $m_e e^4/\hbar^2$)

$$c(n_1n_2m,F) = -\frac{1}{2}\frac{Z^2}{n^2} + \frac{3}{2}\frac{n(n_1-n_2)}{Z}|\underset{\sim}{F}|$$
$$-\frac{1}{16}\frac{n^4}{Z^4}[17n^2 - 3(n_1-n_2)^2-9m^2+19]|\underset{\sim}{F}|^2 \qquad (2\text{-}33)$$

For a first approximation, we may assume the ions in the plasma are uncorrelated In this case, they produce an electric field F with the Holtsmark distribution[10,28]

$$H\left(\frac{F}{F_0}\right) = \frac{2}{\pi}\frac{F}{F_0}\int_0^\infty \exp(-x^{3/2})\sin\left(\frac{F}{F_0}x\right) x dx , \qquad (2\text{-}34)$$

plotted in Fig. 2-4, where the Holtsmark normal field strength produced by perturbers with density N_p and charge q_p is[10]

$$F_0 = 2\pi\left(\frac{4}{15}N_p\right)^{2/3} q_p \qquad (2\text{-}35)$$

Integrating the energies (2-33) over the distributions (2-34) for each level (though the effects on the upper level usually predominate) we arrive at the Holtsmark profile, shown for the hydrogen line H_β in Fig. 2-5. Profiles of lines subject to the linear Stark effect are usually expressed in terms of the reduced wavelength separation, defined by[10,13]

$$\alpha = \left|\frac{\Delta\lambda}{F_0}\right|. \qquad (2\text{-}36)$$

Note that where there is no unshifted Stark component (as in hydrogen transitions n=4→2 or 3→1), the low probability of very small fields (since H(0) = H'(0) = 0) gives a line profile with a central dip, usually partly filled by other effects.

Finally, observed profiles are broadened by the instrument response function of the observing monochromator. According to physical optics,

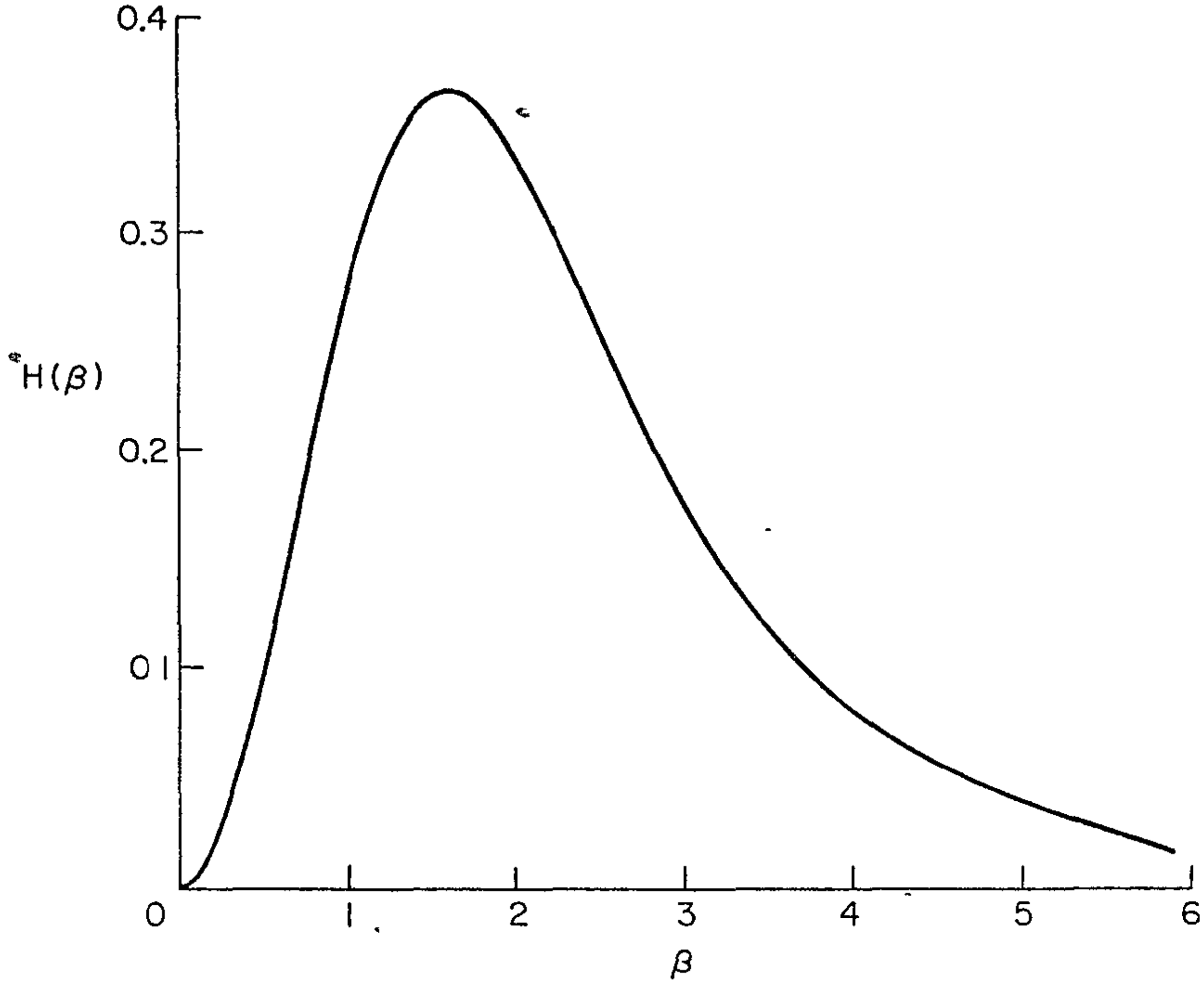


Fig. 2-4 Holtsmark field strength distribution

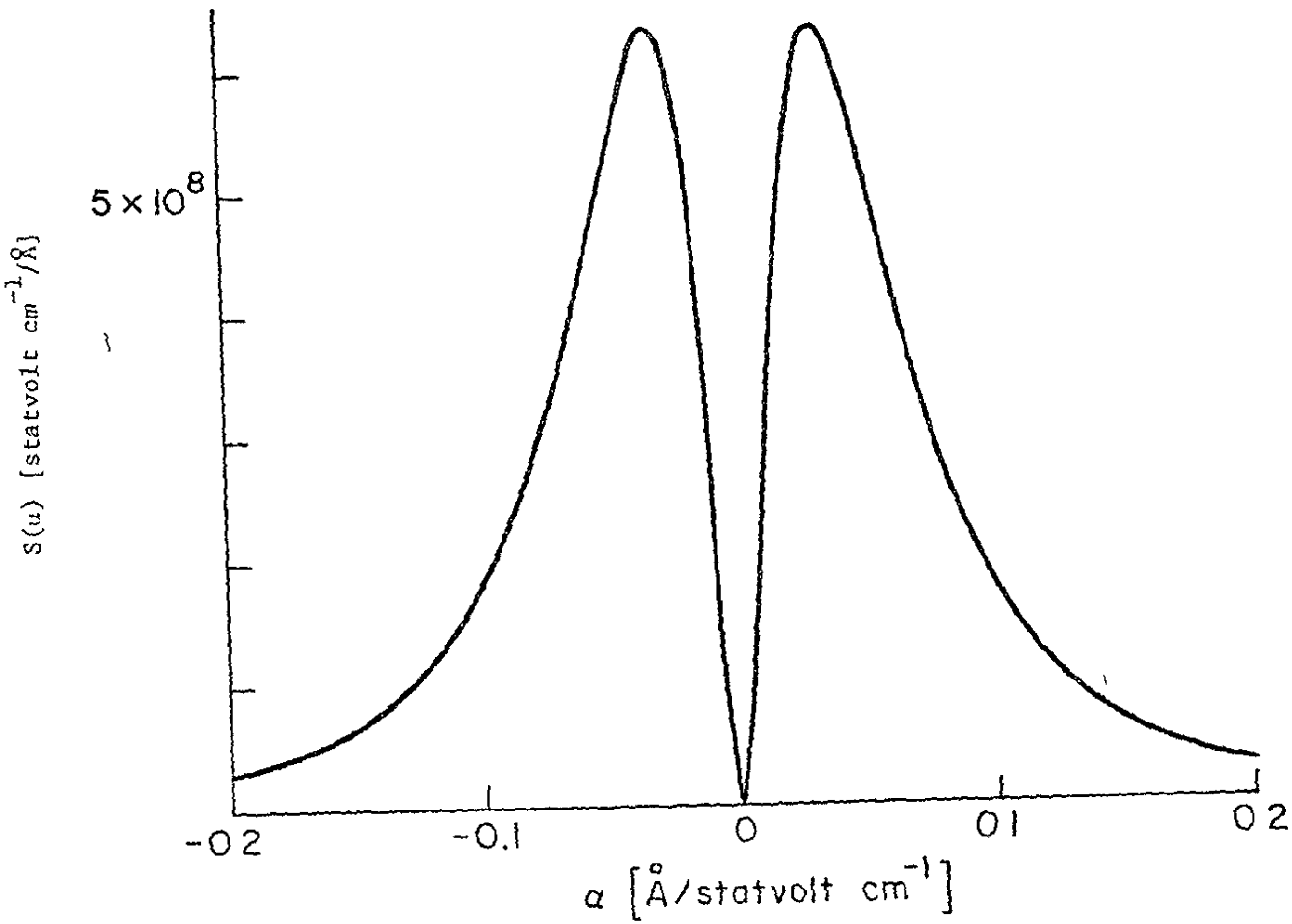


Fig. 2-5 Holtsmark profile for the H_δ line

(broadened only by statistically uncorrelated ions) it is a profile like (2-29) folded with the two rectangular slit functions, plus a constant background. With wide slits, Gaussian or triangular profiles are good approximations

The profile of a line broadened by two independent effects is the convolution of the two profiles,

$$I(x) = I_1(x) \otimes I_2(x) = \int_{-\infty}^{\infty} I_1(x')I_2(x'-x)dx' \ , \qquad (2\text{-}37)$$

and if we assume all of these effects are independent, we may find our theoretical profile by convolving all the profiles:

$$I_{theory} = I_{natural} \otimes I_{electron} \otimes I_{Doppler} \otimes I_{ion} \otimes I_{instrument} . \qquad (2\text{-}38)$$

This assumption of statistical independence is reasonable for plasmas, because, e.g., collisions leading to significant changes of radiator velocities (Doppler effect) usually involve ions whose direct contribution (Stark effect) is insensitive to ion and radiator velocities.

E. Validity of LTE

A plasma is in local thermal equilibrium (LTE) if, locally and instantaneously, all quantum state population densities (except for photon states) correspond to a system in complete thermal equilibrium (CTE) which has the same mass density, energy density, and chemical composition.[13] Departures from LTE occur when some transitions have unbalanced rates, so that some (generally low-energy) states are over- or under-populated when compared to the corresponding CTE system. In optically thin plasmas, where the rates of radiative excitation (photoexcitation and photoionization) are negligible compared to those of radiative de-excitation (spontaneous emission and radiative recombination), the lower-energy states will be overpopulated unless collisional processes dominate radiative ones. That is, populations will be within ~10% of LTE if collisional processes are about an order of magnitude more important than radiative ones. Since collision cross sections are generally larger, and energy gaps smaller, for excited states, LTE is most easily satisfied for them An estimate of the electron density required for the hydrogenic level n to be within ~10% of LTE with respect to the ion density is[13]

$$N_e > (7 \cdot 10^{18} cm^{-3}) \frac{z^7}{n^{17/2}} \left(\frac{\kappa T}{z^2 E_H}\right)^{1/2} \qquad (2\text{-}39)$$

The largest gap between atomic energy levels is generally between the ground and the first excited states, so the requirements for LTE for the ground state are usually the most restrictive. Near LTE, the largest transition rates are those to and from the first excited state, and collisional rates can be expected to dominate if[13]

$$N_e > (9 \times 10^{17} cm^{-3}) \left(\frac{E_2}{E_H}\right)^3 \left(\frac{\kappa T}{E_h}\right)^{1/2} . \qquad (2\text{-}40)$$

It often happens that the resonance line is optically thick, so that radiative de-excitation of the first excited state is balanced by photoexcitation The resonance line profile is generally dominated by Doppler broadening (for N_e sufficiently low that electron collisions cannot maintain LTE), so its optical depth can be estimated by [13]

$$k'_{reson} d \sim (2 \cdot 10^{-10} cm) f_{12} \lambda_{12} \left(\frac{AE_H}{\kappa T}\right)^{1/2} N_{a,1}^{z-1} d \qquad (2\text{-}41)$$

where the resonance line has wavelength λ_{12} and absorption strength f_{12}, and the atoms of interest have atomic weight A and ground state density

$N_{a,1}^{z-1}$. If the optical depth of the resonance radiation is greater than ∿20, the requirement (2-40) can be relaxed by about an order of magnitude.[13]

The validity of LTE for ionization stage populations in stationary plasmas usually need not be checked separately, since the excited states of a given stage are well connected with the ground state of the next ionization stage

In transient plasmas, populations may depart from LTE if equilibrium times are long compared to the times over which plasma parameters change. The lowest transition rates for given stage usually involve the collisional excitation of atoms in the ground state. Assuming hydrogenic behavior, the equilibrium time is then estimated by[13]

$$T_1^{z-1} \approx \frac{(1.1 \times 10^7 \text{sec cm}^{-3}) z^3}{f_{21} N_e} \left\{ \frac{N_a^z}{N_a^z + N_a^{z-1}} \right\} \frac{E_2^{z-1,a}}{z^2 E_H} \left(\frac{\kappa T}{z^2 E_H} \right)^{1/2} \exp \left(\frac{E_2^{z-1,a}}{\kappa T} \right) \tag{2-42}$$

where $E_2^{z-1,a}$ is the energy of the first excited state and the term in brackets is the fraction of atoms or ions that must be excited into the next ionization stage If only partial LTE is required (i e, the state with principal quantum number n is in equilibrium with higher states) the equilibrium time is much shorter, and is estimated by[13]

$$T_n^{z-1} \approx \frac{(4.5 \times 10^7 \text{sec cm}^{-3}) z^3}{n^4 N_e} \left(\frac{\kappa T}{z^2 E_H} \right)^{1/2} \exp \left(\frac{2 z^2 E_H}{n^3 \kappa T} \right) .$$

CHAPTER III

EXPERIMENTAL METHOD

A. Apparatus

A.1 T-tube and circuit. The plasma studied in this work was produced in a T-tube similar to those developed by Kolb[29,30] and used in several previous experiments at the University of Maryland[31-36] and elsewhere[37,38] In this device, illustrated in Fig. 3-1, an aluminum (alloy 2024-T4) electrode was sealed into either end of the top of a T-shaped tube of high-temperature glass with inside diameter of 16 mm. This tube was filled with the test gas at a pressure near .5 Torr (70 Pascals). A current flowed across the 16 mm gap between the electrodes, ionized the gas and ohmically heated it, then returned via a backstrap above the T The backstrap current created a transverse magnetic field in the current-carrying plasma, and pressure and Lorentz force accelerated it down the leg of the T. This luminous front traveled 12 cm down the tube at several cm/μ sec and struck an adjustable reflecting plate, where some of its directed motion was converted to random thermal motion. Longer expansion tubes and higher fill pressures are required for the formation of a separated shock, but this device produced the high temperatures (3.5 eV) and electron densities ($2 \cdot 10^{17} cm^{-3}$) needed to excite ionized helium lines. The decaying plasma lasted approximately one μsec

The circuit used appears in Fig. 3-2. The relatively modest energy needed by the tube was supplied by a .5 μF capacitor charged to 40 kV (thus storing 400 J). When charged, this capacitor was disconnected

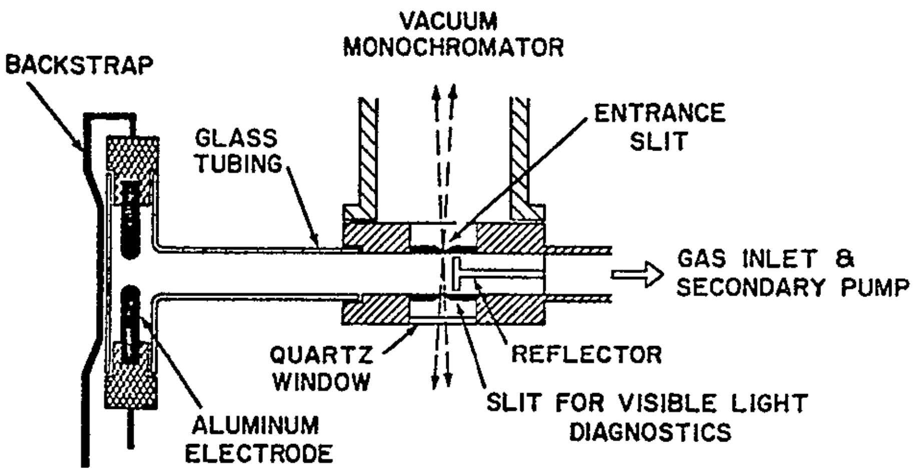


Fig. 3-1 T-tube schematic

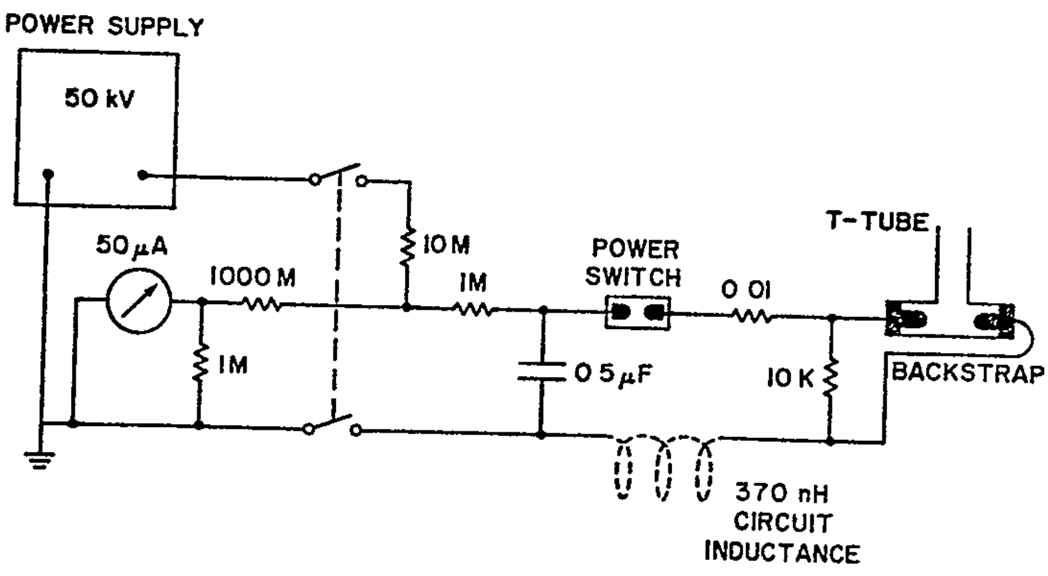


Fig. 3-2 Experiment circuit diagram

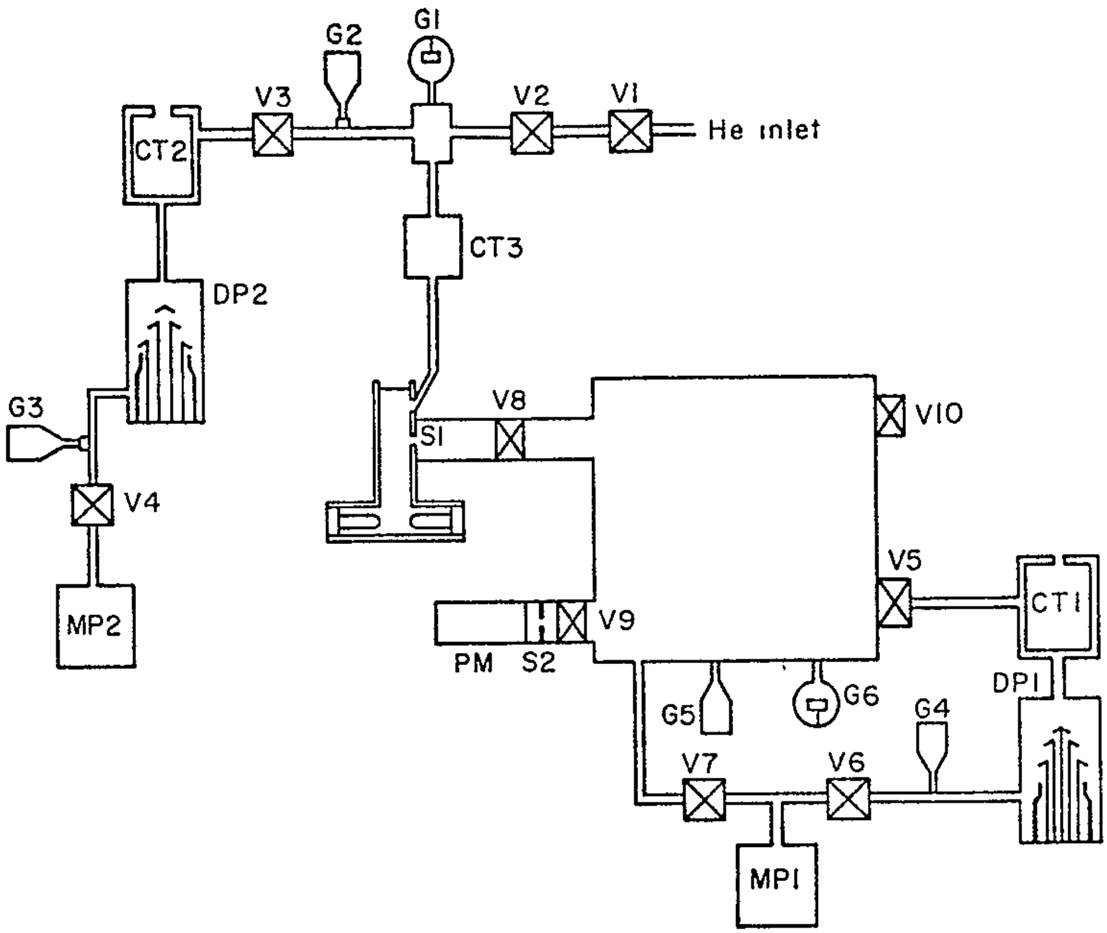
from both the high voltage supply and ground, preventing discharges from either electrode to the monochromator. The high-voltage circuit was enclosed by a copper shield to reduce electromagnetic interference.

To start the discharge, the nitrogen in a two-electrode pressure switch (initially at 30 PSI above atmospheric) was released until its dielectric strength was low enough for electron cascade. Since nitrogen was used, no ozone or nitrogen oxides were formed, as in a discharge in air. The poor control over discharge timing was no problem, since the discharge itself triggered the recording system.

The measured quarter-cycle time was .675 μsec, indicating a total circuit inductance of 370 nH. A carbon resistor of about .01 Ω damped out the oscillations after two cycles.

The vacuum system is shown in Fig. 3-3. During the experiment, valve V3 was closed, while shut-off valve V1 and leak valve V2 were opened, so the test gas flowed from the inlet, through liquid nitrogen cold trap CT3, into the T-tube. It then leaked into the monochromator through entrance slit S1, and was removed by pumps DP1 and MP1. V2 was adjusted so the leak rates into and out of the T-tube balanced, and the pressure, measured by thermistor gauge G2, stayed at the desired value.

Between experimental runs, the T-tube was isolated by closing slit valve V9 and shut-off valve V1, and kept clean by the small diffusion pump DP2. Cold trap CT2 was cooled by a conventional refrigeration system and valves V3 and V4 were solenoid-controlled, so this secondary pumping system could operate unattended. Since the small pump was not forced to pump through a slit, it proved more effective than the large pump at outgassing the T-tube and associated plumbing.



G1	ionization gauge Veeco RG-83
G2,G3	thermistor gauge CVC GT-340A
G4,G5	Gauge thermocouple
G6	Gauge cold cathode discharge
V1	Metering valve, 1/4 in.
V2	Screw valve Veeco, 3/8 in.
V3	Solenoid valve Veeco, 3/4 in.
V4	Solenoid valve Veeco, 3/4 in.
V5	Gate valve
V6	Solenoid valve
V7	Solenoid valve
V8	Entrance slit valve
V9	Exit slit valve
V10	Air inlet valve
DP1	Diffusion pump, NRC, 6 in.
DP2	Diffusion pump, 2 in.
CT1	Liquid nitrogen cold trap
CT2	Freon cold trap
CT3	Liquid nitrogen cold trap
MP1	Fore pump DuoSeal 1397
MP2	Fore pump DuoSeal serial 16025-2
S1	Entrance slit
S2	exit slit
PM	photomultiplier tube

Fig. 3-3 Schematic of vacuum system

A.2 VUV monochromator and detector. The optical arrangement is shown in Fig. 3-4. A McPherson 225 one-meter monochromator scanned the ultraviolet lines shot-to-shot. Its 50 μ entrance slit was flush with the wall of the T-tube, about .5 mm from the reflector. Since the plasma conditions changed sharply as the reflector was moved, the position was chosen which gave the most reproducible plasma. A 1200 lines/mm Pt-coated grating, with speed about f/13.6, focused the light onto a 30 μ exit slit, for a measured reciprocal dispersion of 8.3 Å/mm (4.2 Å/mm in second order) and an approximately Gaussian instrument response function of width ∿.41 Å (∿ .19 Å in second order). The light then fell on a p-terphenyl coated disc, causing it to fluoresce.[39] These visible photons left the vacuum chamber through a quartz window and were detected by an EMI 6522 photomultiplier. For some work, a 2 mm thick MgF_2 filter was placed between the exit slit and the fluorescent screen to remove light from second order, since it transmitted 40% of the light at 1215 Å but essentially none below 1100 Å.[40] The exit slit, screen, and PM tube were replaced by a film holder for photographic work. The instrument function and wavelength calibration were checked using a low-pressure Tanaka lamp.

A.3 Visible monochromators and detectors. For diagnosis of the plasma conditions, three Jarrell-Ash visible-light monochromators were used One 1/2-meter focal length monochromator, with instrument width .4 Å, scanned the He II 4686 line shot-to-shot to determine the electron density (from line width)[10] and temperature (from line: continuum ratio).[41] The reproducibility of the plasma was monitored on each shot by two 1/2-meter instruments, one for the continuum at 4976 Å

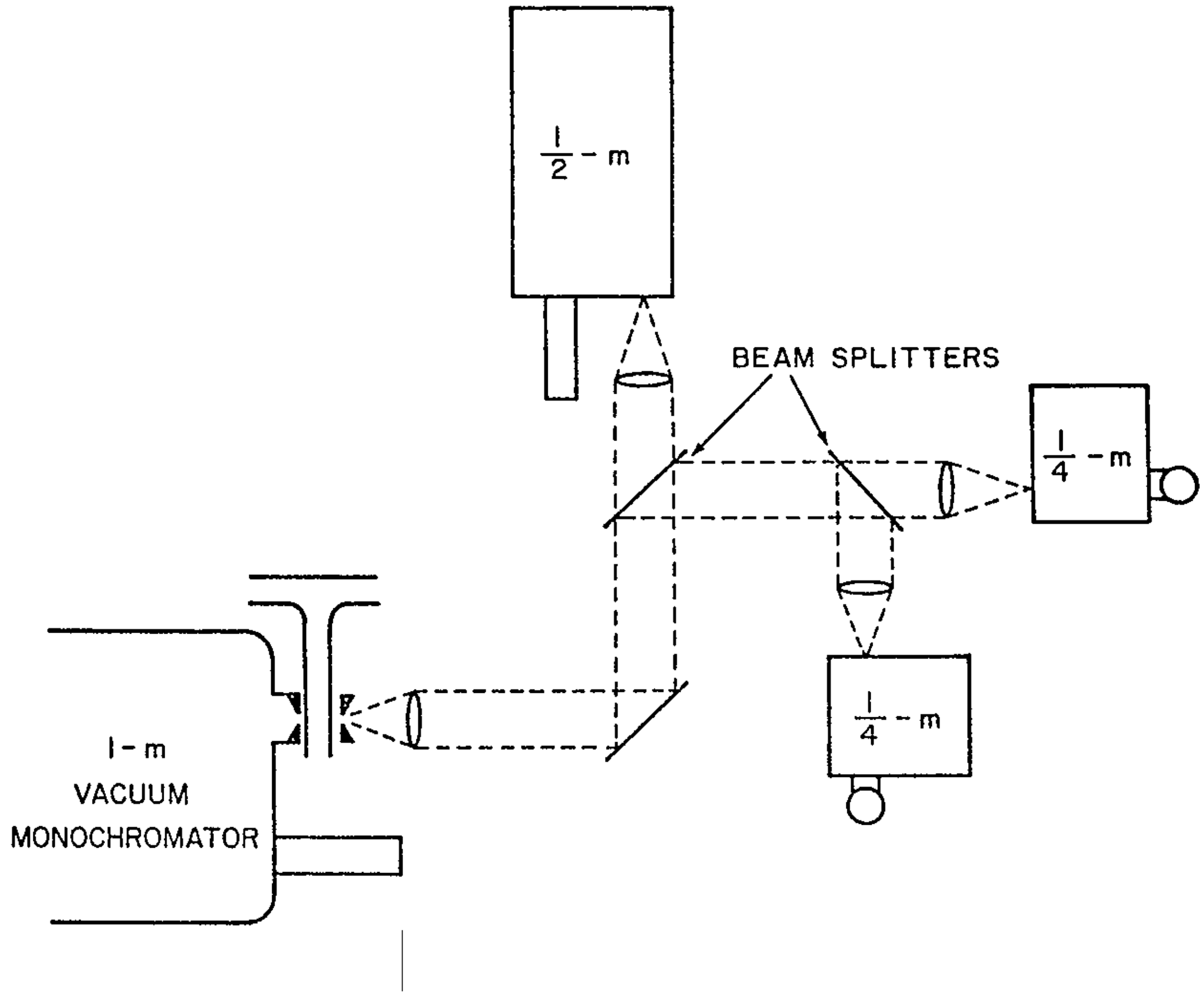


Fig. 3-4 Schematic of optical arrangement

(sensitive to electron density), and one for the He II 4686 line (sensitive to temperature, and used for later data processing).

PM tube response was checked using neutral density filters and pulses from a light emitting diode, and was found linear for signals of up to .2 V (1.1 mA) with a PM supply voltage of 900 V.

Each PM tube housing was insulated from its monochromator, and signals were taken from both the anode (negative pulse) and last dynode (positive pulse), carried by shielded, coaxial cables terminated by 90 Ω resistors, subtracted to suppress noise, amplified, digitized, and stored electronically For details on the waveform recorder, see Appendix A.

B. Data Reduction

The best-fit values of the four parameters (line intensity I, line position λ_0, background intensity B, and electron density N_e) are found using the following procedure. Assume we have the n measurements $y_i(\lambda_i)$ and the corresponding theoretical intensities $T_i = \frac{1}{F_0} T\left(\frac{|\lambda_i - \lambda_0|}{F_0}\right)$, where $T(\alpha)$ is the theoretical profile after convolution with the instrument profile $G(\alpha)$

$$T(\alpha) = \int_{-\infty}^{\infty} S(\alpha-\alpha')G(\alpha')d\alpha' , \qquad (3\text{-}1)$$

and the instrument function has been transformed into α-space. The best-fit values minimize the sum

$$\sigma^2 = \frac{1}{n-4} \sum_{i=1}^{n} [y_i - (IT_i+B)]^2 , \qquad (3\text{-}2)$$

giving the conditions

$$\frac{\partial}{\partial I}\sigma^2 = \frac{\partial}{\partial B}\sigma^2 = 0 ,$$

so I and B are found by solving the linear system

$$\begin{pmatrix} \sum T_i^2 & \sum T_i \\ \sum T_i & n \end{pmatrix} \begin{pmatrix} I \\ B \end{pmatrix} = \begin{pmatrix} \sum y_i T_i \\ \sum y_i \end{pmatrix} . \qquad (3\text{-}3)$$

The computer program "guesses" an electron density to use for the transforming of the instrument function, convolves the theoretical and instrument profiles, then finds σ^2 from (3-2) (subject to (3-3)) for many values of N_e and λ_0. When the best values are found, the new N_e is used to again transform the instrument function. The entire convolution and fit are repeated until successive values of N_e are sufficiently close, e.g., within 2% of each other. A general discussion of least-square fitting when the functional parameters do not occur linearly (e.g., λ_0 and N_e) appears as Appendix B. Details on the computer programs appear in Appendix C.

CHAPTER IV

RESULTS AND DISCUSSION

A. Results

Examples of photoelectric measurements of the emission profiles of the ionized helium lines at 4686, 1640 and 1215 Å are shown in Figs. 4-1 through 4-3. In each case, the solid line is the best-fit theoretical curve of Kepple,[9,10] convolved with the instrument profile (taken to be Gaussian), Dashed lines are the best-fit continuum levels, determined primarily by points far from line center, which are not shown. Crosses represent points not used in the best-fit procedure.

The 4686 line was found to be unshifted, as in previous experiments.[2] Its profile was in good agreement with theory, and the plasma electron density and temperature were deduced from its width and line.continuum ratio, respectively.

The position of the 1640 line was measured relative to the Al II 1670 line, and a fairly constant red shift of .11 Å was found. These shift measurements can be found in Table 4-1 and Fig. 4-4. No conclusions could be drawn about the Stark width of this helium line, because the observed profile was dominated by instrument broadening.

The relative positions of the He II 1215 and Si III 1210 lines were measured photoelectrically. The helium line was found to have a red shift of approximately .19 Å, increasing as the density and temperature fell at the end of the discharge. The halfwidth of the 1215 line was also determined as a part of the best-fit procedure.

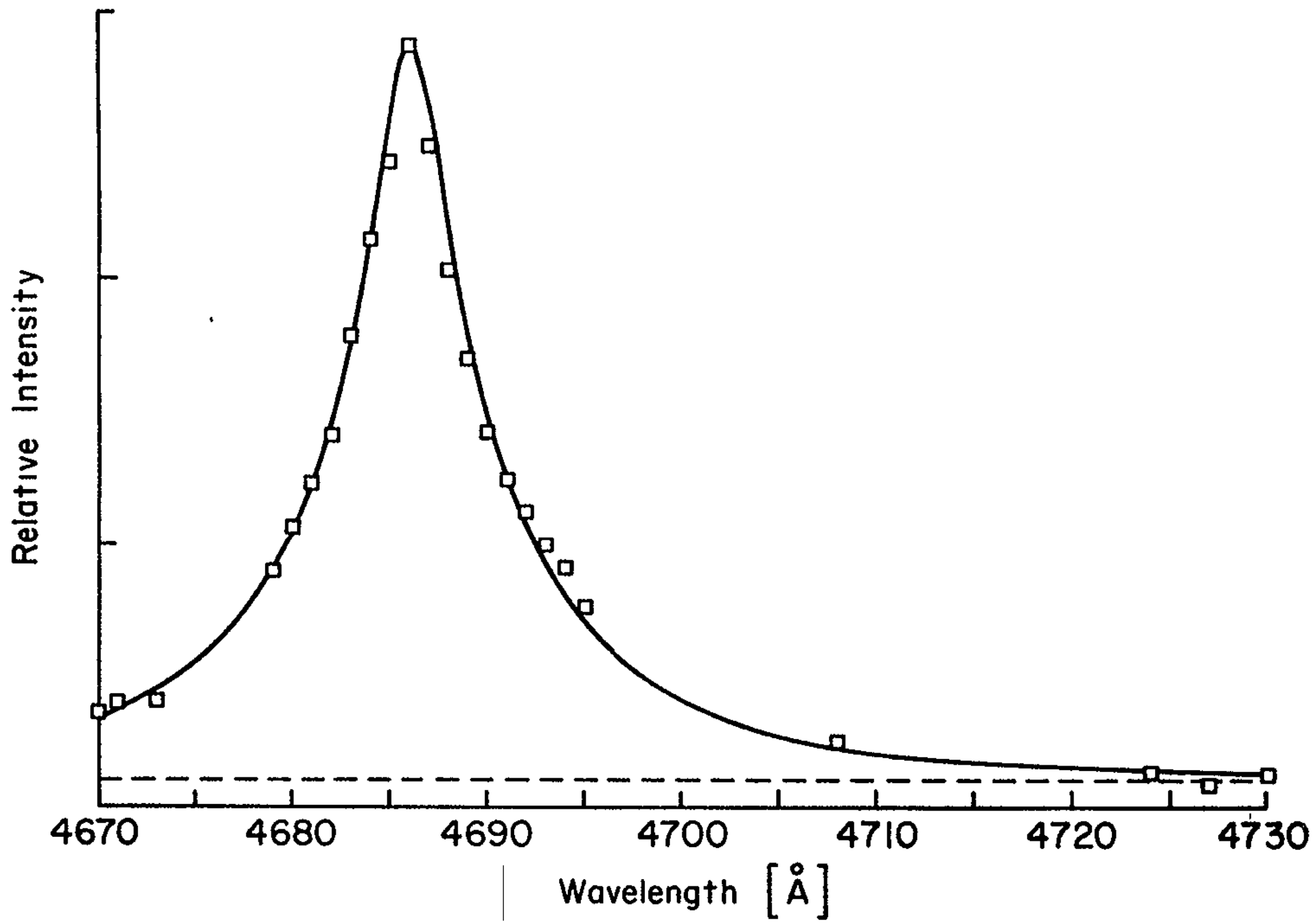


Fig. 4-1 Measured and best-fit profile for He II λ 4686 Å line

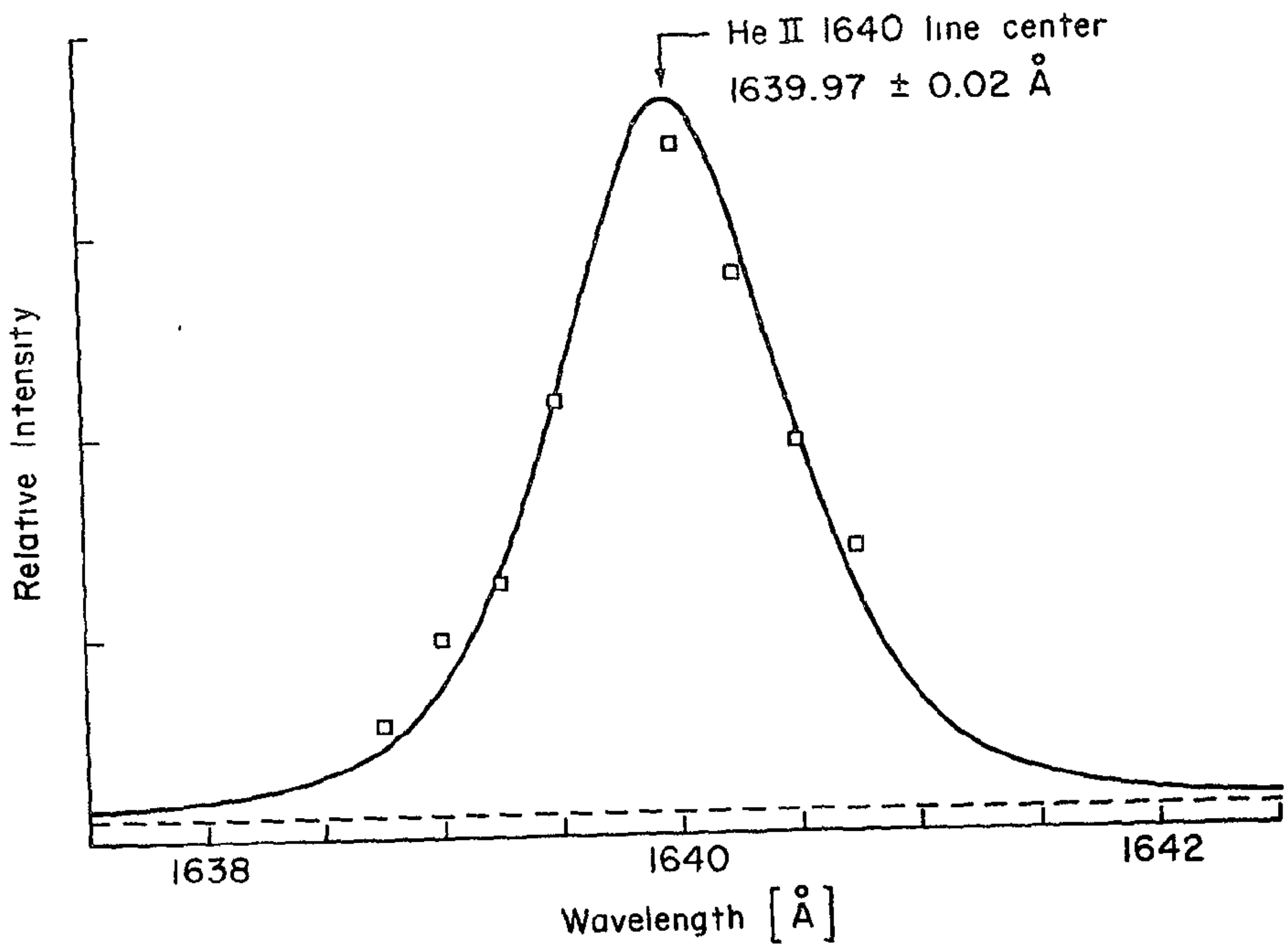


Fig. 4-2 Measured and best-fit profile for He II λ 4686 line

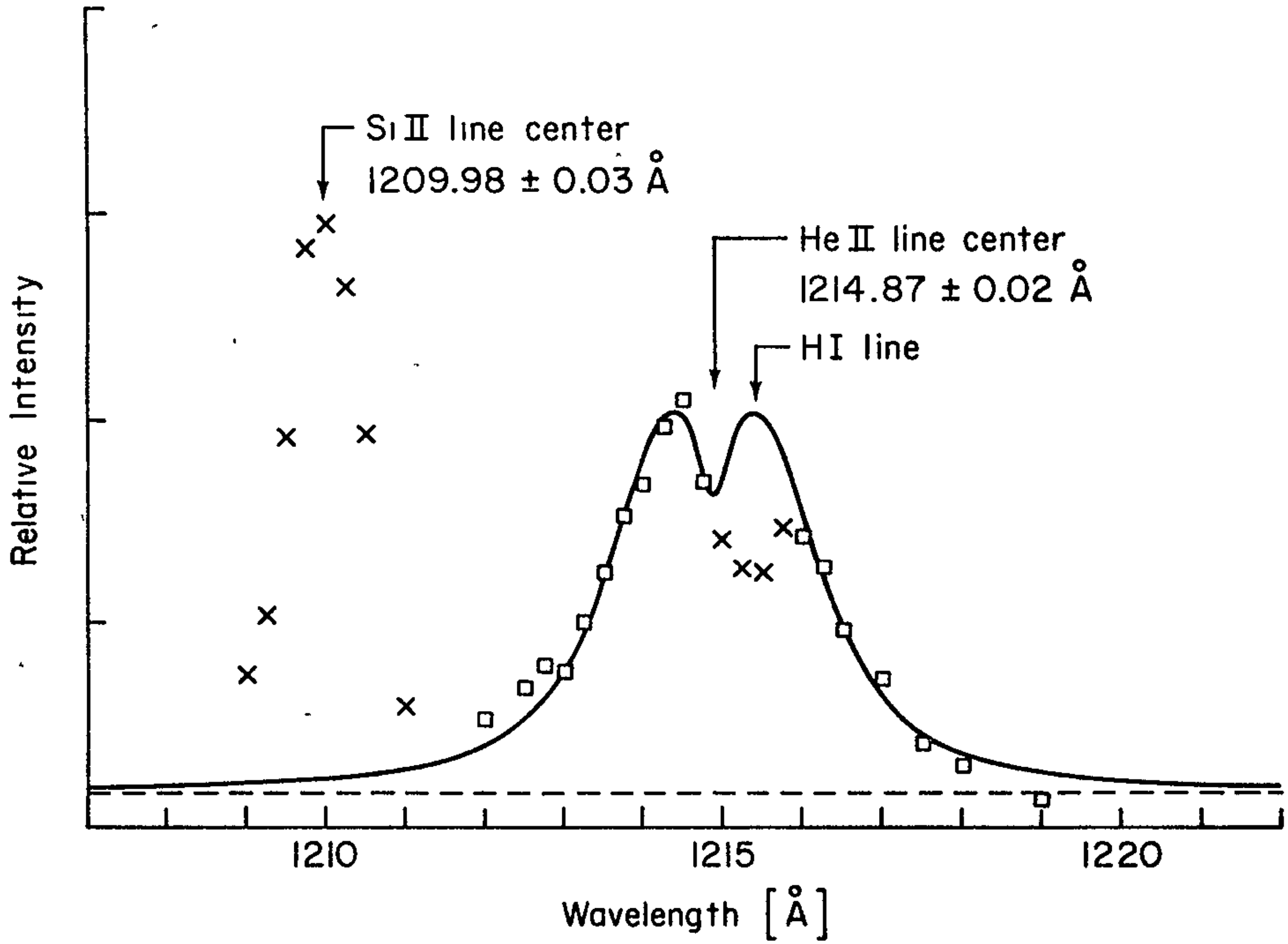


Fig. 4-3 Measured and best-fit profile for He II λ 1215 line

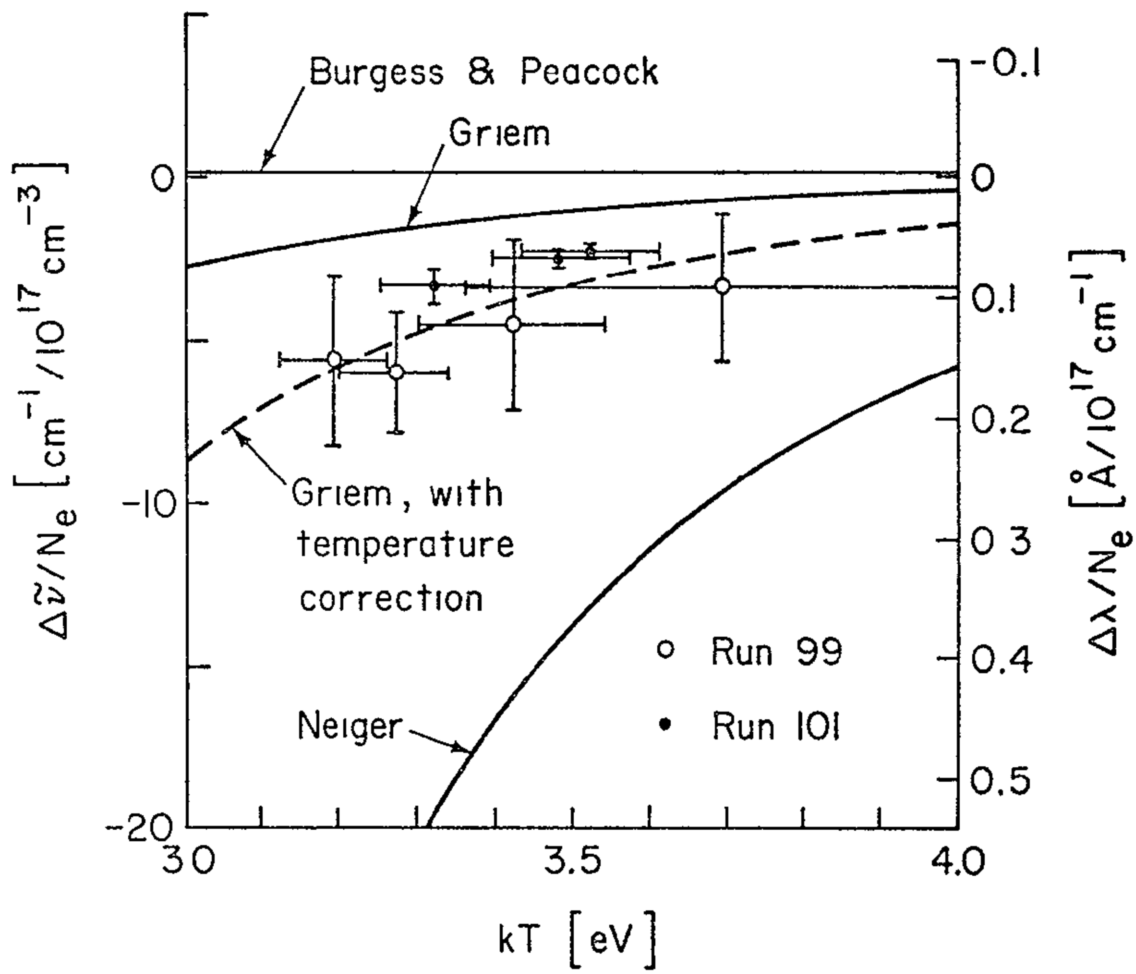


Fig. 4-4 Estimated and measured shifts of He II λ 1640 Å line

	t [μsec]	$V_{monitor}$ [mV]	κT [eV]	N_e [$10^{17}cm^{-3}$]	λ_{Al} [Å]	λ_{He} [Å]	Δλ [Å]	$\Delta\lambda/N_e$ [Å/$10^{17}cm^{-3}$]
unshifted					1670.80	1640.33		
Run 101	3.938	28.6	3.52±.09	1.83±.05	1669.53±.01	1639.17±.01	.11±.01	.060±.005
	4.028	24.3	3.48±.09	1.67±.05	1669.54±.01	1639.18±.01	.11±.01	.066±.006
	4.104	20.6	3.32±.07	1.35±.05	1669.54±.02	1639.19±.01	.12±.02	.089±.015
Run 99	3.912	54.3	3.69±.33	1.42±.04	1670.32±.08	1639.98±.02	.13±.08	.09±.06
	4.004	46.1	3.42±.12	1.20±.03	1670.30±.08	1639.97±.02	.14±.08	.12±.07
	4.089	39.2	3.27±.07	1.02±.03	1670.31±.05	1640.00±.02	.16±.05	.16±.05
	4.146	33.3	3.19±.07	.94±.03	1670.32±.07	1639.99±.02	.14±.07	.15±.07

Table 4-1 Plasma Conditions, Shifts of HeII λ 1640 Å

These data are shown in Fig. 4-5 and Table 4-2.

B. Discussion of Possible Errors

B.1 Impurity Lines. Photographs of spectra near each of the helium lines showed many Si, O, and Al lines. The Jarrell-Ash 1/2-m monochromator could easily resolve the Si III and O II lines near He II 4686, and photoelectric scans were made using points between these impurity lines (see Fig. 4-6).

A survey spectrum was taken near the 1640 line using Kodak SWR film in the camera attachment for the McPherson 225 vacuum monochromator (see Fig. 4-7). Many Si, O, and Al lines were identified, in both first and second orders. Fortunately, none of these obscured the 1640 line. The nearby Al II 1670 line, chosen as the wavelength standard for position measurements of the 1640 line, was partially obscured by second order lines of O II and O III. Photographs using an MgF_2 filter were then taken, which showed no further problems with impurity lines. To eliminate second order lines during photoelectric scans, the filter was placed between the exit slit and the scintillating disc

A photographic spectrum near 1215 Å showed many O II, O III, O IV Si III, and Si IV lines, including the second order O IV 608 line on the red wing of the helium line (see Fig 4-8) To eliminate these, the MgF_2 filter was again used for both photographic and photoelectric runs.

The resonance lines of N II at 1084 Å prevented any observation of the next member of the He series, while the He II 1025 line proved too weak for reliable observation.

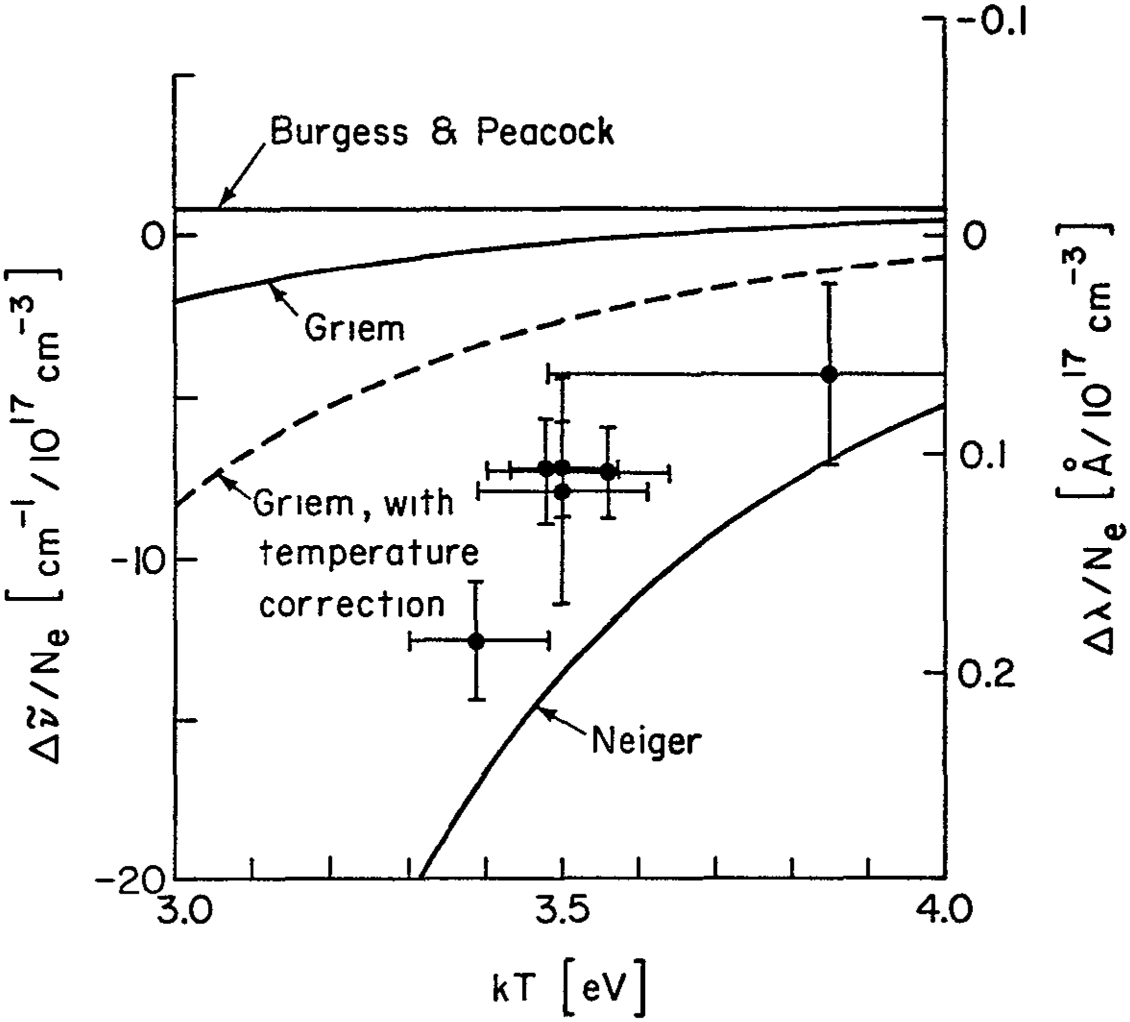


Fig. 4-5 Estimated and measured shifts of He II λ 1215 Å line

t [μsec]	κT [eV]	$\lambda^{exp}_{HHW,\ 4686}$ [Å]	N_e [$10^{17} cm^{-3}$]	$\lambda^{theory}_{HHW,\ 1215}$ [Å]	$\lambda^{exp}_{HHW,\ 1215}$ [Å]	$\frac{\lambda^{exp}_{HHW,\ 1215}}{\lambda^{theory}_{HHW,\ 1215}}$	Δλ [Å]	$\Delta\lambda/N_e$ [$A/10^{17} cm^{-3}$]
3.864	2.23±.07	4.61±.12	2.23± 07	1.97±.05	2.06±.09	1.05±.05	.14±.09	.063±.041
3.948	1.93±.05	4 09±.09	1.93±.05	1.75±.03	1.96±.06	1.12±.04	.21±.04	.109±.021
4 040	1.77±.05	3.80±.09	1.77±.05	1.63±.03	1.95±.05	1.20±.04	.19±.04	.107±.023
4.122	1.66±.05	3.60±.09	1.66± 05	1.54±.04	1.88±.06	1.22±.05	.18±.04	.108±.024
4.191	1.62±.06	3.53±.11	1.62±.06	1.51±.05	1.88±.06	1.25±.06	.19±.04	.117±.052
4.245	1.46±.07	3.24±.13	1.46±.07	1.38±.06	1.82±.05	1.32±.07	.27±.04	.185±.027

Table 4-2 Plasma Conditions, Shifts and Widths of HeII λ 1215 Å

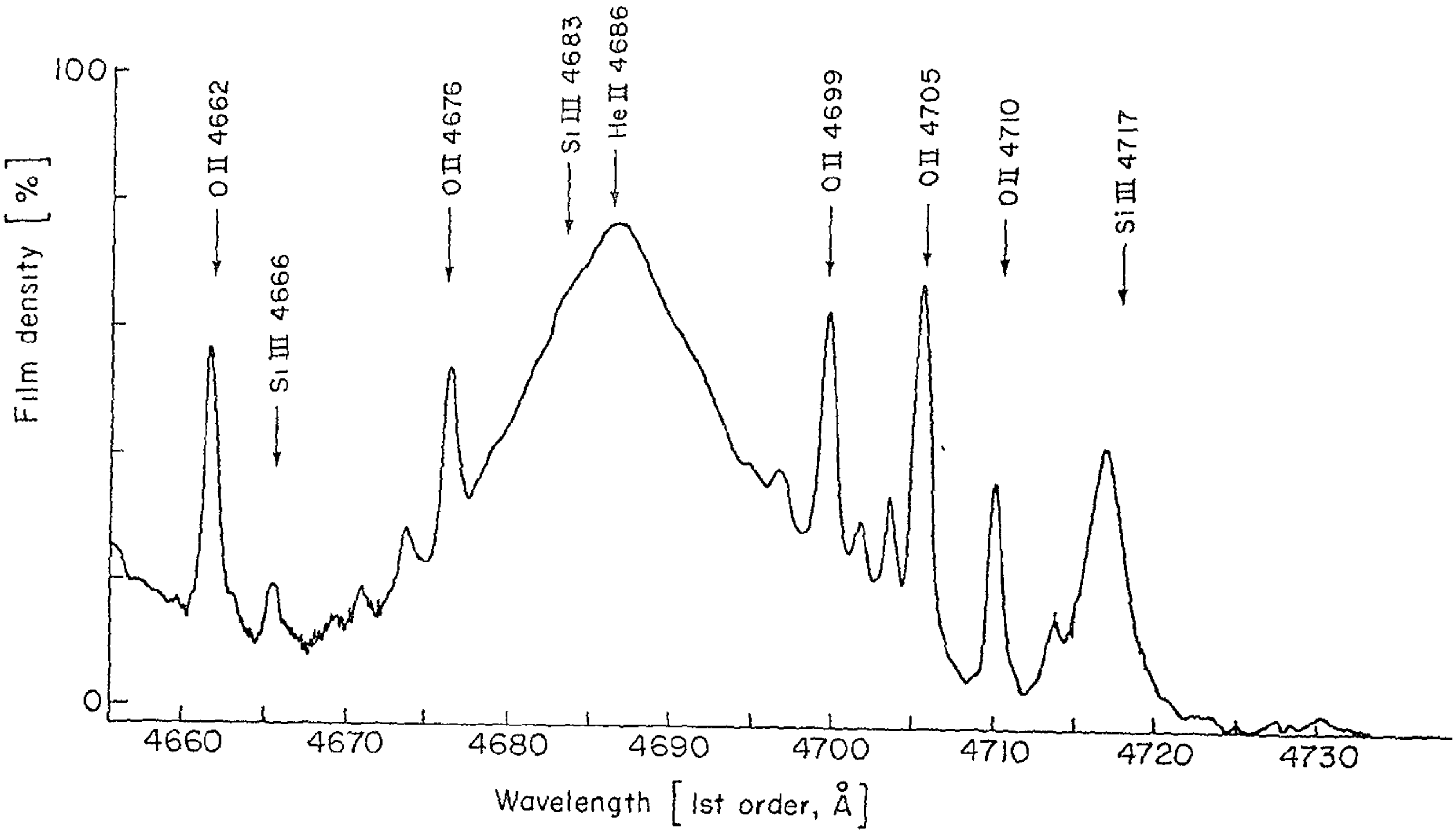


Fig. 4-6 Densitometer scan of spectrum near He II λ 4686 Å line

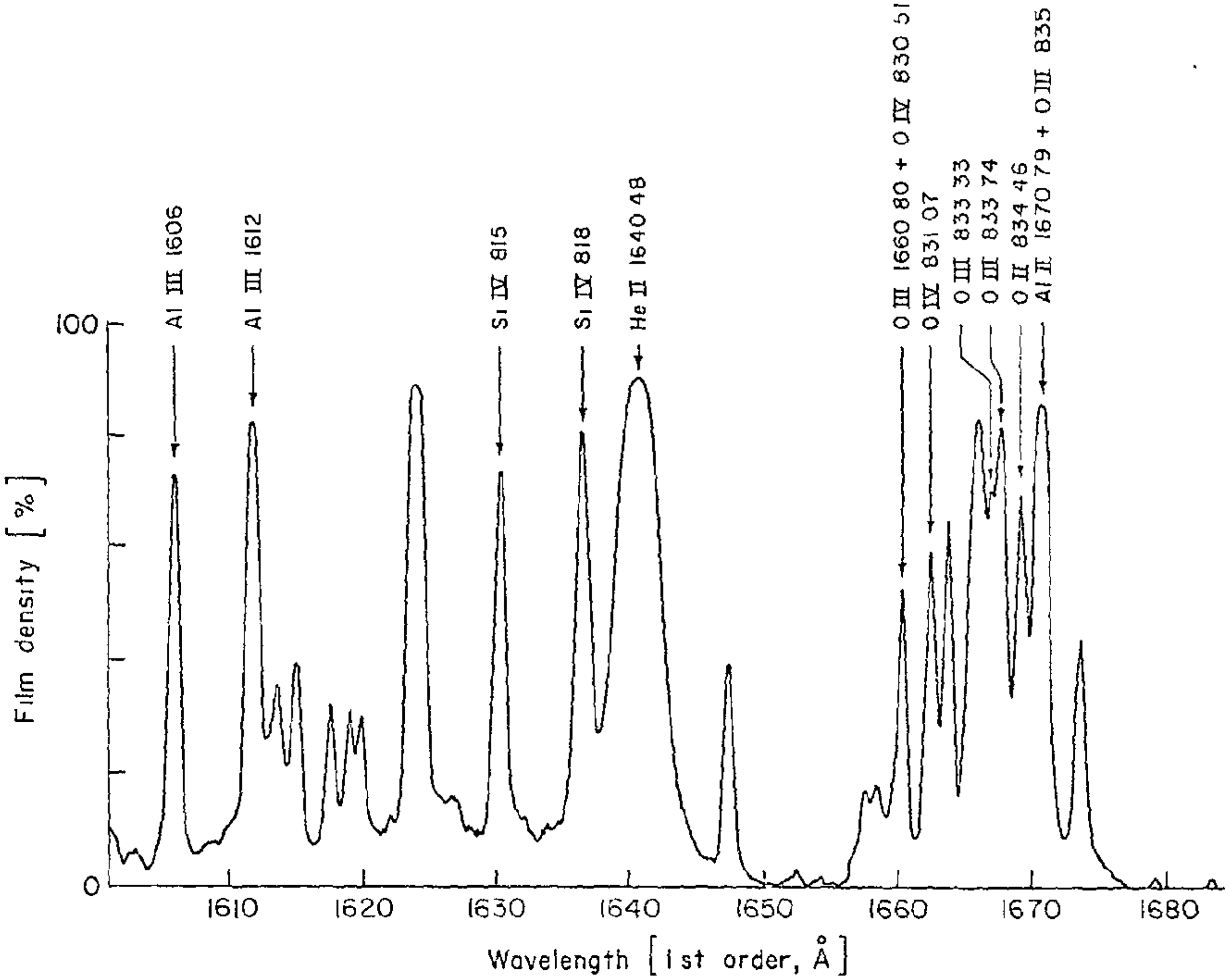


Fig. 4-7 Densitometer scan of spectrum near He II λ 1640 Å line

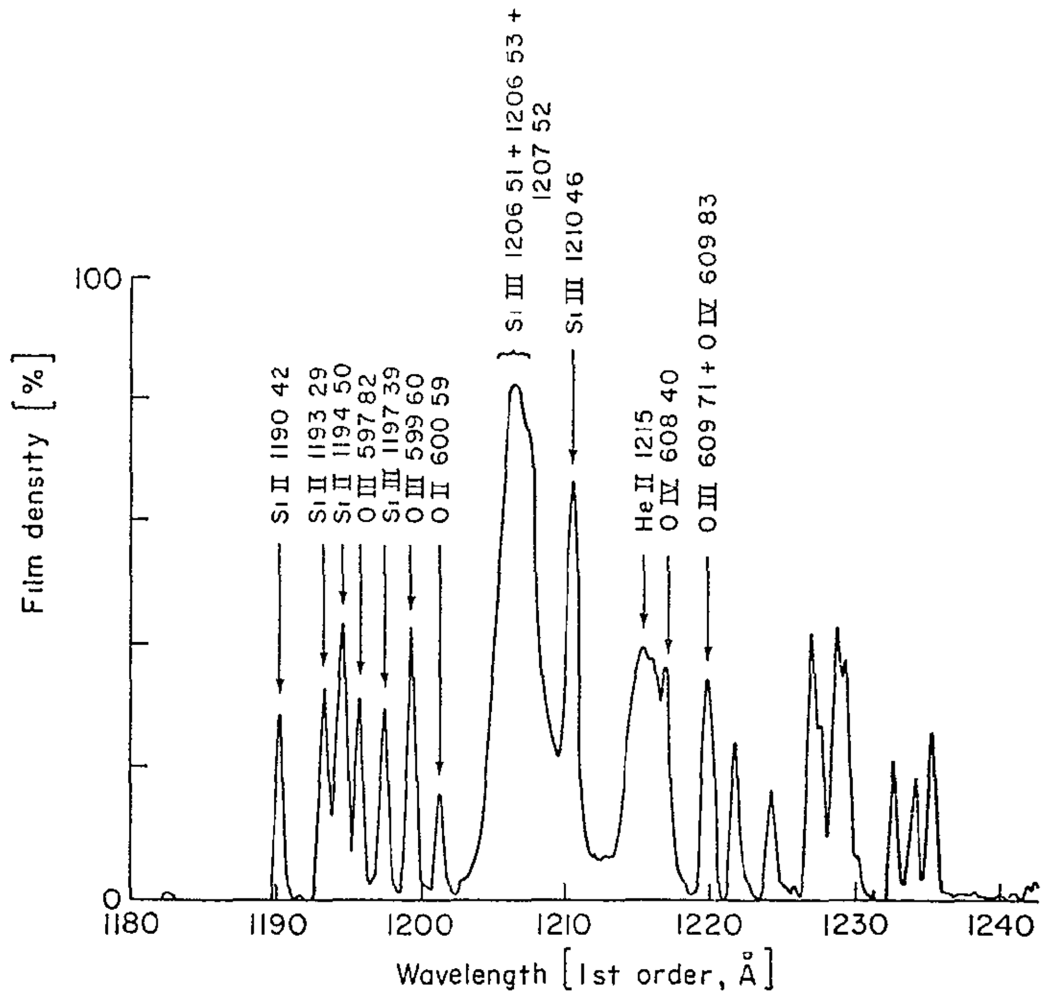


Fig. 4-8 Densitometer scan of spectrum near He II λ 1215 Å line

B.2 Wavelength Standards. All line position measurements were made relative to nearby impurity lines, and the accuracy of this procedure had to be verified. The Stark shifts of these ion lines are expected to be small[42] (just as their widths are small), but a plasma polarization shift certainly cannot be ruled out *a priori*. To check for such shifts, several line position measurements were made on a Grant comparator-microphotometer. The second-order lines were found to be shifted with respect to the first-order lines by .10 Å, but otherwise, shifts were less than the measurement accuracy of .05 Å. This is consistent with previous measurements,[3] in which no shifts were found for the O III and N III lines near 300 Å. In photoelectric (time-resolved) studies, no absolute shifts of the reference lines were measured as the plasma cooled, also arguing against substantial absolute shifts. Only the statistical errors in the measured shifts are indicated in the tables and figures

The monochromator wavelength scale was checked by measuring photographically the wavelength displacement between settings corresponding to the centers of the helium and reference lines. The errors in both cases were less than the setting error of 0.02 Å

B.3 He II 1215 Asymmetry. The helium 1215 line was expected to have a symmetric, double-peak profile (like that of H_β), but photoelectric scans showed only the peak on the blue side (see Fig 4-3). This was interpreted as showing reabsorption by hydrogen in a cooler boundary layer, since the hydrogen Lyman-α line lies .50 Å to the red of the (unshifted) helium line center. To check this explanation, two scans were made, using mixtures of helium plus 0 5% hydrogen, and helium plus 1.0% deuterium, respectively. The amount of absorption increased with the increasing admixture of hydrogen, and, in the case of the deuterium, the dip shifted to the blue, as expected

The residual concentration of hydrogen was estimated from these runs to be approximately 0.2% Since natural, Doppler, and Stark broadening are all very small for the hydrogen line (<.1 Å), points near the dip were merely excluded from the fitting procedure.

B.4 Departure from LTE. Temperature determination from a helium ion line:continuum ratio requires that LTE holds also for the ion ground state populations, so that the line intensity (proportional to the population in the excited state) and the continuum intensity (due mainly to recombination radiation) both have their equilibrium values. The equilibration time for atomic states can be estimated from (2-42) to be only a few nanoseconds, for both neutral and ionized helium On the other hand, the recombination times (into the ground states) are estimated to be[43,44] 2 μsec for formation of singly ionized helium and 20 μsec for neutral helium Singly and doubly ionized states are, then, expected to be overpopulated, simulating a temperature higher than the true electron temperature.

For the validity of complete LTE in a stationary plasma with temperatures near those in the experiment, Eq. (2-11) gives an optical depth of ∿150, for the resonance line (He II λ304 Å). We are thus justified in relaxing (2-40) by an order of magnitude, and the electron density required for complete LTE is $N_e \sim 1.4\times10^{18}\,cm^{-3}$, which is not reached in the experiment. On the other hand, the requirement (2-39) for partial LTE for the level n=4 (upper state of the 4686 Å line) is easily satisfied.

Since the actual electron density is about an order of magnitude lower than that required for complete LTE, and the continuum intensity is proportional to the electron density while the line intensity is not, we estimate that the line:continuum ratio may be too high by an order of magnitude, compared with the LTE value at the true temperature. This yields[41] a temperature (∿3.5 eV) that is too high by about .5 eV. Similarly, if the neutral excited state population density were too low by an order of magnitude, the intensity ratio of an ionized and a neutral line would overestimate the temperature by about .5 eV. A measurement of the intensity ratio of the He II 4686 and the He I 3889 lines was performed, yielding temperatures near 4.1 eV. Since the two effects (overpopulation of singly ionized states due to recombination relaxation during the rapid cooling, and overpopulation of excited states of He II due to low collision rates) are additive, the true electron temperature is estimated to be less than the lower figure by ∿20%, i.e., near 3.0 eV.

A previous measurement[38] of the absolute intensity of the He II 4686 line in a shock-tube plasma at $N_e \gtrsim 10^{17} cm^{-3}$ indicated the populations of the lower excited states of the ion deviate by perhaps a factor of 4 from LTE. However, measurements of temperature in the same experiment by Thompson scattering of laser light (which does not depend on LTE for atomic states) and the intensity ratios of the He II 4686 and He I 5876 lines showed good agreement.

B.5 Summary of Errors. Possible errors in the determination of electron density were judged to be 5% due to statistical fluctuations and 10-15% due to theoretical uncertainties.[10] Errors in temperature measurements were estimated to be .1 eV statistical and .2 eV theoretical (after applying the 20% correction). These possible diagnostic errors were not judged to endanger the principal conclusions of the work. The tables and figures indicate only statistical errors.

Errors in the measurements of the shifts were .05 Å or less due to statistical fluctuations. Systematic errors due to the shift of the reference lines could not be ruled out, but were shown to be less than .05 Å and are expected to be smaller.

C. Discussion of Results

As mentioned in the Introduction (Chapter I), previous shift measurements of He ion lines have concentrated on the Lyman-series lines ($n_{lower}=1$). In principle, these measurements can be used to calculate the energy level perturbations, and the shifts of the "Balmer"-series lines can be found in turn. Since the agreement between the various measurements is so poor, little is learned in this way

The polarization shift is difficult to treat theoretically, and only estimates have been made thus far. Conceptually, the radiating ion is expected to attract plasma electrons, which partially screen the nuclear charge seen by the optical electron. A simple classical argument[3] gives the wavelength (or wavenumber) shifts of the Lyman-series lines to be

$$\frac{\Delta\lambda}{\lambda_0} = -\frac{\Delta\tilde{\nu}}{\tilde{\nu}} = -\frac{8}{3}\pi\frac{N_e a_0^3 n^2(n^2+1)}{z^4}\exp(\frac{V}{\kappa T}) ,$$

where a_0 is the radius of the first Bohr orbit: $a_0 = \hbar^2/me^2$, and V is the interaction energy between the perturbing plasma electron and the radiating ion. Since the wave packet of the perturbing electron will be comparable in size to the atom, Griem proposes[1] to use the averaged interaction $V=e^2/r$, where r is the characteristic distance between the nucleus and the optical electron. $r=n^2a_0/z$. Neiger proposes[6] the modified formula $V=(3/2)e^2/r$, which is the electrostatic energy of a uniform sphere of charge e and radius r in the field of an equal but opposite charge at its center. Burgess and Peacock argue[45] that the density of electrons near an ion is low enough that their velocities are not in equilibrium with the surrounding plasma, being directly related to their electrostatic energies. They suggest using the interaction energy at the average perturber-perturber distance, $V=e^2N_e^{1/3}$. Note that all these estimates predict blue shifts (for the Lyman-series lines) proportional to N_e, but decreasing with temperature (since, at high temperature, the electron's thermal energy is large compared with the electron-ion interaction energy, and it doesn't see the potential well) Denoting by V_n the chosen interaction energy when the optical electron has principal quantum number n, and expressing the unperturbed energy levels in term of the Rydberg constant R, we find, for the wavenumber shifts of the "Balmer"-series lines,

$$\Delta\tilde{\nu} = \frac{8}{3}\pi\frac{N_e a_0^3}{z^2} R \left\{(n^4-1)\exp\left(\frac{V_n}{\kappa T}\right) - (2^4-1)\exp\left(\frac{V_2}{\kappa T}\right)\right\} .$$

This can be converted to a wavelength shift by multiplying with λ_0^2, or an energy shift by multiplying by hc. Shifts predicted by each of these choices for V (ze^2/n^2a_0, $3/2\ ze^2/n^2a_0$, and $e^2N_e^{1/3}$) are plotted in Figs. 4-4 and 4-5. For both lines, Burgess and Peacock predict very small blue shifts, nearly independent of temperature. Griem's estimate gives somewhat larger shifts, while the stronger interaction proposed by Neiger gives large shifts with strong temperature dependence. Using the measured values of the temperature, the data are consistent with an interaction energy between those of Griem and Neiger, while Burgess and Peacock underestimate the shifts To illustrate the effect of the systematic error discussed above in the temperature measurement, the shift predicted by Griem's formula was recalculated using a 20% lower temperature, the results being shown as the dashed curve in Figs. 4-4 and 4-5. After this correction, his interaction energy gives the best fit to the data.

The halfwidth of the 1215 Å line was up to 30% greater than that calculated by Kepple.[9,10] This is to be compared to a previous theta-pinch experiment,[46] in which the ratio of the widths of the 4686 and 1215 Å lines agreed with the calculated value. However, this experiment was done at a substantially higher temperature, $T_e \gtrsim 10$ eV, so that the difference may not be significant.

D. Conclusions and Suggestions

Shifts have been measured of the first two lines of the "Balmer" series of ionized helium. They are consistent with a plasma polarization shift, where the interaction energy between the radiating ion and the plasma electrons is between those proposed by Griem and Neiger and probably closer to the former.

The Stark width of the 1215 Å line of ionized helium has been measured, and found to be up to 30% greater than calculated by Kepple,[9,10] and increasing as the temperature and density of the plasma decreased at the end of the discharge. This is perhaps due to an increased interference by the 1215 Å line of hydrogen.

Further studies of the plasma polarization shift might include more careful measurements of shifts of the hydrogenic spectra of heavier atoms, e.g., C VI 33.8 Å. Previous measurements[39] showed no shifts, but with a possible error of .05 Å. (In this connection, it is interesting to note that measured center wavelengths[47], e.g., of helium-like copper (Cu XXVIII) are slightly below theoretically predicted values.) An attempt might also be made to observe shifts of the higher "Balmer"-series members of ionized helium, perhaps in a Z-pinch or θ-pinch, with their greater optical depth.

APPENDIX A

WAVEFORM RECORDER

To reduce the error and delay of manual data taking with the usual Polaroid oscillographs, a waveform recorder was designed and built for this experiment (Fig. A-1). The signal from one of the PM tubes is amplified and applied simultaneously to 31 comparators. A voltage divider provides reference voltages for the comparators, so for a given signal voltage some of the comparators will be "on" and the rest "off". Integrated circuits accept the output of all the comparators, count the number "on", calculate the corresponding 5-bit binary number, and store it in a 5 bit by 64 word random access memory. When triggered, control circuits advance the memory address counter and give write commands once every 100 nanoseconds (or selectable, slower rates) for a total of 64 cycles. It then switches to "playback" mode, supplying the stored numbers, each in turn, to a digital-to-analog converter. This analog signal is a reconstructed version of the original signal, and can be displayed on an oscilloscope.

The recorder consists of five such analog-to-digital converters and memories, plus two digital-to-analog converters, so 5 signals can be recorded, then any two displayed simultaneously.

If the waveform is acceptable, the investigator may set the twelve "fixed data" thumbwheel switches and initiate recording. The shot number (incremented each time the device is triggered), the fixed data, and the contents of all 5 digital memories are written to a 9-track magnetic tape for later computer processing. The waveform recorder then

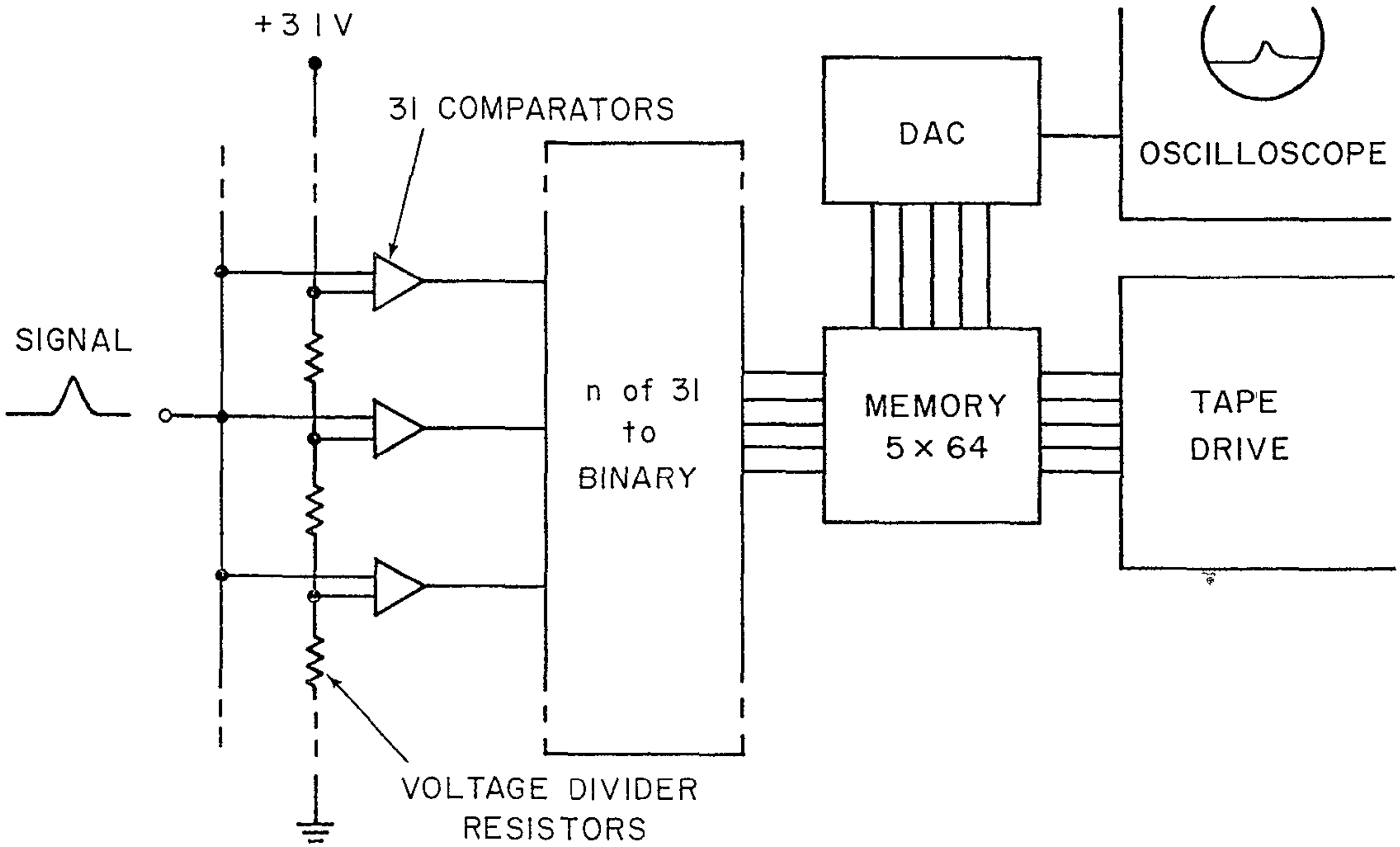


Fig. A-1 Block diagram of waveform recorder reverts to "ready" mode, waiting for the next trigger pulse If the shot was unacceptable (due to switch misfire or abnormal time history of a monitor signal, for example), recording can be bypassed.

Details on operation procedures and performance specifications of the waveform recorder appear in the following instruction sheet.

Digital Data Acquisition System
Instruction Manual

1. General Information

The Digital Data Acquisition System (DDAS) is a high speed analog to digital converter and memory. It can record 64 data samples on each of 5 channels, with a sample interval as short as 100 nsec. These stored samples can be displayed on an oscilloscope and recorded onto a 9-track magnetic tape.

2. Technical Specifications

sample rate, once every	.1, .2, .5, 1., 2., 5., 10, or 20 μsec.
internal amplifier risetime	80 nsec
useful signal range	0 to + 32 V
maximum signal range	-1 to +1 V.
resolution	3.1% of full scale
channels	5
signal input impedance	50 Ω
trigger level	+1.1 V
max trigger signal range	-.6 to +5 V.
trigger input impedance	1MΩ
playback sweep output	22.7 Hz sawtooth, 0-2.6 V
analog output	0-5 V
enabling circuit	enabled if external circuit resistance is less than 100 Ω
mating input amplifier	Tektronix type 127 preamp power supply, with matching Tektronix oscilloscope preamp.
mating digital tape deck	Cipher model 70M-360, producing 800 BPI, 9-track, IBM-compatible magnetic tapes.
magnetic tape record	329 bytes of 8 bits each... 6 bytes (BCD, 2 digits/byte) fixed data from thumbwheel switches 3 bytes (BCD, 4 low order bits) experiment count 320 bytes (binary, 5 low order bits) data, grouped by time

3. Installation

For optimum protection against radio frequency interference, the unit should be mounted in a shielded 19 in. relay rack Several inches clearance below the unit are necessary for ventilation.

4. Operation

The Cipher tape deck should never be switched on unless the DDAS is on, so the proper logic inputs are provided.

1. Turn on the DDAS and associated preamplifiers. Allow preamps to warm up
2. If a tape is desired, turn the tape deck on and load a tape The "RECORDER READY" lamp should light.
3. Switch the operating mode to "AUTO SEQUENCE", switch to "TRIGGER ENABLE INT", and press "RECORD BYPASS" The "ENABLED" lamp should light
4. Switch "DISPLAY CHANNEL SELECT" to "1". The "A-D DISPLAY" lamps are now displaying, in binary digital form, the signal on channel 1.
5. Ground the channel 1 preamp input. Advance the preamp "vertical position" control until all display lamps are lit. If this cannot be done, adjust the 127 preamp power supply "DC level" (on top of case).
6. Back off the "vertical position" control until all lamps just go out. The zero level is now adjusted Repeat steps 4-6 for the remaining channels now, and frequently during the experiment
7. Connect the trigger and signal cables If an "enable" circuit cable is to be used, connect it and switch to "TRIGGER ENABLE EXT" Set the desired sampling interval. When triggered (by a signal or by using the "MAN TRIGGER" button) the unit will record its 64 samples of each channel and increment the "EXPERIMENT COUNT".
8. If a visual monitor is desired, connect the "PLAYBACK SWEEP" to the "EXT HORIZ IN" jack of an oscilloscope, and one or both of the "ANALOG OUTPUT"'s to the vertical amplifier inputs. Set "ANALOG CHAN SELECT" to the desired channels.
9. When a signal is recorded, the unit will automatically switch to playback mode, the corresponding mode lamp will light, and the stored waveforms will be displayed on the oscilloscope.

10. If a recording is desired, set the desired "FIXED DATA", and press "RECORD DATA". Otherwise, press "RECORD BYPASS". The unit is again ready to record a set of signals The unit may be switched to "MAN PLAYBACK" to again display the recorded signals
11. After experiment has been completed, press "EOF" several times, and rewind and unload the tape
12. Turn the tape deck off, then the DDAS and other equipment.

Alternate operating modes are provided for diagnostic purposes. In "SINGLE STEP PLAYBACK" mode, the contents of one word in memory, corresponding to the "DISPLAY CHANNEL SELECT" setting and the octal address shown under "MEMORY ADDRESS", are displayed under "MEMORY DISPLAY" and appear at the "ANALOG OUTPUT" jacks. The associated pushbutton steps to the next sample.

In "MAN SAMPLE" mode, the unit stores samples one at a time, when the "SAMPLE STROBE" pushbutton is pressed. The unit must be enabled and triggered before sampling can begin.

In "CAL" mode, the analog to digital converters operate continuously and any of them can be displayed on the "A-D DISPLAY" lamps.

APPENDIX B

STATISTICS

In most experiments the investigator assumes a functional form governing his data which has several parameters, and the object of his experiment is to determine the values of the parameters. If there is only one parameter, the quoted result might be

$$\alpha = a^* \pm \sigma \ ,$$

where α is the true value (usually unknown), a^* is the "best" value which can be determined using the data, and σ indicates the error in a^*. We usually mean by σ the mean square deviation of the data from the best value

$$\sigma^2 = \overline{(x_i - a^*)^2} \ , \qquad \text{(B-1)}$$

where the x_i are the results from several similar experiments. It is necessary to extend this to the case of several parameters and specify a way of calculating the quoted values.

Assume the functional form is

$$y = f(\underset{\sim}{a}, x) \ , \qquad \text{(B-2)}$$

where x is the independent variable, y the dependent variable, and the a_i are parameters We define the error function[48]

$$M(\underset{\sim}{a}) = \sum_{k=1}^{n} \frac{(y_k - f(\underset{\sim}{a}, x_k))^2}{\sigma(x_k)^2} \ , \qquad \text{(B-3)}$$

and let the "best" $\underset{\sim}{a}$ be that value $\underset{\sim}{a}^*$ which minimizes M We find it by solving the set of m equations

$$\left.\frac{\partial M(\underset{\sim}{a})}{\partial a_i}\right|_{\underset{\sim}{a}=\underset{\sim}{a}^*} = 0 \qquad \text{(B-4)}$$

The errors in these parameters are given by the elements of the variance-covariance matrix[48]

$$\sigma_{ij} = \overline{(a_i - a_i^*)(a_j - a_j^*)} \ , \qquad \text{(B-5)}$$

which can be calculated from[48]

$$\sigma_{ij} = (H^{-1})_{ij} \qquad H_{ij} = \frac{1}{2}\,\frac{\partial^2 M(\underset{\sim}{a})}{\partial a_i \partial a_j} \ . \qquad \text{(B-6)}$$

The variance of one of the parameters is then $\sigma_i^2 = \sigma_{ii}$, and the correlation matrix is[49]

$$C_{ij} = \frac{\sigma_{ij}}{\sigma_i \sigma_j} \qquad \text{(B-7)}$$

If all the $\sigma(x_k)$ have a common value σ, the solution of (B.4) is independent of that value. After this least square solution is found, σ can be calculated using

$$\sigma^2 = \frac{1}{n-m} \sum_{k=1}^{n} [y_k - f(\underset{\sim}{a}^*; x_k)]^2 \ , \qquad \text{(B-8)}$$

where we divide by n-m because after the parameters $a_1 \ldots a_m$ have been calculated from the data, only n-m degrees of freedom remain.

If $f(\underset{\sim}{a};x)$ is linear in its parameters, the calculations are, of course, much simpler, since (B-4) is then a linear system which can be solved exactly. Failing this, a search must be performed in $\underset{\sim}{a}$ space for the best value.

APPENDIX C

PROGRAMS

The data read from the waveform recorder tapes are processed by several programs, each accepting an input file plus control or data cards, and producing one or more output files The last programs, PROFILE, VPLOT, and THEORY, also print their results. Other programs are available to read and list each file for debugging. All mainline programs were written in FORTRAN for use on a Univac 1108 computer with the EXEC-8 operating system. Intermediate files are "direct-access" files on disc or drum storage, like those developed by IBM for their computers,[50] but not defined within ANS FORTRAN. Other nonstandard features used include PARAMETER statements and FORTRAN procedures.[51]

The first program, REVERT, uses the assembly-language subroutine TREAD to read the 9-track tape produced by the waveform recorder. The tape record format is shown in Fig. C-1 REVERT assumes the scale settings of the input amplifiers and the sample rate of the recorder were set on the "fixed data" thumbwheel switches. The alphanumeric file header (a prose description of the run), number of channels used, and wavelength for each channel and shot number are read from cards. The file header is written into the output file, copied by later programs, and identifies all printed output. Specified shots may be dropped at this point.

Since the waveform recorder stores 6.4 μsec of the signal, while the plasma lasts only about one μsec, REVERT tries to select only the useful part of each signal. The first twelve records are read, the average time T_{max} of the maximum of the monitor signal is found, and the tape is rewound. Each record is then read, and the data for eight samples, starting at time T_{max}, are scaled and written to the output file, with format shown in Fig. C-2. An end-of-file marker is written after the last record.

During the experiment, the light is sometimes attenuated to prevent PM tube saturation, and PARAM corrects the measured intensities to account for this. Since PROFILE requires that the monitor signal be strictly decreasing, PARAM also chooses a decreasing portion of each signal and discards the rest. The output record format is shown in Fig. C-3.

BSORT sorts the records, first on wavelength, then on shot number. Experimental points can be taken in any order, but in this step all data for a given wavelength are collected. The format of the records is unchanged by BSORT.

PROFILE unfolds the data, recorded as intensity as a function of time at different wavelengths, into intensity as a function of wavelength (a line profile) at different times. Since the ionized helium line intensities are sensitive to temperature, all data for one profile must be taken under the same plasma conditions. PROFILE does this by taking all the data for equal monitor signal (from the total intensity of the He II 4686 line). The time at which the monitor signal decays to this level is found, and the shot is discarded if this time is further than 1.73 standard deviations from the mean. Similarly, any intensities at a given wavelength which differ from the mean by more than 1.8 standard deviations are discarded. Profiles are then found for successively lower monitor intensities (therefore later times). The means and standard deviations of intensities at each wavelength go to one file (shown in Fig. C-4), which VPLOT uses to make a printer-plot of the line profile. All undeleted data points are written to a second file (shown in Fig. C-5), used for fitting.

The actual least-squares fit is done by THEORY. As described in the section on data reduction, the convolution of the theoretical line profile with the instrument response function is done first, in alpha space, using an assumed electron density. The instrument function is assumed Gaussian, so the convolution integrals are done using the Gaussian-Hermite 3-point quadrature formula.[52] This profile is fit to the experimental data and a new electron density is found. The convolution and fit are repeated until the electron density converges, usually within four iterations. Each of these fits requires a search for the values of the four parameters (line intensity I, background intensity B, line center λ_0, and electron density N_e (line width)) that minimize the mean square deviation σ^2 of the fitting function from the experimental points. The subroutine ZXPOWL, from the International Mathematical and Statistical Library (IMSL)[53] uses the function-minimization algorithm described by Zangwill[54,55] to find the best-fit values of λ_0 and N_e. For each trial values of λ_0 and N_e, it calls the subroutine FUNCT3, which in turn calls other subroutines to calculate the best values of the two linear parameters, and the corresponding σ^2, using standard methods.

When the best values of all four parameters are found, subroutine FUNCT2 finds the second derivative matrix of σ^2 numerically, inverts it, and normalizes it to get the standard deviations and correlation matrix of the best-fit parameters. If the line is He II 4686, it uses the line:continuum ratio to calculate the plasma temperature Subroutine TPLOT plots the average of the experimental points at each wavelength, the best-fit theoretical profile, and the background level. The entire procedure is repeated for each profile, but since the line center and electron density are carried over each time, subsequent fits converge rapidly.

6 bytes	3 bytes	320 bytes
FIXED	COUNT	DATA

FIXED	6 bytes BCD, 2 characters/byte	data from thumbwheel switches
COUNT	3 bytes BCD, 1 character/byte	shot number
DATA	320 bytes binary number, 1/byte	data, grouped by time

total. 329 8-bit bytes/record (excluding parity and check bits)

Fig. C-1 Record format of waveform recorder tape

2 words	1 word	1 word	16 words
LABEL	SCALE	COUNT	T_1 Y_1 T_2 Y_2 ... T_8 Y_8

LABEL	2 words, FIELDATA	First 5 characters are the wavelength in Å (decimal point assumed before last character). Next 3 characters are the shot number
SCALE	1 word, real (R)	Amplification on preamplifier (V/div)
COUNT	1 word, integer	Shot number (same as above).
T_i	1 word, R	Time of sample (μsec. after trigger pulse)
Y_i	1 word, R	Signal amplitude (V)

total: 20 words/ record

Fig. C-2 Format of data record written by REVERT

2 words	1 word	1 word	1 word	8 words	8 words
LABEL	SCALE	COUNT	POINTS	$T_1T_2...T_8$	$Y_1Y_2...Y_8$

LABEL, SCALE, COUNT, T_i, Y_i as before

POINTS 1 word, integer Number of data points (always 8)

total. 21 words/record

Fig. C-3 Format of data record written by PARAM or BSORT

1 word	36 words	36 words	36 words
MONITOR	WAVELENGTH	AVERAGE	SIGMA

MONITOR	1 word, R	Intensity of monitor for this profile
WAVELENGTH	36 words, R	Wavelengths (Å)
AVERAGE	36 words, R	Average of signal intensities at corresponding wavelength .
SIGMA	36 words, R	Standard deviation of signal intensities

total: 109 words/record

Fig. C-4 Format of plot-file data record written by PROFILE

1 word	55 words	36 words	36 words	28 × 36 = 1008 words
MONITOR	BLOCK	NUMBER	WAVELENGTH	INTENSITY

MONITOR	1 word, R	Intensity of monitor signal for this profile
BLOCK	54 words, integer	(currently not used)
NUMBER	36 words, R	number of shots at this wavelength
WAVELENGTH	36 words, R	Wavelengths
INTENSITY	1008 words, R	INTENSITY (I,J) is the signal for the Jth shot at wavelength WAVELENGTH(I)

total: 1135 words/record

Fig C-5 Format of fit-file data record written by PROFILE.

A Note on Program Documentation

A code is used to describe the parameters of some subroutines. For example, in TIM,

INT   R,I   Given intensity ,

the R indicates INT is real (single precision floating point) and the I means it's used only for input (i.e., the subroutine doesn't change its value). Possible parameter modes are:

F   single precision floating point

DP   double precision floating point

I   integer

S   statement number, for alternate return

L   logical

C   complex,

and possible uses are:

I   input only (unchanged)

O   output only (changed, contains useful information)

IO   input and output

W   work area (changed, not meaningful on return).

Programs Listed

REVERT

TREAD*, OPT*

PARAM

BSORT

STORES, START, SADD, SDROP, HADD, HDROP, ADDTO,

FINDTO, EPUSH, EPOP

PROFILE

TIM, INTENS, LOOKUP, YESNO*

VPLOT

THEORY

DBANK, GROUP, FETCHS, FUNCT3, FUNCT2, TPLOT,

AXISN**, NEWS, NEWT, NEWU, SIGMA, SYMSLV**, VALUE**

*Programs in UNIVAC Assembly Language.

**These programs may be of general interest

****** REVERT ******

```
205373JIM*WORKSPACE$(1).REVERT
      C
      C       NAME...
      C               REVERT
      C
      C       PURPOSE...
      C               TO ACCEPT A TAPE PRODUCED BY THE DIGITAL DATA ACQUISITION
      C               SYSTEM AND PRODUCE A FILE ACCEPTABLE TO PROGRAM 'PARAM'.
      C
      C       USAGE...
      C               @XQT REVERT          (NOT Q.REVERT)
      C               <DATA CARDS>
      C
      C               OPTIONS:
      C               'L'     PRINTS INFORMATION FROM DATA CARDS AND FIXED DATA
      C                       FROM TAPE RECORDS (THUMBWHEEL SWITCHES)
      C               'N'     IGNORES IMPROPER SCALE OR INTERVAL FROM TAPE
      C                       RECORD HEADER...NO MESSAGES
      C               'R'     OMIT INITIAL REWIND (DEFAULT: REWIND TAPE BEFORE
      C                       READING)
      C
      C       INPUT...
      C               DATA TAPE WITH NAME 'INTAPE', PRODUCED BY THE DIGITAL DATA
      C               ACQUISITION SYSTEM
      C               DATA FROM THUMBWHEEL SWITCHES IS INTERPRETED AS FOLLOWS'
      C               DIGITS 1-5...SCALE (V/DIV) FOR CHANNELS 1-5
      C               DIGIT 6...SAMPLE INTERVAL (MICROSEC)
      C                       SETTING    0      1    2    3    4    5    6    7    8    9
      C                       MEANING ILLEGAL .005 .01 .02 .05 .1   .2   .5   1.   2.
      C                       .005 .LE. SCALE .LE. 2.
      C                       .05 .LE. INTERVAL .LE. 2.
      C                       INTERVAL SPECIFIED ON CARD 3 SUPERCEDES DIGIT 6.
      C                       A WARNING IS PRINTED IF INTERVAL ISN'T .1 MICROSEC.
      C
      C               THE FOLLOWING DATA CARDS:
      C               CARDS 1 AND 2...
      C                       (72A1/72A1) ALPHANUMERIC FILE HEADER IMAGES
      C               CARD 3...
      C                       (I5)    NUMBER OF CHANNELS BEING USED
      C                       (F5.0)  SAMPLE INTERVAL IN MICROSECONDS
      C                       (I5)    MONITOR SIGNAL CHANNEL (IF BLANK, THE PROGRAM
      C                               USES THE FIRST CHANNEL WITH BLANKS IN THE
      C                               WAVELENGTH SPECIFICATION COLUMNS OF CARD 4.)
      C                       (I5)    STARTING SAMPLE NUMBER (IF BLANK, THE PROGRAM
      C                               READS THE FIRST 12 RECORDS AND USES THE
      C                               AVERAGE OF THE MAXIMA OF THE MONITOR.)
      C               CARDS 4-N       (SORTED BY SHOT #, INCREASING)
      C                       (I5)    FIRST SHOT NUMBER OF A GROUP OF SHOTS WITH
      C                               THIS SET OF WAVELENGTH SETTINGS.
      C                       (5F5.1) WAVELENGTHS IN ANGSTROMS FOR EACH CHANNEL
      C                               BLANK FIELD INDICATES A MONITOR CHANNEL
      C               CARD N+1...
      C                       '@EOF ' IN FIRST FIVE COLUMNS
      C               CARDS N+2 - M
      C                       (I5)    SHOT NUMBER WITH INCORRECT SCALE #
      C                       (5F5.4) NEW SCALE #'S (BLANKS FOR CORRECT ONES)
      C               CARD M+1...
```

****** REVERT ******

```
C                 'QEOF ' IN FIRST FIVE COLUMNS
C
C      OUTPUT...
C            IN FILE 10, A FORTRAN RANDOM-ACCESS FILE ACCEPTABLE
C            TO PROGRAM 'PARAM'
C
C      DATA RECORD FORMAT: LABEL(2),SCALE,NSHOT,T1,Y1,T2,Y2 ... T8,Y8
C      TOTAL: 20 WORDS
C
C      SUBPROGRAMS REQUIRED...
C
C            BEGIN
C            OPT
C            TREAD
C
       PARAMETER POINTS=8
       PARAMETER MPTS=50
       PARAMETER MBAD=15
       PARAMETER MCHAN=4
       PARAMETER MRCD=1000
       PARAMETER NWORDS=5+POINTS+POINTS
       INTEGER HEADER,CARD
       LOGICAL WARNED,SGIVEN
       LOGICAL OPT,QUIET,LONG
       DIMENSION SCALE(9),HEADER(12),WAVEL(MPTS,MCHAN),RECORD(NWORDS),
      -     IREC(NWORDS),KSHOT(MPTS),W(MCHAN),LSHOT(MBAD),
      -     GOOD(MBAD,MCHAN)
       DATA SCALE/.005,.01,.02,.05,.1,.2,.5,1.,2./
       DATA NERR/0/
       EQUIVALENCE (RECORD(1),IREC(1)),(HEADER(1),RECORD(1))
       DATA   JPTS, NFILE,  ENDREC,   NRD,  CARD, WARNED, SGIVEN
      -   /      1,    10,'QEOF  ',     9,     5,.FALSE.,.FALSE./
       DATA NXCHAN, NXPTS, NXRCD, NXBAD
      -     / MCHAN,  MPTS,  MRCD,  MBAD/
       COMMON NSHOT,NUM(12),ISIG(5,64)
       CALL BEGIN('REVERT 1.23 W')
       QUIET=OPT('N')
       LONG=OPT('L')
       IF(.NOT.OPT('P'))CALL REWIND
       DEFINE FILE NFILE(MRCD,NWORDS,U,NREC)
       NREC=1
C
C                 TRANSFER HEADER INFORMATION
       DO 10 I=1,2
       READ(CARD,810,END=106)HEADER
   810 FORMAT(12A6)
       IF(LONG)PRINT 812,HEADER
   812 FORMAT(1X,12A6)
    10 WRITE(NFILE'NREC)HEADER
C
C                 WE ALWAYS ENTER THE MAXIMUM NUMBER OF DATA POINTS
       IREC(5)=POINTS
C
C                 READ NUMBER OF CHANNELS IN USE, SAMPLE INTERVAL,
C                 MONITOR CHANNEL #, AND STARTING CHANNEL #
       READ(CARD,820,END=106)NCHAN,SAMPLE,MONIT,KTIME
   820 FORMAT(I5,F5.0,2I5)
```

ORIGINAL PAGE IS
OF POOR QUALITY

****** REVERT ******

```
      IF(NCHAN.GT.MCHAN .OR. NCHAN.LE.0)GO TO 108
      IF(SAMPLE.EQ.0.)GO TO 12
      IF(SAMPLE.LT..05 .OR. SAMPLE.GT.2.)GO TO 110
      SGIVEN=.TRUE.
   12 IF(MONIT.LT.0 .OR. MONIT.GT.NCHAN)GO TO 112
   15 IF(KTIME.LT.0 .OR. KTIME.GT.57)GO TO 114
   18 IF(LONG)PRINT 815,NCHAN,SAMPLE,MONIT,KTIME
  815 FORMAT(1X//1X,I2,' CHANNELS USED,',F6.2,' USEC SAMPLE INTERVAL'/
     -      '  CHANNEL',I2,' IS MONITOR,   STARTING CHANNEL IS',I4)
C
C                     READ WAVELENGTHS FOR EACH SHOT NUMBER
      IF(LONG.AND. .NOT.OPT('Y'))PRINT 825
  825 FORMAT(1X//'  SHOT #    WAVELENGTHS'/)
      DO 23 NPTS=1,MPTS
      READ(CARD,830,END=25)KSHOT(NPTS),(WAVEL(NPTS,M),M=1,NCHAN)
  830 FORMAT(I5,5A5)
      DO 20 M=1,NCHAN
   20 DECODE(832,WAVEL(NPTS,M))W(M)
  832 FORMAT(F5.1)
   23 IF(LONG.AND. .NOT.OPT('Y'))PRINT 835,KSHOT(NPTS),(W(M),M=1,NCHAN)
  835 FORMAT(1X,I5,2X,5F9.2)
      GO TO 116
   25 KSHOT(NPTS)=10000
      NPTS=NPTS-1
      DO 28 NBAD=1,MBAD
      READ(CARD,836,END=30)LSHOT(NBAD),(GOOD(NBAD,M),M=1,NCHAN)
  836 FORMAT(I5,5F5.4)
   28 CONTINUE
      GO TO 117
   30 LSHOT(NBAD)=10000
      NBAD=NBAD-1
      IF(MONIT.NE.0)GO TO 40
C
C                     WE WEREN'T TOLD THE MONITOR CHANNEL #...
C                     FIGURE IT OUT (BLANKS IN THE WAVELENGTH FIELD)
      DO 35 MONIT=1,NCHAN
      IF(WAVEL(1,MONIT).EQ.'     ')GO TO 40
   35 CONTINUE
C
C                     THERE'S STILL NO MONITOR CHANNEL SPECIFIED...
C                     USE CHANNEL 1
      PRINT 901
  901 FORMAT(' NO MONITOR SPECIFIED...USING CHAN. 1')
      MONIT=1
   40 IF(KTIME.NE.0)GO TO 58
C
C                     WE WEREN'T TOLD WHICH TIME TO START WITH...
C                     FIND AVERAGE TIME FOR PEAK OF MONITOR SIGNAL
C                     AMONG FIRST 12 RECORDS
      DO 47 L=1,12
      CALL TREAD(NSHOT,KEOF)
      IF(KEOF.NE.0)GO TO 118
      MAX=ISIG(MONIT,1)
      I=1
      DO 45 K=2,64
      IF(ISIG(MONIT,K).LE.MAX)GO TO 45
      I=K
```

****** REVERT ******

```
      MAX=ISIG(ADNIT,K)
   45 CONTINUE
   47 KTIME=KTIME+1
      KTIME=MINO(57,KTIME/12)
      CALL REWIND
      IF(OPT('Z'))STOP
   58 INREC=0
      MSHOT=0
      IF(LONG)PRINT 838
  838 FORMAT(1X//'  RECORD   SHOT #     FIXED DATA'/)
      DO 82 L=1,NRCD
C
C                        READ A RECORD
      CALL TREAD(NSHOT,KEOF)
      IF(KEOF.NE.0)GO TO 85
      MSHOT=MSHOT+1
      IF(LONG)PRINT 840,MSHOT,NSHOT,NUM
  840 FORMAT(1X,I4,I9,6X,5I2,2X,I2,2X,6I2)
      INREC=INREC+1
C
C                        FIND THE WAVELENGTH INFO FOR THIS SHOT NUMBER
      IF(NSHOT.LT.KSHOT(JPTS))JPTS=1
      ISTOP=NPTS-JPTS+1
      DO 62 I=1,ISTOP
      IF(NSHOT.LT.KSHOT(JPTS+1))GO TO 63
   62 JPTS=JPTS+1
   63 CONTINUE
      DO 82 M=1,NCHAN
C
C                        LOAD DATA FROM ONE CHANNEL INTO A RECORD
C
C                        DISCARD DATA IF DESIRED
      IF(WAVEL(JPTS,M).EQ.'9999 '.OR.WAVEL(JPTS,M).EQ.'99999')GO TO 82
C
C                        PICK UP SCALE # FROM RECORD HEADER
      IS=NUM(M)
      IF(OPT('U'))IS=NUM(M-1)
      IF(IS.GT.0 .AND. IS.LT.9)GO TO 65
      IF(.NOT.QUIET)PRINT 902,INREC,NSHOT,M,IS
      NERR=NERR+1
  902 FORMAT(' TAPE RECORD',I4,', SHOT',I5,',CHANNEL',I2,
     -      '...SCALE # OUT OF RANGE:',I5/
     -      ' USING .005 V/DIV')
      IS=1
   65 K=KTIME
C
C                        SUBSTITUTE CORRECT AMPLIFICATION IF NEEDED
      AMPLFY=SCALE(IS)
   66 IF(LSHOT(JBAD).EQ.10000)GO TO 68
      IF(NSHOT.LT.LSHOT(JBAD))JBAD=1
      IF(NSHOT.LT.LSHOT(JBAD+1))GO TO 67
      JBAD=JBAD+1
      GO TO 66
   67 IF(NSHOT.EQ.LSHOT(JBAD) .AND. GOOD(JBAD,M).NE.0.0)
     -      AMPLFY=GOOD(JBAD,M)
   68 IF(SGIVEN)GO TO 71
C
```

****** REVLPT ******

```
C                       PICK UP SAMPLE INTERVAL FROM RECORD HEADER
          IT=NUM(6)
          IF(IT.GT.3 .AND. IT.LE.9) GO TO 70
          NERR=NERR+1
          IF(.NOT.QUIET)PRINT 903,INREC,NSHOT,IT
   903 FORMAT(' TAPE RECORD',I4,', SHOT',I5,
      -      '...SAMPLE INTERVAL # OUT OF RANGE:',I5/
      -      ' USING .1 MICROSEC')
          IT=2
    70 SAMPLE=SCALE(IT)
C
C                       GIVE ONE WARNING IF INTERVAL ISN'T .1 US
    71 IF(SAMPLE.EQ..1 .OR. WARNED)GO TO 72
          NERR=NERR+1
          WARNED=.TRUE.
          PRINT 904,INREC,NSHOT,SAMPLE
   904 FORMAT(' TAPE RECORD',I4,' SHOT',I5,'...SAMPLE INTERVAL LOW',
      -      F5.2,' MICROSECONDS')
C
C                       TRANSFER DATA POINTS
    72 TIME=K*SAMPLE
          DO 75 KK=7,NWORDS,2
          RECORD(KK-1)=TIME
C
C                       WE MAKE A CORRECTION OF A FACTOR OF 10 BECAUSE
C                       THERE ARE TWO EXTRA AMPLIFIERS IN THE DATA SYSTEM
          RECORD(KK)=.1*ISIG(M,K)*AMPLFY
          K=K+1
    75 TIME=TIME+SAMPLE
C
C                       SET UP OUTPUT RECORD HEADER
          ENCODE(850,IREC)WAVEL(JPTS,M),NSHOT
   850 FORMAT(A5,I3)
          RECORD(3)=AMPLFY
          IREC(4)=NSHOT
          WRITE(NFILE'NREC)RECORD
    82 CONTINUE
          GO TO 124
C
C                       END OF FILE...QUITTING TIME
    85 PRINT 860,NSHOT,NREC
   860 FORMAT(1X,I6,' SHOTS PROCESSED'/1X,I6,' RECORDS WRITTEN')
          IF(NERR.GT.0)PRINT 905,NERR
   905 FORMAT(1X,I6,' ERRORS OR WARNINGS')
          GO TO 199
C
C                       COMPLAIN
   106 PRINT 906
   906 FORMAT(' HEADER CARDS ARE MISSING')
          GO TO 199
   108 PRINT 908,ICHAN,MCHAN
   908 FORMAT(' NUMBER OF CHANNELS,',I5,', IS OUT OF RANGE 1 TO',I2)
          GO TO 199
   110 PRINT 910,SAMPLE
   910 FORMAT(' SAMPLE INTERVAL OF',G15.5,' IS BAD'/
      -      ' USING TAPE RECORD HEADERS')
          GO TO 12
```

****** REVERT ******

```
      112 PRINT 912,MONIT
      912 FORMAT(' GIVEN MONITOR CHANNEL #,',I5,', IS BAD')
          MONIT=0
          GO TO 15
      114 PRINT 914,KTIME
      914 FORMAT(' GIVEN STARTING CHANNEL #,',I5,', IS BAD')
          KTIME=0
          GO TO 13
      116 PRINT 916,NMPTS
      916 FORMAT(' THERE ARE MORE THAN',I3,' WAVELENGTH CARDS')
          GO TO 199
      117 PRINT 917,NNBAD
      917 FORMAT(' THERE ARE MORE THAN',I3,' CORRECTION CARDS')
          GO TO 199
      118 PRINT 918
      918 FORMAT(' FEWER THAN 12 SIGNALS ARE PRESENT')
          GO TO 199
      124 PRINT 924,NMPCO
      924 FORMAT(' MORE THAN',I5,' TAPE RECORDS...QUITTING')
C
C                      CLOSE OUTPUT FILE
      199 WRITE(NFILE'NREC)ENDREC
          STOP
          END
```

@WORK.EJCT

ORIGINAL PAGE IS
OF POOR QUALITY

****** REVERT (Sample data) ******

```
@XQT,L .REVERT
HE DATA OF WED 19 NOV 75...PRESSURE=185'=.50T=2.7V, REFLECTOR =.8
SCANS OF HE II 1640 AND 4686, AL II 1670 ... MGF2 FILTER  RUN 101
    3
   93277 4671
   13327754679
   273278 4681
   33327854683
   393279 4684
   46327954685
   533280 4686
   59328054687
   693281 4688
   763305 4689
   849999 9999
   93333854692
   96333854690
  1013339 4692
  10833395 4695
  1163340 4724
  12233405 4730
@EOF
   76 .005
   77 .005
   78 .005
   79 .005
@EOF
@XQT,A .PARAM
.151, 3276., 3292.
.294, 4670., 4696.
@EOF
```

Long printout is wanted. (L option on @XQT,L .REVERT)

3 channels were used. (3)

First shot number at these wavelengths (33)

Channel 1 set at 3280.0 Å (line 53: 3280)

Channel 2 set at 4688.0 Å (line 69: 4688)

Discard data for channel 2, shots 84-92. (line 84: 9999)

Channel 3 is for monitor signal. (line 101)

Shot 76 had wrong amplifier setting recorded (76)

Channel 1 amplification was .005 V/div (line 78: .005)

Channel 2 amplification was correctly recorded (line 79)

Some signals were attenuated (A option on @XQT,A .PARAM)

Attenuation factor was .151 . (.151)

Signals for 4670 Å through 4696 Å were attenuated (4670., 4696.)

****** REVERT (TREAD) ******

```
205373JIM*WORKSPACE$(1).TREAD
       .
       .      NAME...
       .             DATATAPE
       .
       .      PURPOSE...
       .             TO READ THE HIGH SPEED DATA ACQUISITION SYSTEM TAPE.
       .
       .      CALLING SEQUENCE...
       .
       .             CALL TREAD (BUFFER,EOF)
       .
       .             BUFFER 333 WORD DATA INPUT BUFFER, INTEGER
       .                    BUFFER(1) IS THE EXPERIMENT COUNT
       .                    BUFFER(2-13) ARE MISC FIXED DATA
       .                    BUFFER(14-333) ARE DATA POINTS, DIMENSIONED (5,64)
       .             EOF    END OF FILE MARKER, SET NON-ZERO IF EOF
       .                    WAS DETECTED WHEN THIS READ WAS ATTEMPTED,
       .                    ZERO OTHERWISE.
       .
       .             ONE TAPE RECORD IS READ AND UNPACKED INTO THE USER'S BUFFER
       .
       .             CALL REWIND
       .
       .             THE DATA TAPE IS REWOUND.
       .
       .      INPUT...
       .             TAPE RECORD FORMAT IS:
       .             6 BYTES (BCD, 2/BYTE) FIXED DATA
       .             3 BYTES (BCD) EXPERIMENT COUNT
       .             320 BYTES (BINARY) DATA, GROUPED BY TIME
       .
       $(1)      AXR$.
       .
       .         MAIN ENTRY POINT
       .
       TREAD*    LA     A0,END.          ARE WE AT THE END OF THE FILE?
                 JNZ    A0,3,X11.        IF SO RETURN AT ONCE
       ANOTHER   LA,U   A0,PKTT.
                 ER     IOW$.            FETCH A BUFFER FULL
                 LA     A0,PKTT+3.       PICK UP STATUS AND CHECK.
                 TE     A0,STATUS.       SHOULD HAVE AN AFC OF 5
                 J      EOF.
       OKAY      SX     X1,SAVEX.
                 LXM    X1,0,X11.        X1 WILL POINT TO THE NEXT WORD IN THE
                 LXI,U  X1,1.            USER'S BUFFER ALL THROUGH THE PROGRAM
        .
        .        PICK UP EXPT COUNT
        .
                 LA     A0,INBUF+1.  .
                 AND,U  A0,017.          WIPE OUT EXTRANEOUS STUFF
                 LA     A2,A1.
                 SSL    A0,8.
                 AND,U  A0,017.
                 MSI,U  A1,10.
                 AA     A2,A1.
                 SSL    A0,8.
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
                     ******  REVERT (THEND)  ******
                AND,U A0,017.
                MSI,U A1,100.
                AA    A2,A1.            EXPT COUNT IS IN A2
                SA    A2,0,*X1.         STORE EXPT COUNT IN BUFFER
        .
        .       PICK UP MISC DATA
        .
                DL    A0,INBUF.         SIX BYTES OF TWO CHARACTERS/BYTE
                LR,U  R2,5.
                DSC   A0,4.             BACK UP ONE DIGIT
        LOOP1   LDSC  A0,12.            MOVE FORWARD 3 DIGITS, PUT IN A1(3-0)
                AND,U A1,017.           MOVE LAST DIGIT TO A2(3-0)
                SA    A2,0,*X1.         STORE DIGIT
                DSC   A0,4.             MOVE BACK 1 DIGIT
                AND,U A1,017.           PUT ONE DIGIT INTO A2(3-0)
                SA    A2,0,*X1.         STORE BCD DIGIT
                JGD   R2,LOOP1.         DECREMENT COUNTER
        .
        .       GET REAL DATA
        .
                SX    X2,SAVEX+1.       X2 POINTS TO NEXT PAIR
                LX    X2,(2,INBUF+2)    OF WORDS IN INPUT BUFFER
                LR,U  R2,34.            MOVE 35 PAIRS OF WORDS (315 BYTES)
        LOOP3   DL    A0,0,*X2.         PICK UP TWO PACKED WORDS
                LR,U  R1,8.             NINE BYTES AT A SHOT
        LOOP2   LDSC  A0,8.
                AND,U A1,0377.          TRANSFER ONE BYTE TO A2(7-0)
                SA    A2,0,*X1.
                JGD   R1,LOOP2.         SHIFT UNTIL DOUBLE WORD IS FINISHED
                JGD   R2,LOOP3.         FINISH 35 WORD PAIRS
                DL    A0,0,X2.          PICK UP LAST TWO WORDS
                LR,U  R1,4.             PROCESS ONLY 5 BYTES
        LOOP4   LDSC  A0,8.
                AND,U A1,0377.          TRANSFER ONE BYTE TO A2(7-0)
                SA    A2,0,*X1.
                JGD   R1,LOOP4.         FINISH THE LAST 5 BYTES
                SZ    *1,X11.           CLEAR EOF FLAG
        RETURN  LX    X1,SAVEX.
                LX    X2,SAVEX+1.
                J     3,X11.
        .
        .       END OF FILE OR TAPE ERROR
        .
        EOF     LA,S1 A0,PKTT+3.        TEST FIRST FOR EOF
                TE,U  A0,01.            01 MEANS END OF FILE.
                J     B0.
                SA    A0,END.           NOTE THAT EOF REACHED
                SA    A0,*1,X11.        TELL CALLING PROGRAM ABOUT EOF.
                J     RETURN.
        B0      LA,H2 A0,PKTT+3.     .  TEST FOR WRONG RECORD LENGTH
                TNE,U A0,74.
                J     B1.
                SLJ   PRINT.            LENGTH WRONG...PRINT STATUS
                ER    ABORT$.           AND QUIT.
        B1      LA,S1 A0,PKTT+3.        GET I/O COMPLETION STATUS CODE AGAIN.
                TNE,U A0,00.            00 MEANS NORMAL COMPLETION. (MUST BE
                J     OKAY.             COPIED TAPE, SINCE FRAME CT IS NORMAL)
```

****** REVERT (THEAD) ******

```
                TE,U  A0,04.             04 MEANS ABNORMAL FRAME COUNT.
                J     B2.
                SLJ   PRINT.             AEC NOT 5, SO WE PRINT STATUS AND
                J     ANOTHER.           GET NEXT RECORD.
        B2      SLJ   PRINT.             SOME OTHER I/O ERROR...PRINT STATUS
                ER    ABORT$.            AND QUIT.
        .
        .       SUBROUTINE FOR PRINTING OUT THE STATUS WORD
        .
        PRINT   +     $-$ .
                LA    A0,PKTT+3.         GET THE STATUS WORD
                LR,U  R2,1.
        E2      SA    A2,INBUF+1.        (USEFUL ONLY ON 2ND ITERATION OF LOOP)
                LR,U  R1,5.
        E1      AND,U A0,07.             MOVE ONE OCTAL DIGIT TO A1(2-0)
                AA,U  A1,060.            CONVERT TO FIELDATA DIGIT
                DSC   A1,6.              MOVE INTO A2(35-30)
                SSL   A0,3.              MOVE NEXT OCTAL DIGIT TO A0(2-0)
                JGD   R1,E1.
                JGD   R2,E2.
                SA    A2,INBUF.
                LA    A0,(0104,INBUF-2).
                ER    PRINT$.
                J     *PRINT.
        .
        .       REWIND ENTRY POINT
        .
        REWIND* L,U   A0,RWD.
                ER    IOW$.              REWIND THE TAPE
                LA,S1 A0,RWD+3.          CHECK FOR BAD STATUS
                TNZ   A0.
                J     RE2.
                SLJ   PRINT.             STATUS BAD...PRINT THE STATUS
                ER    ABORT$.            AND QUIT
        RE2     SZ    END.               NOTE WE AREN'T AT AN END OF FILE NOW
                J     1,X11.
        .
        .       STORAGE AREA
        .
        $(0),SAVEX RES 2.
        PKTT    I$OT  'INTAPE',R$ 74,INBUF.
                +     'I/O STATUS  ' .
        INBUF   RES   74.
        STATUS  +042005000112.
        END     +     0 .                SET NONZERO WHEN EOF FOUND
        RWD     I$OT  'INTAPE',REW$.
                END

@.EJCT
```

ORIGINAL PAGE IS
OF POOR QUALITY

****** REVERT (OPT) ******

```
2053/301P*WORKSPACE$(1).OPT
.       NAME...
.
.             OPT
.
.       PURPOSE...
.
.             TO OBTAIN FOR THE USER PROGRAM THE OPTIONS SPECIFIED ON
.             THE EXECUTING STATEMENT.
.
.       CALLING SEQUENCE...
.
.             LOGICAL SWITCH,TEST,OPT
.             .
.             .
.             SWITCH=OPT('U')
.             TEST=OPT('T')
.             .
.             SWITCH WILL HAVE THE VALUE .TRUE. IF THE 'U' OPTION WAS
.             SPECIFIED ON THE @XQT OR @FILE.PROGRAM CARD, AND .FALSE.
.             OTHERWISE. TEST WILL SIMILARLY INDICATE THE PRESENCE OF
.             THE 'T' OPTION.
$(0)       LIT.
$(1)       AXR$.
OPT*       TZ      HAVE    .        GO GET OPTIONS IF WE HAVEN'T ALREADY
           J       GET     .
GO         LA      A1,*0,X11 .
           SSL     A1,30   .
           ANA,U   A1,06   .
           LA      A0,WORD .
           LSSL    A0,10,A1 .       SHIFT CORRECT BIT TO HIGH-ORDER BIT
           SSL     A0,35   .        SHIFT TO LOW-ORDER (RESULT IS 1 OR 0)
           J       2,X11   .        RETURN
GET        SX      X11,WORD .
           ER      OPT$    .        GET OPTION WORD
           LX      X11,WORD .
           SA      A0,WORD .
           SZ      HAVE    .        NOTE OPTION WORD IS PRESENT
           J       GO      .
$(0).
RETURN     RES     1       .
HAVE       +       1       .
WORD       RES     1       .
           END     .
```

@.EJECT

****** PARAM ******

```
205373J1M*WORKSPACE$(1).PARAM
C
C     NAME...
C            PARAM
C
C     PURPOSE...
C            TO CREATE RECORDS WITH STRICTLY DECREASING MONITOR SIGNALS
C
C     USAGE...
C            @.PARAM  OR  @XQT .PARAM
C
C            OPTIONS:
C            A      (@XQT ONLY) AMPLIFY SOME SIGNALS WHICH WERE
C                   ATTENUATED WITH A NEUTRAL DENSITY FILTER
C
C            <WLOW,WHIGH> (FREE) SIGNALS WITH WAVELENGTHS IN THE
C                   RANGE  (WLOW,WHIGH) WILL BE AMPLIFIED BY 1/.294
C
C     INPUT...
C            ACCEPTS FILES CREATED BY PROGRAMS 'RCOVER' OR 'REVERT'.
C
C            RECORDS 1 & 2:
C            (72A1/72A1) FILE HEADER
C
C            RECORDS 3-N:
C                   WORDS 1,2: (F5.1,I3) WAVELENGTH,SHOT #
C                   WORD 3: (R) SCALE, VOLTS/DIV
C                   WORD 4: (I) SHOT #
C                   WORD 5: (I) # POINTS IN THIS RECORD
C                   WORDS 6-13: (R) TIMES (USEC)
C                   WORDS 14-21: (R) SIGNALS (V)
C            RECORD N+1:
C            '@EOF  ' IN FIRST WORD
C
C     OUTPUT...
C            FILE ACCEPTABLE TO PROGRAM 'BSORT'
C
C            RECORDS 1,2:
C            (72A1/72A1) FILE HEADER
C            RECORDS 3-N.
C                   WORDS 1,2: (F5.1,I3) WAVELENGTH,SHOT #
C                   WORD 3: (R) SCALE (V/DIV)
C                   WORD 4: (I) SHOT #
C                   WORDS 5-20: (R) PAIRS OF TIME (USEC), SIGNAL (V)
C            RECORD N+1:
C            '@EOF  ' IN FIRST WORD
C
C     SUBPROGRAMS REQUIRED...
C
C            BEGIN,OPT
C
      PARAMETER MRCD=1000
      INTEGER OUTFIL,OUTREC,TEST,END1
      INTEGER HEAD(20),HIGH,VALLEY,PEAK
      LOGICAL OPT
      DIMENSION A(8),B(8),FACTOR(8),WLOW(8),WHIGH(8)
      EQUIVALENCE (A(1),HEAD(5)),(B(1),HEAD(13))
```

****** PARAM ******

```
      DATA     END1,INFILE,OUTFIL, INREC,OUTREC
     -   /'?EOF  ',    10,    15,     0,     0/
      DIMENSION X(8),Y(8),A(8)
      EQUIVALENCE (X(1),A(1))
      LOGICAL SAME
      CALL BEGIN('PARAM 2.11 @')
      KATTEN=1
      IF(.NOT.OPT('A'))GO TO 5
      PRINT 800
  800 FORMAT(' ENTER ATTEN AND WAVELENGTH RANGE')
      DO 3 KATTEN=1,8
      READ 805,END=5,FACTOR(KATTEN),WLOW(KATTEN),WHIGH(KATTEN)
  805 FORMAT()
      WLOW(KATTEN)=WLOW(KATTEN)-.05
      WHIGH(KATTEN)=WHIGH(KATTEN)+.05
      IF(FACTOR(KATTEN).GT.1.)PRINT 901
  901 FORMAT(' >1?')
    3 CONTINUE
      KATTEN=8
    5 WLOW(KATTEN)=8000.
      WHIGH(KATTEN)=7999.
      DEFINE FILE INFILE(MRCD,21,U,INREC)
      DEFINE FILE OUTFIL(MRCD,20,U,OUTREC)
C
C                   TRANSFER FILE HEADER
      DO 8 J=1,2
      READ(INFILE'J)(HEAD(I),I=1,12)
    8 WRITE(OUTFIL'J)(HEAD(I),I=1,12)
C
C                   READ A RECORD
   10 READ(INFILE'INREC)(HEAD(I),I=1,4),N,(X(I),Y(I),I=1,N)
C
C                   QUIT AT END OF FILE
      IF(HEAD(1).EQ.END1)GO TO 90
      AMPLFY=1.
C                   REMOVE BAD RECORDS & CORRECT AMPLIFICATION
      DECODE(830,HEAD)WAVE
  830 FORMAT(F5.1)
      DO 12 KK=1,KATTEN
      IF(WAVE.LT.WLOW(KK))GO TO 12
      IF(WAVE.LE.WHIGH(KK))GO TO 14
   12 CONTINUE
      GO TO 15
   14 AMPLFY=FACTOR(KK)
C
C                   TRANSFER RECORD TO OUTPUT AREA
   15 N=MIN0(N,8)
      DO 20 I=1,N
      A(N+1-I)=X(I)
   20 B(N+1-I)=Y(I)/AMPLFY
C
C                   SORT POINTS ON TIME
      IF(N.LE.1)GO TO 40
      DO 28 J=N,2,-1
      SAME=.TRUE.
      DO 25 I=2,J
      IF(A(I).GE.A(I-1))GO TO 25
```

****** PARAM ******

```
      S=A(I)
      A(I)=A(I-1)
      A(I-1)=S
      S=B(I)
      B(I)=B(I-1)
      B(I-1)=S
      SAME=.FALSE.
   25 CONTINUE
      IF(SAME)GO TO 30
   28 CONTINUE
C
C                    IF THIS IS A MONITOR SIGNAL, ENSURE IT'S
C                    MONOTONICALLY DECREASING
   30 DECODE(840,HEAD)TEST
  840 FORMAT(A5)
      IF(TEST.EQ.'     ')GO TO 31
      IB=N
      GO TO 44
   31 DROP=0.
      HIGH=1
      VALLEY=1
      PEAK=1
      IB=0
C
C                    FIND A LOCAL MAXIMUM
   32 IB=IB+1
      IF(IB.GT.N)GO TO 36
      IF(B(IB).LE.B(N-ABS(IB+1-N)))GO TO 32
C
C                    NOTE LOCATION OF LOCAL MAXIMUM
      HIGH=IB
C
C                    FIND A LOCAL MINIMUM
   34 IB=IB+1
      IF(IB.GT.N)GO TO 36
      IF(B(IB).GE.B(N-ABS(IB+1-N)))GO TO 34
C
C                    IS THIS DROP BIGGER THAN PREVIOUS BIGGEST?
      IF(B(HIGH)-B(IB).LE.DROP)GO TO 32
C
C                    NOTE THIS IS BIGGEST DROP
      DROP=B(HIGH)-B(IB)
      PEAK=HIGH
      VALLEY=IB
      GO TO 32
   36 IF(B(HIGH)-B(IB-1).LE.DROP)GO TO 38
      PEAK=HIGH
      VALLEY=IB-1
C
C                    HAVE FOUND BIGGEST DROP...GET RID
C                    OF POINTS BEFORE PEAK
   38 IB=0
   40 IB=IB+1
      IF(IB.GE.PEAK)GO TO 42
      A(IB)=A(PEAK)
      B(IB)=B(PEAK)
      GO TO 40
```

****** PARAM ******

```
      C
      C                    GET RID OF POINTS AFTER VALLEY
         42 IB=VALLEY
         44 IB=IB+1
            IF(IB.GT.8)GO TO 45
            A(IB)=A(VALLEY)
            B(IB)=B(VALLEY)
            GO TO 44
      C
      C                    WRITE A RECORD
         45 WRITE(OUTFIL'OUTREC)HEAD
            GO TO 10
      C
      C                    CLOSE THE FILE AND EXIT
         90 WRITE(OUTFIL'OUTREC)END1
            I=INREC-4
            PRINT 890,I
        890 FORMAT(I5,' CURVES PROCESSED')
            STOP
            END
```

@.EJCT

****** BSORT ******

```
205373JIM*WORKSPACES(1).BSORT
      C
      C     NAME...
      C            BSORT
      C
      C     PURPOSE...
      C            TO SORT THE RECORDS, FIRST BY WAVELENGTH, THEN BY SHOT #.
      C
      C     USAGE...
      C
      C            W.BSORT  OR  @XQT .BSORT     (NO OPTIONS)
      C
      C     SUBPROGRAMS CALLED...
      C
      C            BEGIN,START,SADD,SDROP,HADD,HDROP,ADDTO,FINDTO,EPUSH,EPOP
      C
      C     METHOD...
      C            ON A FORWARD PASS, EACH RECORD IS READ. IF IT RANKS HIGH
      C            ENOUGH (HIGHER THAN LEAST ONE CURRENTLY SAVED, IF THE
      C            BUFFERS ARE FULL) IT IS SAVED AND, IF THE BUFFERS ARE FULL,
      C            THE LEAST ONE CURRENTLY SAVED IS WRITTEN IN ITS PLACE. WHEN
      C            THE END OF THE UNSORTED PORTION OF THE FILE IS REACHED, ALL
      C            RECORDS BEING HELD ARE EXCHANGED WITH STORED RECORDS. THE
      C            PROCESS IS REPEATED, IN ALTERNATING DIRECTIONS, UNTIL THE
      C            ENTIRE FILE IS SORTED.
      C
            INCLUDE STORES,LIST
            LOGICAL FOUND
            DATA E1/'@EOF  '/
            DATA NFILE/15/
            CALL BEGIN('BSORT 2.01 Q')
            DEFINE FILE NFILE(1000,20,U,NREC)
            CALL START
            NEXT=2
            FOUND=.FALSE.
            LAST=0
            IREC=2
            INCR=1
            NPASS=0
            NWRITE=0
            NREAD=0
            KNOWN=0
            SURE=.TRUE.
      C                   BEGIN NEW SWEEP
         10 CHANGE=.FALSE.
            NPASS=NPASS+1
      C                   CALCULATE NEW RECORD NUMBER
         12 IREC=IREC+INCR
            IF(IREC.EQ.LAST)GO TO 40
            IF((KNOWN.LE.0).AND.(.NOT.SURE))GO TO 30
            IF(HBASE)15,15,14
         14 IF(IREC.EQ.FROM(HBASE))GO TO 24
      C                   READ NEW RECORD
         15 CONTINUE
            READ(NFILE'IREC)(R(I,BUFFER),I=1,LGH)
            NREAD=NREAD+1
            IF(FOUND)GO TO 20
```

****** ISORT ******

```
      C                    STOP SWEEP IF THIS IS END OF FILE
           IF(R(1,BUFFER).NE.E1)GO TO 20
           FOUND=.TRUE.
           LAST=IREC
           RECRD=IREC-3
           GO TO 40
      C                    ADD THIS RECORD TO SORT STACK
        20 CONTINUE
           FROM(BUFFER)=IREC
           CALL SADD(BUFFER)
           BUFFER=DEMAND($89)
           GO TO 12
      C                    WE ARE HOLDING A RECORD WE WANT TO WRITE HERE...
      C                    DO SO, THEN ADD IT TO THE SORT STACK
        24 CONTINUE
           WRITE(NFILE'IREC)(R(I,HBASE),I=1,LGH)
           NWRITE=NWRITE+1
           CALL SADD(HDROP($89))
           IF(SURE)GO TO 12
           CALL EPUSH(SDROP($89))
           GO TO 12
      C                    THERE'S NOT ENOUGH ROOM TO DO ANY SORTING DURING
      C                    THIS SCAN...BYPASS ALL READING
        30 IF(HBASE.LE.0)GO TO 32
           IREC=FROM(HBASE)
           WRITE(NFILE'IREC)(R(I,HBASE),I=1,LGH)
           NWRITE=NWRITE+1
           CALL EPUSH(HDROP($89))
           GO TO 30
        32 IREC=LAST
      C                    CALCULATE NEW SWEEP LIMITS
        40 CONTINUE
           LAST=NEXT
           NEXT=IREC-INCR*KNOWN
           IF((.NOT.CHANGE).AND.(KNOWN.GT.0))GO TO 88
           KNOWN=0
      C                    RECORD DESTINATIONS OF RECORDS TO BE HELD
           I=SBASE
           NTO=0
        51 IF(I)55,55,52
        52 CONTINUE
           CALL ADDTO(I)
           I=UP(I)
           GO TO 51
      C                    SET POINTERS
        55 CONTINUE
           J=LAST-INCR*NTO
           JTO=NTO
           CALL FINDTO(J)
           INCR=-INCR
           SURE=.TRUE.
           TTOP=STOP
           STOP=0
           SBASE=0
      C                    WRITE SORTED RECORDS IN PROPER ORDER
        58 IF(TTOP)74,74,60
        60 IREC=IREC+INCR
```

****** HSORT ******

```
          IF(IREC.EQ.FROM(TTOP))GO TO 64
       61 IF((TO(JTO)-IREC)*INCR)62,63,68
       62 JTO=JTO-1
          GO TO 61
C                           FILE RECORD THAT WAS HERE IS IN THE SORT
C                           STACK AND CAN BE OVERWRITTEN
       63 CONTINUE
          WRITE(NFILE'IREC)(R(I,TTOP),I=1,LGH)
          NWRITE=NWRITE+1
       64 I=DOWN(TTOP)
          CALL EPUSH(TTOP)
          TTOP=I
          GO TO 58
C                           FILE RECORD THAT WAS HERE MUST BE HELD
C                           AND WRITTEN BACK LATER THIS SWEEP
       68 CONTINUE
          READ(NFILE'IREC)(R(I,BUFFER),I=1,LGH)
          NREAD=NREAD+1
          WRITE(NFILE'IREC)(R(I,TTOP),I=1,LGH)
          NWRITE=NWRITE+1
          CALL HADD(BUFFER)
          I=DOWN(TTOP)
          BUFFER=TTOP
          TTOP=I
          GO TO 58
C                           ASSIGN DESTINATIONS TO THE RECORDS HELD
       74 I=HTOP
          ITO=0
       75 IF(I)82,82,78
       78 ITO=ITO+1
          FROM(I)=TO(ITO)
          I=DOWN(I)
          GO TO 75
C                           GO FOR REST OF THIS SWEEP
       82 CONTINUE
          IF(ABS(LAST-NEXT).GT.1)GO TO 10
C                           SORTING COMPLETE...REPORT & QUIT
       88 CONTINUE
          PRINT 808,RECRD,NPASS,NWRITE,NREAD
      808 FORMAT(I5,' RECORDS SORTED'/
     -       I5,' PASSES'/
     -       I5,' WRITES'/
     -       I5,' READS')
          STOP
       89 PRINT 905,NPASS
      905 FORMAT(' STACKS FOULED UP BY PASS',I4)
          STOP
          END
```

@.EJCT

****** DSORT (SADD) ******

```
205373JIM*WORKSPACE$(1).SADD
              SUBROUTINE SADD(WHERE)
        C
        C     PURPOSE...
        C             TO ADD A RECORD TO THE 'SORTED' STACK
        C
        C     USAGE...
        C             CALLED BY PROGRAM 'DSORT'
        C
              INCLUDE STORES,LIST
              IF(SURE)KNOWN=KNOWN+1
              IF(STOP)5,5,10
            5 STOP=WHERE
              SBASE=WHERE
              UP(WHERE)=0
              DOWN(WHERE)=0
              RETURN
           10 IF(CMPARE(WHERE,STOP))20,15,15
        C                           ENTER RECORD AT TOP OF STACK
           15 UP(STOP)=WHERE
              UP(WHERE)=0
              DOWN(WHERE)=STOP
              STOP=WHERE
              RETURN
           20 CHANGE=.TRUE.
              IF(CMPARE(WHERE,SBASE))22,22,25
        C                           ENTER RECORD AT BASE OF STACK
           22 DOWN(SBASE)=WHERE
              UP(WHERE)=SBASE
              DOWN(WHERE)=0
              SBASE=WHERE
              RETURN
           25 I=STOP
           30 I=DOWN(I)
              IF(CMPARE(WHERE,I))30,35,35
        C                           ENTER RECORD ABOVE RECORD I
           35 J=UP(I)
              DOWN(J)=WHERE
              UP(WHERE)=UP(I)
              DOWN(WHERE)=I
              UP(I)=WHERE
              RETURN
              END

@.EJCT
```

****** BSORT (STORES) ******

```
205373JIM*WORKSPACES(1).STORES
       STORES PROC
       C
       C      PROCEDURE NAME...
       C              STORES
       C
       C      PURPOSE...
       C              TO COMMUNICATE THE RECORD STACK INFORMATION FOR SORTING
       C              PROGRAM 'BSORT'.
       C
       C      USED BY PROGRAMS...
       C
       C              BSORT,BEGIN,START,SADD,SDROP,HADD,HDROP,ADDTO,FINDTO,EPUSH,
       C              EPOP
       C
       C                      LL IS THE NUMBER OF RECORDS HELD IN MEMORY,
       C                      AND MUST BE AT LEAST 3
              PARAMETER LL=24
              PARAMETER LGH=20
              IMPLICIT INTEGER (A-Z)
       C      DEFINE RECORD(ILOC)=(R(JJJ,ILOC),JJJ=1,LGH)
              COMMON INCR,SURE,CHANGE,KNOWN,ITO,NTO,BUFFER,
             -        STOP,HTOP,ETOP,SBASE,HBASE,
             -        DOWN(LL),UP(LL),FROM(LL),TO(LL),R(LGH,LL)
              LOGICAL SURE,CHANGE
         END
```

****** BSORT (START) ******

```
205373JIM*WORKSPACES(1).START
              SUBROUTINE START
       C
       C      PURPOSE...
       C              TO INITIALIZE STORAGE FOR PROGRAM 'BSORT'
       C
              INCLUDE STORES,LIST
              BUFFER=1
              ETOP=2
              DO 10 I=3,LL
           10 DOWN(I-1)=I
              DOWN(LL)=0
              STOP=0
              SBASE=0
              HTOP=0
              HBASE=0
              INCR=1
              RETURN
              END
```

@.EJCT

ORIGINAL PAGE IS
OF POOR QUALITY

****** JSORT (SDROP) ******

```
205373JIM*WORKSPACE*(1).SDROP
      INTEGER FUNCTION SDROP(S)
C
C     PURPOSE...
C             TO DROP A RECORD FROM THE 'SORTED' STACK
C
C     USAGE...
C             CALLED BY PROGRAM 'SSORT'
C
      INCLUDE STORES,LIST
      IF(SBASE)90,90,5
    5 SDROP=SBASE
      SBASE=UP(SBASE)
      IF(SBASE)10,10,15
   10 STOP=0
      RETURN
   15 DOWN(SBASE)=0
      RETURN
   90 PRINT 901
  901 FORMAT(' SORT STACK OVERDROPPED')
      RETURN 1
      END
```

W.EJCT

****** HSORT (HADD) ******

```
205373JIH*WORKSPACE$(1).HADD
      SUBROUTINE HADD(WHERE)
C
C     PURPOSE...
C             TO ADD A RECORD TO THE 'HOLD' STACK
C
C     USAGE...
C             CALLED BY PROGRAM 'BSORT'
C
      INCLUDE STORES,LIST
      IF(HTOP)5,5,10
    5 HTOP=WHERE
      HBASE=WHERE
      UP(WHERE)=0
      DOWN(WHERE)=0
      RETURN
   10 IF(CMPARE(WHERE,HBASE))15,20,20
C                         ENTER TO BOTTOM OF STACK
   15 DOWN(HBASE)=WHERE
      UP(WHERE)=HBASE
      DOWN(WHERE)=0
      HBASE=WHERE
      RETURN
   20 IF(CMPARE(WHERE,HTOP))25,22,22
C                         ENTER TO TOP
   22 UP(HTOP)=WHERE
      DOWN(WHERE)=HTOP
      UP(WHERE)=0
      HTOP=WHERE
      RETURN
   25 I=HTOP
   30 I=DOWN(I)
      IF(CMPARE(WHERE,I))30,35,35
C                         ENTER ABOVE ELEMENT I
   35 J=UP(I)
      DOWN(J)=WHERE
      UP(WHERE)=UP(I)
      DOWN(WHERE)=I
      UP(I)=WHERE
      RETURN
      END

@.EJCT
```

****** BSORT (HDROP) ******

```
2U5373JJIM*WORKSPACE$(1).HDROP
              I,TEUER FUNCTION HDROP(S)
        C
        C     PURPOSE...
        C             TO DROP A RECORD FROM THE 'HOLD' STACK
        C
        C     USAGE...
        C             CALLED BY PROGRAM 'BSORT'
        C
              INCLUDE STORES,LIST
              IF(HBASE)90,90,5
            5 HDROP=HBASE
              HBASE=UP(HBASE)
              IF(HBASE)10,10,15
           10 HTOP=0
              RETURN
           15 DOWN(HBASE)=0
              RETURN
           90 PRINT 902
          902 FORMAT(' HOLD STACK OVERDROPPED')
              RETURN 1
              END
```

****** BSORT (ADDTO) ******

```
2U5373JIM*WORKSPACE$(1).ADDTO
              SUBROUTINE ADDTO(I)
        C
        C     PURPOSE...
        C             TO ADD A RECORD TO THE 'TO' STACK
        C
        C     USAGE...
        C             CALLED BY PROGRAM 'BSORT'
        C
              INCLUDE STORES,LIST
        C                     STOP IF STACK IS FULL
              NTO=NTO+1
              IF(NTO.GT.LL)GO TO 90
        C                     FIND PROPER PLACE TO INSERT RECORD
              CALL FINDTO(I)
        C                     MOVE REST OF RECORDS & INSERT NEW ONE
              J=NTO
           16 J=J-1
              IF(J.LE.ITO)GO TO 18
              TO(J+1)=TO(J)
              GO TO 16
           18 TO(ITO+1)=FROM(I)
              RETURN
        C                     ERROR...STACK OVERFLOW
           90 PRINT 708
          708 FORMAT(' NTO .GT. LL')
              STOP
              END
```

@.EJCT

****** BSORT (FINDTO) ******

```
205373JIM*WORKSPACES(1).FINDTO
            SUBROUTINE FINDTO(I)
      C
      C     PURPOSE...
      C             SET POINTER 'ITO' TO  POINT IN 'TO' STACK WHERE
      C             A GIVEN NEW RECORD SHOULD BE INSERTED
      C
      C     USAGE...
      C             CALLED BY PROGRAM 'BSORT'
      C
            INCLUDE STORES,LIST
            ITO=NTO
          5 ITO=ITO-1
            IF(ITO)15,15,10
         10 IF((FROM(I)-TO(ITO))*INCH)5,15,15
         15 RETURN
            END
```

****** BSORT (EPUSH) ******

```
205373JIM*WORKSPACES(1).EPUSH
            SUBROUTINE EPUSH(LOC)
      C
      C     PURPOSE...
      C             TO STORE A LOCATION IN THE 'EMPTY' STACK
      C
      C     USAGE...
      C             CALLED BY PROGRAM 'BSORT'
      C
            INCLUDE STORES,LIST
            DOWN(LOC)=ETOP
            ETOP=LOC
            RETURN
            END
```

****** BSORT (EPOP) ******

```
205373JIM*WORKSPACES(1).EPOP
            INTEGER FUNCTION EPOP($)
      C
      C     PURPOSE...
      C             TO GET A LOCATION FROM THE 'EMPTY' STACK
      C
      C     USAGE...
      C             CALLED BY PROGRAM 'BSORT'
      C
            INCLUDE STORES,LIST
            IF(ETOP)90,90,5
          5 EPOP=ETOP
            ETOP=DOWN(ETOP)
            RETURN
         90 RETURN 1
            END
```

ORIGINAL PAGE IS
OF POOR QUALITY

****** PROFILE ******

```
205373JIM*WORKSPACE$(1).PROFILE
C
C      NAME...
C              PROFILE
C
C      PURPOSE...
C              TO UNFOLD THE DATA INTO INTENSITY VS WAVELENGTH CURVES
C
C      USAGE...
C
C              @.PROFILE   OR   @XQT .PROFILE
C
C              OPTIONS:
C              A       PRINT AND WRITE TO OUTPUT FILE POINTS FOR ALL
C                      MONITOR INTENSITIES    (OTHERWISE, IF < 50% OF THE
C                      POINTS ARE ACCEPTED, THE WHOLE PROFILE IS DISCARDED)
C              C       DISCARD POINTS WITH TIMES FOR THIS MONITOR INTENSITY
C                      FURTHER THAN 1.6 SIGMA (DEFAULT 1.73) FROM THE MEAN,
C                      THUS DELETING ABOUT 11% (DEFAULT 8%)
C              E       DELETE NO DATA POINTS (OVERRIDES 'C' OPTION)
C              L       PROVIDE FULL LISTING (OTHERWISE, ONLY A SUMMARY)
C              R       REPORT RESULTS FOR ALL WAVELENGTHS (EVEN IF MOST
C                      POINTS ARE DISCARDED)
C              S       SKIP SOME PROFILES
C              T       GENERATE FILES FOR PROGRAM 'THEORY'
C
C      SUBPROGRAMS REQUIRED...
C
C              BEGIN,OPT,TIM,INTENS,LOOKUP,YESNO
C
C                      MAXIMUM NUMBER OF WAVELENGTHS
       PARAMETER LIMEXP=36
C                      MAXIMUM NUMBER OF POINTS PER WAVELENGTH
       PARAMETER LIMSH=8
C                      OUTPUT RECORD LENGTH
       PARAMETER CSIZE=360
       PARAMETER CSIZE2=CSIZE+2
       DIMENSION NUMSH(LIMEXP),INTEXP(LIMEXP,LIMSH),LENGTH(LIMEXP)
       DIMENSION BLOCK(55),EVNOTE(2)
       EQUIVALENCE (INTREF,BLOCK(1)),(TAVER,BLOCK(2)),(J,BLOCK(3))
       INTEGER TEMP(20),GRP
       DIMENSION HEADER(24),SIG(LIMEXP),ERROR(LIMEXP),LABEL(20)
       EQUIVALENCE(TEMP (4),RSHOT),(TEMP (5),AREF(1)),(TEMP (13),BREF(1))
       EQUIVALENCE(LABEL(4),NSHOT),(LABEL(5),ALIN(1)),(LABEL(13),BLIN(1))
       DIMENSION AREF(8),BREF(8),ALIN(8),BLIN(8),LOCATE(CSIZE),
      -    LIST(CSIZE2)
       LOGICAL SKIP(10),RETURN,PRINT,OPT,CLOSE,ALL,THEORY,PRSKIP,EVERY
       LOGICAL YESNO,REPORT
       REAL INTENS,INT(10),INTAV(LIMEXP),LAMDA,LENGTH,INTREF
       REAL IBEGIN,INTEXP
       EXTERNAL INTENS
       INTEGER POOR,EARLY,FOUND,PCENT
       INTEGER GROUP(8),FBEGIN(8),END(8),CREC,PFILE,PREC/1/,GP,TRY,OUT
       INTEGER RSHOT,REFFND,REF1,CEND,CFILE,E1,POINTS,BAD
       INTEGER SHOT(LIMEXP,10),TAG(LIMEXP,10),NTAG(10),LIMTAG(LIMEXP)
       INTEGER TFILE,TREC,TFMT
       DATA (BLOCK(I),I=4,21)/18*0./
```

```
                    ****** PROFILE ******
      DATA INFILE, DELT,        E1, LAMDA, NOPROF, REFI, CFILE,TFILE,TFMT
     -      /  15,   .1,'REOF  ',   0.0,        0,     0,     16,   21, 503/
      DATA  LIST(1), ALTER,SPREAD,EVNOTE
     -       /   132,   .85,    3.,'        ','        '/
      CALL BEGIN('PROFILE 2.41  J')
      DEFINE FILE INFILE(1000,20,U,INREC)
      DEFINE FILE CFILE(CSIZE,20,U,CREC)
C                   FIND OUT WHETHER TO PRINT PROFILE OUT
      ALL   =OPT('A')
      CLOSE =OPT('C')
      EVERY =OPT('E')
      PRINT =OPT('L')
      REPORT=OPT('R')
      PRSKIP=OPT('S')
      THEORY=OPT('T')
      IF(CLOSE)SPREAD=2.56
      IF(.NOT.EVERY)GO TO 5
      EVNOTE(1)='    INC'
      EVNOTE(2)='LUDED  '
    5 IF(.NOT.THEORY)TFILE=0
      IBEGIN=0.0
      L=0
      K=0
C                   SAVE FILE HEADER
      READ(INFILE'1)(HEADER(I),I=1,12)
      READ(INFILE'2)(HEADER(I),I=13,24)
C                   FIND BEGINNING AND END OF EACH GROUP
   10 READ(INFILE'INREC)LABEL
      IF(LABEL(1).EQ.E1)GO TO 25
      DECODE(800,LABEL)GRP
  800 FORMAT(A5)
      DECODE(803,LABEL)GP
  803 FORMAT(I5)
      GP=GP*100
      IF(GRP.NE.'     ')GO TO 12
      IBEGIN=MAX(IBEGIN,BLIN(1))
      K=K+1
      LOCATE(K)=NSHOT
   12 I=0
   15 I=I+1
      IF(I.GT.L)GO TO 20
      IF((97*GROUP(I).GT.GP).OR.(GP.GT.103*GROUP(I)))GO TO 15
      GO TO 10
C                   FOUND BEGINNING OF NEW GROUP
   20 IF(L.GE.8)GO TO 197
      L=L+1
      GROUP(L)=GP/100
      FBEGIN(L)=INREC-1
      PRINT 805,GROUP(L),FBEGIN(L)
  805 FORMAT(' FOUND GROUP: ',I5,' AT RECORD',I4)
      IF(L.NE.1)END(L-1)=INREC-2
      GO TO 10
   25 IF(L.NE.0)END(L)=INREC-2
C                   NOTE BEGINNING & END OF REFERENCE SIGNAL GROUP
      INREC=1
      K=0
      DO 30 KK=1,L
```

****** PROFILE ******

```
      30 IF(GROUP(KK).EQ.0)GO TO 32
         GO TO 191
      32 REF1=FBEGIN(KK)
         REFEND=END(KK)
         KK=0
         KLIM=L-1
         IHEAD=0
         IF(.NOT.PRINT)PRINT 806
     806 FORMAT('OFILES  INTENSITY    POINTS'/
       -        '                (VOLTS)   FOUND  BAD')
C                       PRODUCE NEW FILE FOR EACH LINE PRESENT
         DO 100 K=1,KLIM
C                       INITIALIZE THE FILE
      35 KK=KK+1
         IF(KK.GT.KLIM)GO TO 190
         IF(GROUP(KK).EQ.'       ')GO TO 35
         PFILE=CFILE+K
         CREC=1
         JA=FBEGIN(KK)
         JB=END(KK)
         IF(JB-JA+1.GT.CSIZE)GO TO 190
         DO 38 J=JA,JB
         READ(INFILE'J)LABEL
      38 WRITE(CFILE'CREC)LABEL
         CEND=CREC-1
         DEFINE FILE PFILE(14,3*LINEXP+1,U,PREC)
         WRITE(PFILE'1)HEADER
         INTREF=.93*IBEGIN
         TRY=0
         NT=0
         LINES=100
         IF(.NOT.THEORY)GO TO 40
         DEFINE FILE TFILE(13,55+(2+LINSH)*LIMEXP,U,TREC)
         WRITE(TFILE'1)TFMT,HEADER
C                       START NEXT MONITOR SIGNAL LEVEL
      40 INTREF=ALTER*INTREF
         TRY=TRY+1
         IF(TRY.GT.20)GO TO 97
         IF(.NOT.PRSKIP)GO TO 41
         PRINT 813,PFILE,TFILE,INTREF
         IF(YESNO('WANTED?Q',$97))GO TO 41
         NT=0
         GO TO 40
      41 AVERR=0.0
         CREC=1
         NSHOT=0
         J=1
         LENGTH(1)=-2.
         POINTS=0
         NOMON=0
         FOUND=0
         POOR=0
         BAD=0
         OUT=0
         EARLY=0
         LATE=0
         N=0
```


C.2

****** PROFILE ******

```
C                   FIND MEAN & STANDARD DEVIATION OF TIMES FOR THIS
C                   MONITOR INTENSITY.
      IF(NT.GT.1)GO TO 44
C                   WE MUST GO READ THE FILE THE FIRST TIME THROUGH
      T=0.
      TS=0.
      DO 42 L=REF1,REFEND
      READ(INFILE'L)TEMP
      TA=TIM(INTREF,AREF,BREF,$42,$42)
      NT=NT+1
      T=T+TA
      TS=TS+TA*TA
   42 CONTINUE
      GO TO 50
C                   RECORD TIMES FOR ALL MONITOR SIGNALS NOT USED
C                   FOR THIS PROFILE
   44 DO 45 L=REFEND,REF1,-1
      CALL LOOKUP(LOCATE(L+1-REF1),I,LIST,$45)
      READ(INFILE'L)TEMP
      TA=TIM(INTREF,AREF,BREF,$45,$45)
      T=T+TA
      NT=NT+1
      TS=TS+TA*TA
   45 CONTINUE
   50 IF(NT.LE.1)GO TO 192
      CALL EMPTY(LIST)
      TAVER=T/FLOAT(NT)
      TSIGMA=SQRT((TS-TAVER*T)/FLOAT(NT-1))
      TSIG=((TS-TAVER*T)/FLOAT(NT-1))*SPREAD
      T=0.
      TS=0.
      NT=0
      INREC=REF1
      RSHOT=-2
C                   GET ANOTHER CURVE UNLESS WE'RE AT THE END OF THE FILE
   52 IF(CREC.LE.CEND)GO TO 54
C                   IF WE HAVE DATA FOR THIS WAVELENGTH, FIND AVERAGES
      IF(N.GT.0)GO TO 70
C                   IF WE HAVE DATA FOR THIS TIME GO RECORD IT
      IF(J.GT.1)GO TO 81
C                   GO TO NEXT TIME
      GO TO 96
C                   GET NEW CURVE
   54 READ(CFILE'CREC)LABEL
      DECODE(812,LABEL)LAMDA
  812 FORMAT(F5.1)
      IF(ABS(LAMDA-LENGTH(J)) .LT. .02)GO TO 58
      IF(N.GT.0)GO TO 70
   56 LENGTH(J)=LAMDA
      N=0
      NF=0
C                   GET REFERENCE CURVE FOR THIS SHOT
   58 NF=MIN0(NF+1,10)
      SHOT(J,NF)=NSHOT
      TAG(J,NF)=' '
      IF(INREC.LE.REFEND)GO TO 59
      I=REF1
```

```
      GO TO 60
   59 IF(LOCATE(INREC+1-REF1).EQ.NSHOT)GO TO 63
      I=INREC
   60 DO 61 INREC=REF1,REFEND
   61 IF(LOCATE(INREC+1-REF1).EQ.NSHOT)GO TO 63
C                    NO MONITOR SIGNAL FOUND FOR THIS SHOT NUMBER'
      INREC=I
      NOMON=NOMON+1
      TAG(J,NF)='N'
      GO TO 52
   63 READ(INFILE'INREC)TEMP
C                    RECORD TIME AT NEXT INTENSITY
      TA=TI(INTREF*ALTFR,AREF,BREF,$64,$64)
      NT=NT+1
      T=T+TA
      TS=TS+TA*TA
C                    IF TIME FOR THIS MONITOR INTENSITY IS MORE THAN
C                    1.73 (OR 1.6, UNDER 'C' OPTION) SIGMA FROM THE MEAN,
C                    THE MONITOR SIGNAL IS BAD AND WE DISCARD THIS POINT.
C                    THIS SHOULD, ASSUMING A GAUSSIAN DISTRIBUTION,
C                    DELETE ABOUT 8% (OR 11%) OF THE POINTS.
   64 TA=TI(INTREF,AREF,BREF,$66,$193)
      IF((TA-TAVER)**2.LT.TSIG)GO TO 65
      POOR=POOR+1
      TAG(J,NF)='P'
      IF(.NOT.EVERY)GO TO 52
C                    FOUND ONE MORE CURVE FOR THIS LEVEL..RECORD
   65 N=N+1
      IF(N.GT.LIMSH)GO TO 1?6
      INT(N)=INTENS(TA,ALIN,BLIN,$67,$68)
      SKIP(N)=.FALSE.
      NTAG(N)=NF
      GO TO 52
C                    INTENSITY IS OUT OF RANGE OF MONITOR VALUES
   66 OUT=OUT+1
      TAG(J,NF)='O'
      GO TO 69
C                    TIME IS TOO EARLY FOR SIGNAL CURVE
   67 EARLY=EARLY+1
      TAG(J,NF)='E'
      GO TO 69
C                    TIME IS TOO LATE FOR SIGNAL CURVE
   68 LATE=LATE+1
      TAG(J,NF)='L'
      IF(LATE.GT.10)GO TO 97
   69 N=N-1
      GO TO 52
C                    FOUND ALL DATA FOR ONE WAVELENGTH...
C                    CALCULATE AVERAGE INTENSITY
   70 RETURN=.FALSE.
   71 NN=0
      SUM=0
      SUMSQ=0.0
      DO 72 I=1,N
      IF(SKIP(I))GO TO 72
      NN=NN+1
      SUM=SUM+INT(I)
```

****** PROFILE ******

```
      SUMSQ=SUMSQ+INT(I)*INT(I)
      INTEAR(J,NN)=INT(I)
   72 CONTINUE
      NUMSH(J)=NN
      IF(NN-1)79,75,73
   73 INTAV(J)=SUM/NN
      SIG(J)=(SUMSQ-SUM*INTAV(J))/(NN-1)
C                      DISCARD POINTS ONLY ONCE
      IF(RETURN)GO TO 76
C                      THROW OUT ALL POINTS FURTHER AWAY THAN 1.8 SIGMA
C                      THIS SHOULD DELETE ABOUT 6% OF THE POINTS.
      DO 74 I=1,N
      IF(SKIP(I))GO TO 74
      IF((INT(I)-INTAV(J))**2.LT.SIG(J)*3.24)GO TO 74
      BAD=BAD+1
      II=NTAG(I)
      TAG(J,II)='B'
      IF(EVERY)GO TO 74
      RETURN=.TRUE.
      SKIP(I)=.TRUE.
   74 CONTINUE
C                      RECALCULATE MEAN & STANDARD DEVIATION IF
C                      WE'VE THROWN OUT ANY MORE POINTS
      IF(RETURN)GO TO 71
      GO TO 76
   75 INTAV(J)=SUM
      SIG(J)=0.
   76 SIG(J)=SQRT(SIG(J))
      IF((INTAV(J) .LT. 1.E-6).OR.(N.EQ.0))GO TO 194
      ERROR(J)=100.*SIG(J)/INTAV(J)
      AVERR=AVERR+ERROR(J)
      LIMTAG(J)=NF
      POINTS=POINTS+NN
      J=J+1
      GO TO 80
   79 IF(REPORT)J=J+1
   80 FOUND=FOUND+N
      IF(CREC.GT.CEND)GO TO 81
      IF(J.LE.LINEXP)GO TO 56
      J=J-1
      PRINT 950,J
  980 FORMAT('0****  MORE THAN',I4,' WAVELENGTHS, REST DISCARDED ****'/)
C
C                      DON'T BOTHER RECORDING OR PRINTING IF MORE
C                      THAN 40% OF THE POINTS WERE THROWN OUT
   81 FOUND=FOUND+NOMON+POOR+OUT+EARLY+LATE
      IF(FOUND.LE.0)GO TO 195
      PCENT=(100*(NOMON+POOR+OUT+EARLY+LATE+BAD))/FOUND
      J=J-1
      IF(ALL)GO TO 82
      IF(PCENT .GT. 40)GO TO 92
C                      IF WAVELENGTH IS IN UV DIVIDE BY TWO
C                      TO COMPENSATE FOR INCORRECT MCPHEARSON SCALE
   82 IF(LENGTH(1) .GT. 3300.)GO TO 86
      DO 84 I=1,J
   84 LENGTH(I)=.5*LENGTH(I)
   86 IF(PRINT)GO TO 87
```

****** PROFILE ******

```
      PRINT 813,PFILE,TFILE,INTREF,FOUND,PCENT
  813 FORMAT(1X,I2,I3,F8.3,I9,I5,1H%)
      GO TO 91
C                   PRINT PROFILE IF REQUESTED TO
   87 LINES=LINES+J+17
      IF(IHEAD.LT.0)GO TO 88
      IF(LINES.LT.57)GO TO 89
   88 PRINT 814,HEADER
  814 FORMAT(1H1,12A6/1H ,12A6)
      LINES=J+19
   89 PRINT 815,TAVER,TSIGMA,INTREF,PFILE,TFILE,FOUND,NOMON,
     -     POOR,EVNOTE,OUT,EARLY,LATE,BAD,EVNOTE,POINTS
  815 FORMAT(1X//' TIME =',F6.3,' +-',F5.3,' MSEC    MONITOR =',
     -     F6.4,' V    FILES',I3,' &',I3//
     -           T10,I3,' POINTS FOUND'/
     -           T10,I3,' HAD NO MONITOR SIGNALS     (N)'/
     -           T10,I3,' HAD POOR MONITOR SIGNALS   (P)',2A6/
     -           T10,I3,' OUT OF MONITOR RANGE       (O)'/
     -           T10,I3,' TIMES TOO EARLY            (E)'/
     -           T10,I3,' TIMES TOO LATE             (L)'/
     -           T10,I3,' SIGNALS TOO FAR FROM MEAN (B)',2A6/
     -           T10,I3,' ACTUALLY USED'//)
      PRINT 816
  816 FORMAT(' WAVELENGTH      INTENSITY     ERROR',T50,'POINTS FOUND'/
     -       ' (ANGSTROMS)      (VOLTS)')
      IHEAD=1
      DO 90 I=1,J
      III=LIMTAG(I)
   90 PRINT 818,LENGTH(I),INTAV(I),SIG(I),ERROR(I),
     -          (SHOT(I,II),TAG(I,II),II=1,III)
  818 FORMAT(F10.2,F9.5,' +-',F7.5,F6.0,T35,1H%,
     -       2X,10(I5,1X,A1))
      AVERR=AVERR/FLOAT(J)
      PRINT 821,AVERR
  821 FORMAT(T17,'AVERAGE SIGMA',F6.0,T35,1H%)
C
C                   WRITE INFORMATION TO FILES
   91 IF(J.LE.29)LENGTH(J+1)=0.
      WRITE(PFILE'PREC)INTREF,LENGTH,INTAV,SIG
      IF(THEORY)WRITE(TFILE'TREC)BLOCK,NUMSH,LENGTH,INTEXP
      GO TO 96
C
C                   REPORT ONE PROFILE DISCARDED
   92 NOPROF=NOPROF+1
      IF(.NOT.PRINT)GO TO 96
C                   GO TO NEXT PAGE IF THIS PAGE HAS A PROFILE ALREADY
      IF(IHEAD.GT.0)PRINT 814
      PRINT 825,INTREF,PCENT,NOMON,POOR,OUT,EARLY,LATE,BAD
  825 FORMAT(' MONITOR =',F5.3,I5,'% DISCARDED:',
     -       I4,' N',I4,' P',I4,' O',I4,' E',I4,' L',I4,' B')
      IHEAD=-1
      GO TO 96
C
C                   REPORT ERRORS OCCURING WITHIN MAJOR LOOP
C
  180 PRINT 901,GROUP(KK),JA,JB,CFILE,CSIZE
  901 FORMAT(' GROUP: ',I5,' USES RECORDS',I4,' THROUGH',I4,
```

```
                    ******  PROFILE  ******
     -      '...TOO MANY FOR FILE',I4/
     -      ' WHICH HOLDS',I4,' RECORDS')
        GO TO 97
  192 PRINT 902,INTREF
  902 FORMAT(' MONITOR =',F5.3,': TOO FEW VALID MONITOR SIGNALS')
        GO TO 40
  193 I=INREC-1
      PRINT 903,I,(TEMP(I),I=1,4),(TEMP(I),I=1,7,2),(TEMP(I),I=2,8,2)
  903 FORMAT(' INVALID DATA IN RECORD',I3,', GROUP ',2A6,', SCALE',F6.3,
     -         ', SHOT',I4/
     -         1X,6F8.5/1X,8F8.5)
  194 FOUND=FOUND+NOMON+POOR+OUT+EARLY+LATE
  195 PRINT 904,J,LENGTH(J),INTAV(J),N,NN
  904 FORMAT(' ERROR ON POINT',I3,'  (',F8.2,')...AV INTENS=',F8.5/
     -         ' FOUND',I3,' POINTS, USING THE FOLLOWING',I3,1H')
      PRINT 818,LENGTH(J),INTAV(J),SIG(J),ERROR(J),
     -     (SHOT(J,II),TAG(J,II),II=1,NF)
      PRINT 905
  905 FORMAT(1X/' PREVIOUS POINTS...')
      PRINT 815,TAVER,TSIGMA,INTREF,PFILE,TFILE,FOUND,NOMON,
     -     POOR,EVNOTE,OUT,EARLY,LATE,BAD,EVNOTE,POINTS
      GO TO 96
  196 KKK=LIMSH
      PRINT 906,KKK,J,INTAV(J),(SHOT(J,I),TAG(J,I),I=1,NF)
  906 FORMAT(' >',I3,' CURVES FOUND FOR POINT',I3,
     -         ' OF PROFILE...AV INTENSITY =',F8.5/
     -         ' INCLUDING THESE:',10(I5,1X,A1))
      GO TO 97
C
C                     TRY TO FIND 10 PROFILES IN ALL
   96 IF(PREC.LT.13 .AND. (PCENT.LT.40 .OR. PREC.LT.4))GO TO 40
      GO TO 97
C
C                     FINISH FILE
C
   97 IF(PREC.LE.14)WRITE(PFILL'PREC)E1
      I=PREC-3
      PRINT 830,I,NOPROF
  830 FORMAT(T16,'TOTAL OF',I4,' PROFILES ENTERED AND',I3,' DISCARDED')
      IF(.NOT.THEORY)GO TO 100
      IF(TREC.LT.41)WRITE(TFILE'TREC)E1
      TFILE=TFILE+1
  100 CONTINUE
      STOP
C
C                     REPORT ERRORS OCCURING BEFORE MAJOR LOOP
C
  190 PRINT 910
  910 FORMAT(' NO CURVES FOUND FOR MAIN SIGNAL')
      STOP
  191 PRINT 911
  911 FORMAT(' NO CURVES FOUND FOR REFERENCE SIGNAL')
      STOP
  197 PRINT 917,L,(GROUP(I),I=1,L),GP
  917 FORMAT(' MORE THAN',I3,' GROUPS FOUND:'/
     -         (8I8))
      STOP
```

****** PROFILE ******

```
          END
```

****** PROFILE (TIM) ******

```
205373JIM*WORKSPACES(1).TIM
          FUNCTION TIM(INT,A,B,$,$)
    C
    C     PURPOSE...
    C             TO FIND THE TIME CORRESPONDING TO A GIVEN INTENSITY
    C
    C     USAGE...
    C
    C             T=TIM(INT,A,B,$80,$90)
    C
    C             TIM     R,O     CALCULATED TIME
    C             INT     R,I     GIVEN INTENSITY
    C             A       R,I     ARRAY OF TIMES
    C             B       R,I     ARRAY OF CORRESPONDING INTENSITIES
    C             $80     S,I     EXIT USED IF DESIRED INTENSITY IS OUTSIDE THE
    C                             RANGE OF THE INTENSITIES IN ARRAY B
    C             $90     S,I     EXIT USED IF GIVEN DATA IS INVALID
    C                             (I.E. TIMES NOT INCREASING OR INTENSITIES NOT
    C                             DECREASING)
    C
    C     METHOD...
    C             LINEAR INTERPOLATION.
    C
          REAL INT
          DIMENSION A(8),B(8)
          IF((A(8).LT.A(1)).OR.(B(8).GT.B(1)))RETURN 5
          IF((INT.LT.B(8)).OR.(INT.GT.B(1)))RETURN 4
          DO 10 I=2,8
          IF(INT.GE.B(I))GO TO 12
       10 CONTINUE
       12 IF(B(I).NE.B(I-1))GO TO 15
          TIM=A(I)
          RETURN
       15 TIM=A(I)-(A(I)-A(I-1))*(B(I)-INT)/(B(I)-B(I-1))
          RETURN
          END
```

@.EJCT

****** PROFILE (INTENS) ******

```
205373-1N*WORKSPACE$(1).INTENS
                REAL FUNCTION I'ITFNS(TIME,A,B,$,$)
          C
          C     PURPOSE...
          C             TO FIND THE INTENSITY FOR A GIVEN TIME
          C
          C     USAGE...
          C
          C             Y = INTENS(TIME,A,B,$80,$90)
          C
          C             TIME    R,I     GIVEN TIME
          C             A       R,I     SAMPLE TIMES
          C             B       R,I     SAMPLES (INTENSITIES)
          C             $80     S,O     ERROR EXIT TAKEN IF GIVEN TIME TOO EARLY
          C             $90     S,O     ERROR EXIT TAKEN IF GIVEN TIME TOO LATE
          C
          C     METHOD...
          C             LINEAR INTERPOLATION
          C
                DIMENSION A(8),B(8)
                IF(TIME.LT.A(1))RETURN 4
                IF(TIME.GT.A(8))RETURN 5
                DO 10 I=2,8
                IF(TIME.LE.A(I))GO TO 12
             10 CONTII.UE
             12 IF(A(I).NE.A(I-1))GO TO 15
                INTENS=B(I)
                RETURI.
             15 INTENS=B(I)-(B(I)-B(I-1))*(A(I)-TIME)/(A(I)-A(I-1))
                RETURI.
                END

W.EJCT
```

```
                         ****** PROFILE (LOOKUP) ******

205373JIM*WORKSPACE$(1).LOOKUP
            SUBROUTINE LOOKUP(NUMBER,I,LIST,$)
      C
      C     NAME...
      C             TABLE LOOKUP
      C
      C     PURPOSE...
      C             TO CREATE, AND LATER FIND ENTRIES IN, A SORTED TABLE OF
      C             INTEGERS.
      C
      C     USAGE...
      C
      C             CALL EMPTY (LIST)              MARK LIST AS EMPTY
      C
      C             LIST    I,IO    WORK ARRAY (SAVED BETWEEN CALLS)
      C                             LIST(1) SHOULD BE SET TO THE LENGTH OF THE
      C                             ARRAY.
      C
      C             CALL ENTER (NUMBER,LIST,$)   ADD NUMBER TO LIST
      C
      C             NUMBER  I,I     NUMBER TO BE ADDED
      C             $       S,I     THIS RETURN TAKEN IF LIST IS ALREADY FULL
      C
      C             CALL LOOKUP (NUMBER,I,LIST,$) SEARCH FOR NUMBER IN LIST
      C
      C             NUMBER  I,I     NUMBER TO BE FOUND
      C             I       I,O     RELATIVE LOCATION IN LIST, IF FOUND
      C                             ZERO, IF NOT FOUND
      C             $       S,I     THIS RETURN IS TAKEN IF NUMBER IS FOUND
      C                             (OTHERWISE, NORMAL RETURN)
      C
            DIMENSION LIST(50)
            I=0
            IF(LIST(2).LT.3)RETURN
            DO 20 I=3,LIST(2)
         20 IF(LIST(I).EQ.NUMBER)RETURN 3
            I=0
            RETURN
            ENTRY ENTER(NUMBER,LIST,$)
            L=MAX0(LIST(2)+1,3)
            IF(L.GE.LIST(1))RETURN 3
            LIST(2)=L
            LIST(L)=NUMBER
            RETURN
            ENTRY EMPTY(LIST)
            LIST(2)=2
            RETURN
            END


@.EJCT
```

****** PROFILE (YESNO) ******

```
2053735J1M*WORKSPACE$(1).YESNO
        .          NAME...
        .               YESNO
        .
        .          PURPOSE...
        .               TO GET A YES OR NO ANSWER TO A QUESTION FOR
        .               AN INTERACTIVE PROGRAM.
        .
        .          CALLING SEQUENCE...
        .               .
        .               .
        .               LOGICAL YESNO
        .               .
        .               .
        .               IF(YESNO('SHALL I SKIP OPTIONAL PART?@',$90))GO TO 40
        .            20 CONTINUE
        .               .
        .               .
        .               <OPTIONAL PART OF PROGRAM>
        .               .
        .               .
        .               IF(YESNO('SHALL I REPEAT OPTIONAL PART?@'))GO TO 20
        .            40 <REST OF PROGRAM>
        .               .
        .               .
        .            90 <SPECIAL SECTION FOR END-OF-FILE RETURN>
        .
        .               THE QUESTION MUST END WITH THE STOP CHARACTER @ (WHICH
        .               ISN'T PRINTED), OR THE QUESTION WILL BE FOLLOWED BY A
        .               WHOLE STRING OF TRASH, AND THE PROGRAM MAY BLOW UP. THE
        .               QUESTION WILL BE PRINTED, AND THE TELETYPE WILL WAIT ON
        .               THE SAME LINE FOR THE USER TO TYPE HIS ANSWER. THAT
        .               ANSWER MAY START IN ANY COLUMN AND CONSIST OF ANY NORMAL
        .               AFFIRMATIVE OR NEGATIVE WORD (I.E., ANY ONE I COULD THINK
        .               OF WHEN I WROTE IT).THE USER MAY SUPPLY AN &EOF RETURN
        .               ADDRESS AS THE SECOND ARGUMENT, BUT THIS IS OPTIONAL
        .               (THE PROGRAM WILL FIND IT'S WAY BACK EITHER WAY).
        .
        .               CONTENTS OF ALL REGISTERS EXCEPT A0 ARE SAVED.
        .
        .          ERROR CONDITIONS...
        .
        .               IF THE USER'S ANSWER IS A BLANK LINE OR A CHARACTER
        .               STRING THE PROGRAM DOESN'T RECOGNIZE (IT CAN BE FOOLED)
        .               IT TRIES AGAIN, PRINTING ONLY 'WHAT?'. IT WILL REPEAT THE
        .               ORIGINAL QUESTION ONE TIME IN FOUR.
        .
        .               IF THE RESPONSE IS @EOF, THE PROGRAM USES THE ALTERNATE
        .               RETURN ADDRESS, IF SUPPLIED. THIS CAN BE USED, FOR
        .               INSTANCE, TO TERMINATE THE PROGRAM OR RE-ASK A
        .               PREVIOUS QUESTION (THIS WAY YOU DON'T HAVE TO RE-RUN THE
        .               WHOLE PROGRAM), IF THE ANSWER IS ANY OTHER CHARACTER
        .               STRING BEGINNING WITH @ THE SYSTEM THINKS THE PROGRAM
        .               IS TRYING TO READ A CONTROL CARD, AND ALLOWS NO FURTHER
        .               READS. IN THIS CASE, OR IF @EOF IS ENCOUNTERED AND NO
        .               @EOF RETURN ADDRESS HAS BEEN SUPPLIED, THE PROGRAM PRINTS
        .               A SHORT MESSAGE AND EXITS.
```

****** PROFILE (YESNO) ******

```
/
$(0)      LIT .
$(1)      AXRS .
YESNO*    SA        X11,RETURN .
          DS        A1,SAVE .
          DS        A3,SAVE3 .
          SR        R1,SAVER1 .
          SR        R14,SAVER14 .
          E$DIT     PACKET .
          LX        X11,RETURN .
          L,H1      A0,1,X11      . GET FIRST WORD FOLLOWING QUESTION POINTER
          AN,U      A0,0742000    . COMPARE TO JUMP INSTRUCTION
          S         A0,PRESENT    , THIS INDICATES PRESENCE OF QEOF ADDRESS
          L         A0,0,X11      . GET ADDRESS OF USER'S QUESTION
          LMJ       X11,EMSG$     . AND INSERT IT INTO PRINT LINE
          LMJ       X11,EDITX$    . END EDIT MODE & RESTORE REGISTERS
          L,U       A4,3          . INITIALIZE QUERY COUNTER
ASK       L,U       A0,READPKT .
READ      L,U       A1,BLANKS     . FILL INPUT LINE WITH BLANKS SO THE
          LXI,U     A2,1          . PREVIOUS INPUT DOESN'T CONFUSE THE ISSUE
          LXM,U     A2,INPUT .
          LR,U      R1,14 .
          BT        A2,0,*A1 .
          ER        TREAD$        . DO A TREAD$ TO PRINT QUESTION & GET ANS.
          LSSL      A0,4          . IS REPLY ACTUALLY IN 'INFOR' FORMAT?
          JP        A0,EXAMINE    . REPLY IS PRESENT
          LA        A0,READPKT+1 . INPUT IS IN 'INFOR' FORMAT...REREAD
          ER        READ$         .
EXAMINE   LXI,U     A2,0          . INITIALIZE INDEX REGISTERS
          L,S1      A3,INPUT      . IF FIRST CHARACTER IS NON-BLANK, SKIP
          L         A0,INPUT      . TO SEARCHING FOR A MATCHING WORD
          TE,U      A3,5          . 05 IS A BLANK
          J         MATCH .
          LR,U      R1,14         . OK...WE'LL HAVE TO DO IT THE LONG WAY
          LA        A1,BLANKS .
          SNE       A1,INPUT,*A2 . FIND FIRST WORD NOT ENTIRELY BLANKS
          J         AGAIN         . OOPS...THE WHOLE LINE WAS BLANK!
          L         A0,INPUT-1,A2 . GET THAT FIRST NON-BLANK CHARACTER
          L,U       A3,5          . FIGURE OUT WHICH CHARACTER  IT IS
LOOP      AND       A0,(077000000000) . MASK OUT LAST 5 CHARACTERS
          TE        A1,(005000000000) . IS IT A BLANK?
          J         LOAD          . NO...GO LOOK FOR A MATCHING WORD
          LSSL      A0,6          . YES...TRY NEXT CHARACTER
          JGD       A3,LOOP .
LOAD      DL        A0,INPUT-1,A2 . GET THE MESSAGE
          EX        MOVE,A3       . SHIFT THE BLANKS AWAY
          LXM,U     A2,0 .
MATCH     LR,U      R1,WDCOUNT    , SEARCH FOR MATCHING WORD IN TABLE
          SE        A0,TABLE,*A2 .
          J         AGAIN         ; NO MATCH...ASK AGAIN
          L         A0,A2         . FOUND A MATCH...GET INDEX
          LSSL      A0,35         . LAST BIT IS 1 IF 'YES', 0 IF 'NO'
          SSL       A0,35         . (SINCE A2 HAS BEEN INCREMENTED)
          SLJ       RESTORE       . RESTORE REGISTERS & RETURN
          TZ        PRESENT .
          J         2,X11         . RETURN TO CALL+2 IF NO QEOF ADDR SUPPLIED
          J         3,X11         . RETURN TO CALL+3, SINCE QEOF ADDR PRESENT
```

****** PROFILE (YESNO) ******

```
AGAIN    L,U     A0,AGAINPKT  . PRINT THE ENTIRE QUESTION ONLY ONE TIME
         JGD     A4,READ      . OUT OF FOUR
         L,U     A4,3 .
         J       ASK .
EOF      SLJ     RESTORE      . END-OF-FILE RETURN...RELOAD REGISTERS
         TNZ     PRESENT      . RETURN ONLY IF QEOF ADDR SUPPLIED
         JP      A0,*1,X11    . RETURN TO QEOF ADDRESS
         L       A0,(PF 1,PRTCNT,PRTLINE) .
         ER      PRINT$       . NON-QEOF CONTROL CARD ENCOUNTERED...
         ER      EXIT$        . WE'RE FORCED TO QUIT
RESTORE  RES     1            . ROUTINE FOR RESTORING REGISTERS
         DL      A1,SAVE .
         DL      A3,SAVE3 .
         LR      R1,SAVER1 .
         LR      R14,SAVER14 .
         LX      X11,RETURN .
         J       *RESTORE .
/
$(0) .
WBCK     'YESNO'
RETURN   +       0 .
SAVE     RES     2 .
SAVE3    RES     2 .
SAVER1   RES     1 .
SAVER14  RES     1 .
PRESENT  +       -1 .
PACKET   ESPKT   24,LINE 'MSG','Q' . IF THE USER FORGETS THE STOP
.                       CHARACTER, A Q IS THE CHARACTER MOST
.                       LIKELY TO BE FOUND BY ACCIDENT.
PRTLINE  'CONTROL CARD FORCES PROGRAM EXIT' .
PRTCNT   EQU     $-PRTLINE    . NUMBER OF WORDS IN MESSAGE
PF       FORM    12,6,18 .
READPKT  PF      1,22,LINE .
         +       EOF,INPUT .
LINE     RES     24 .
AGAINPKT PF      1,1,QUESTION .
         +       EOF,INPUT .
QUESTION 'WHAT?' .
INPUT    RES     14 .
BLANKS   '      '             . THIS ENSURES THE SECOND WORD LOADED HAS
.                             . BLANKS IF THE LAST WORD IN INPUT HAS INSTR.
MOVE     LDSL    A0,30        . INSTRUCTIONS FOR SHIFTING OUT BLANKS
         LDSL    A0,24 .
         LDSL    A0,18 .
         LDSL    A0,12 .
         LDSL    A0,6 .
         NOP .
TABLE    'YES'   . EVEN RELATIVE LOCATIONS FOR 'YES',
         'NO'    . ODD FOR 'NO'
         'Y' .
         'N' .
         'OUI' .
         'NON' .
         'ALRIGH' .
         'NOPE' .
         'YEP' .
         'NAW' .
```

****** PROFILE (YESNO) ******

```
                   'YEA' .
                   'WRONG' .
                   'RIGHT' .
                   'NEIN' .
                   'JA' .
                   'NYET' .
                   'DA' .
                   'DONT' .
                   'DO' .
                   'DON''T' .
                   'OK' .
                   'NOT' .
                   'OKAY' .
                   'N' .
                   'SI' .
         WDCOUNT   EQU     $-TABLE      . THE NUMBER OF WORDS IN THE TABLE
                   END .
```

N.EJCT

****** VPLOT ******

```
205373JIM*WORKSPACE$(1).VPLOT
      C
      C     NAME...
      C             VPLOT
      C
      C     PURPOSE...
      C             TO PRODUCE A PRINTER-PLOT OF THE EXPERIMENTAL LINE PROFILE
      C             PRODUCED BY PROGRAM 'PROFILE'.
      C
      C     USAGE...
      C
      C             @XQT .VPLOT  OR  @.VPLOT
      C             <FILE #>      (FREE) NUMBER OF 1ST FILE TO PLOT
      C             <FILE #>      (FREE) NUMBER OF 2ND FILE TO PLOT
      C             @EOF
      C
      C             OPTIONS:
      C             T       PLOT IS TO BE ON A TERMINAL, SO IT USES ONLY
      C                     COLUMNS 1-72.
      C
      C     INPUT...
      C             DATA FILE AS PRODUCED BY PROGRAM 'PROFILE'
      C
      C     SUBPROGRAMS REQUIRED...
      C             BEGIN,OPT,NUMBER
      C
            PARAMETER LIMEXP=36
            LOGICAL OPT,BATCH
            REAL INTMON,LENGTH,INTAV,IMAX,INCR,NL
            DIMENSION LINE(105),HEADER(24),LENGTH(LIMEXP),INTAV(LIMEXP),
           -     SIG(LIMEXP)
            DATA E1/'@EOF'/,MARK/'!'/,IZERO/'0'/,IONE/'1'/
            JCOL(X)=1+IFIX(X*INCR)
            CALL BEGIN('VPLOT 1.12 @')
            IDIF=IONE-IZERO
      C                     FIND FILE AND READ FILE HEADER
          5 NFILE=NUMBER('FILE NUMBER??',7,29,$99)
            DEFINE FILE NFILE(14,1+3*LIMEXP,U,NREC)
            READ(NFILE'1)HEADER
      C                     DECIDE WHETHER SMALL ('T' OPTION) OR LARGE GRAPH
            ICOL=41
            BATCH=.NOT.OPT('T')
            IF(BATCH)ICOL=101
            COL=FLOAT(ICOL-1)
            LAST=' '
            IF(BATCH)LAST=MARK
      C                     READ A PROFILE
          8 IF(NREC.LE.14)GO TO 11
            I=MAX0(0,NREC-2)
         10 PRINT 805,I
        805 FORMAT(1X//I3,' PROFILES')
            PRINT 808
        808 FORMAT(1H1)
            GO TO 5
         11 READ(NFILE'NREC)INTMON,LENGTH,INTAV,SIG
            IF(INTMON.EQ.E1)GO TO 10
      C                     SET UP SCALING PARAMETERS
```

****** VPLOT ******

```
      IMAX=0.
      NL=10.
      N=0
   12 IF((LENGTH(N+1).LT. 1E-5).OR.(N.GE.LIMEXP))GO TO 15
      N=N+1
      IF(N.GE.2)NL=AMIN1(NL,LENGTH(N)-LENGTH(N-1))
      IMAX=AMAX1(IMAX,INTAV(N)+SIG(N))
      GO TO 12
   15 NL=1./NL
      IF((NL*(LENGTH(N)-LENGTH(1)).LE. 24.).AND. BATCH)NL=NL*2
C
C                   NL IS NOW THE SCALE IN PRINT LINES PER ANGSTROM
      TOTAL=NL*(LENGTH(N)-LENGTH(1))
      IF(TOTAL.GT.200.)GO TO 115
      POWER=1.
      NP=0
   20 IF(IMAX*POWER.GT.1.)GO TO 25
      POWER=POWER*10.
      NP=NP-1
      GO TO 20
   25 IF(IMAX*POWER.LE.10.)GO TO 30
      POWER=POWER*.1
      NP=NP+1
      GO TO 25
   30 IF(IMAX*POWER.LE.2)GO TO 36
      IF(IMAX*POWER.LE.5.)GO TO 34
      NT=10
      GO TO 40
   34 NT=5
      GO TO 40
   36 NT=2
C                   PRINT GRAPH HEADER
   40 PRINT 810,HEADER,INTMON,NFILE
  810 FORMAT(1H1,12A6/1H ,12A6//' MONITOR INTENSITY =',F6.4,' VOLTS',
     -       8X,'FILE',I3/)
      INCR=COL*POWER/FLOAT(NT)
      PREV=LENGTH(1)
C                   PRINT TOP BORDER
      DO 42 I=1,ICOL
   42 LINE(I)='-'
      L=ICOL/NT
      DO 44 I=0,ICOL,L
   44 LINE(I+1)='+'
      PRINT 811,(LINE(J),J=1,ICOL)
  811 FORMAT(27X,105A1)
      DO 46 I=1,ICOL
   46 LINE(I)=' '
C
C                   INSERT NEEDED BLANK LINES
      DO 60 I=1,N
      IF(SIG(I) .LT. 0.0)GO TO 60
      LINES=IFIX(NL*(LENGTH(I)-PREV)+.5)
      PREV=LENGTH(I)
      IF(LINES.GT.25)GO TO 50
   48 IF(LINES.LE.1)GO TO 55
      LINES=LINES-1
      PRINT 812,MARK,LAST
```

```
****** VPLOT ******
  812 FORMAT(27X,A1,99X,A1)
      GO TO 48
   50 PRINT 812,(MARK,LAST,II=1,4)
      PRINT 813,LAST
  813 FORMAT(25X,'/////',T128,A1)
      PRINT 812,(MARK,LAST,II=1,4)
C
C                    PRINT ONE LINE OF GRAPH
   55 LINE(1)=MARK
      LINE(ICOL)=LAST
      J1=JCOL(INTAV(I)+SIG(I))
      J2=JCOL(AMAX1(0,INTAV(I)-SIG(I)))
      DO 57 J=J2,J1
   57 LINE(J)='*'
      PRINT 815,INTAV(I),SIG(I),LENGTH(I),(LINE(J),J=1,ICOL)
  815 FORMAT(1X,F7.5,' +-',F7.5,F9.2,101A1)
      DO 59 J=J2,J1
   59 LINE(J)=' '
   60 CONTINUE
C                    PRINT LOWER BORDER
      DO 62 I=1,ICOL
   62 LINE(I)='-'
      DO 64 I=0,ICOL,L
   64 LINE(I+1)='+'
      PRINT 811,(LINE(J),J=1,ICOL)
      DO 66 I=1,ICOL
   66 LINE(I)=' '
C                    PRINT HORIZONTAL SCALE
      DO 68 I=0,NT
   68 LINE(L*I+1)=IZERO+I*IDIF
      IF(NT.NE.10)GO TO 69
      LINE(ICOL)=IZERO
      LINE(ICOL-1)=IONE
   69 IF(NP.EQ.0)GO TO 70
      LINE(ICOL+1)=' '
      LINE(ICOL+2)='E'
      LINE(ICOL+3)=' '
      IF(NP.LT.0)LINE(ICOL+3)='-'
      LINE(ICOL+4)=IZERO+IABS(NP)*IDIF
      NCOL=ICOL+4
      PRINT 811,(LINE(J),J=1,NCOL)
      GO TO 8
   70 PRINT 811,(LINE(J),J=1,ICOL)
      GO TO 8
C                    QUIT
   99 STOP
C                    ERROR MESSAGES
  115 PRINT 915, TOTAL
  915 FORMAT(' GRAPH LENGTH OF',F6.0,' LINES IS TOO LONG!')
      GO TO 8
      END
```

@.EJCT

****** THEORY ******

```
205373U1( *WORKSPACES(1).THEORY
C
C      NAME...
C             THEORY
C
C      PURPOSE...
C             TO FIND THE VALUES OF THE PARAMETERS (LINE POSITION,
C             LINE INTENSITY, LINE WIDTH OR ELECTRON DENSITY, AND
C             BACKGROUND INTENSITY) WHICH BEST FIT THE THEORETICAL
C             PROFILE TO THE EXPERIMENTAL DATA.
C
C      USAGE...
C
C             @.THEORY  OR  @XQT .THEORY
C             <DATA>
C             OPTIONS:
C             'D'    DELETE SOME POINTS
C             'N'    PRODUCE PLOTS NOW
C             'T'    PRODUCE FILES FOR PLOTS LATER
C                    (FEATURE UNTESTED)
C             'S'    SKIP SOME PROFILES
C             'Y'    PRINT DIAGNOSTIC INFO FOR EVERY POINT REQUESTED
C                    BY 'ZXPOWL'
C             'Z'    PRINT DIAGNOSTIC INFO EVERY TIME 'ZXPOWL'
C                    CHANGES SEARCH DIRECTION
C
C             DATA IMAGES:
C             CARD 1:(FREE) INPUT FILE NUMBER
C             CARD 2:(FREE) OUTPUT FILE NUMBER, (ONLY WITH 'T' OPTION)
C             CARD 3:(FREE) WAVELENGTHS TO DELETE (ONLY WITH 'D' OPTION)
C             CARD 4:(FREE) LINE NUMBER
C                    1      HE II 4686 (DENSITY 1.E17)
C                    2      HE II 1640
C                    3      HE II 1215
C                    4      HE II 1025
C                    5      HE II 4686 (DENSITY 1.E18)
C             CARD 5:(FREE) 'YES' IF FIT TO THIS PROFILE IS WANTED
C                           (ONLY WITH 'S' OPTION)
C             CARD 6,(FREE) 'YES' IF PLOT DESIRED, 'NO' IF NOT
C                           (ONLY WITH 'N' OPTION)
C             (REPEAT CARDS 5 & 6 FOR REMAINING PROFILES AS NEEDED)
C
C      SUBPROGRAMS REQUIRED...
C
C             FETCHS OBTAINS THE NORMALIZED LINE PROFILE AND THEORETICAL
C                    LINE POSITION FOR THE LINE.
C             ZXPOWL (FROM IMSL) GENERAL FUNCTION MINIMIZER, USED TO
C                    FIND THE NONLINEAR PARAMETERS WHICH MINIMIZE THE SUM
C                    OF THE SQUARES OF THE DEVIATIONS OF THE EXPERIMENTAL
C                    POINTS FROM THE THEORETICAL PROFILE
C             FUNCT3 HAS THE THEORETICAL PROFILE CALCULATED FOR THE
C                    CURRENT PARAMETERS, AND OBTAINS THE MEAN SQUARE
C                    DEVIATION OF THE DATA FROM THE NEW PROFILE.
C             FUNCT2 FINDS THE CORRELATION MATRIX OF THE BEST-FIT
C                    PARAMETERS, USING THE SECOND PARTIAL DERIVATIVES
C                    OF THE ERROR FUNCTION.
C             TPLOT  PLOTS THE EXPERIMENTAL DATA AND THEORETICAL PROFILE
```

****** THEORY ******

```
C                   USING THE OFF-LINE PLOTTER.
C             AXISN,BEGIN,FETCHS,IFAS,NEXT,NEWU,OPT,PLOTC,SIGMA,SYMBLV,
C             TPLOT,VALUE
C
C      METHOD...
C             IMSL ROUTINE 'ZXPOWL' FINDS THE MINIMUM OF THE ERROR
C             FUNCTION (THE SUM OF THE SQUARES OF THE DEVIATIONS OF THE
C             FITTED FUNCTION FROM THE DATA POINTS)  AS A FUNCTION OF
C             ITS TWO NON-LINEAR PARAMETERS. THE COVARIANCE MATRIX IS
C             COMPUTED AS THE INVERSE OF THE MATRIX OF SECOND PARTIAL
C             DERIVATIVES OF THE ERROR FUNCTION NEAR ITS MINIMUM.
C
       INCLUDE DBANK,LIST
       INCLUDE GROUP,LIST
       COMMON /F3COM/ ARG2(2)
       EXTERNAL FUNCT3
       REAL IMAX
       LOGICAL YESNO,KEEP,OUT,OPT,LATER,ALL
       DIMENSION HEADER(24),H(30),ARG0(4),BAD(25)
       DIMENSION LABEL(20)
       INTEGER OUTFIL,OUTFMT,OUTREC,DFILE,DREC,TFMT
       DATA     EST, CLOSF,CLOSER,     END, EPSNE,  EPSI,OUTFMT,   TFMT
      -     / 1.E-4, 1.E-4, 3.E-6,'DEOF  ',    .2,   .02,   700,   503/
       DATA   LINEP
      -     /     0/
       DATA (LABEL(I),I=1,10)/'HE II ','4686  ','HE II ','1640  ',
      -     'HE II ','1215  ','HE II ','1025  ','HE II ','4686  '/
       IPCENT(QQ)=IFIX(100.*ABS(QQ)+.5)
       CALL BEGIN('THEORY 1.74 W')
C                   GET OPTIONS FROM CONTROL CARD
       OUT=OPT('T')
       LATER=.NOT.OPT('N')
       ALL=.NOT.OPT('S')
C                   SET UP PARAMETERS
    10 IF(LINEP.NE.0)PRINT 820
       DFILE=NUMBER('INPUT FILE?@',7,29,$96)
       DEFINE FILE DFILE(13,ISIZE,U,DREC)
       IF(OUT)OUTFIL=NUMBER('OUTPUT FILE?@',7,29,$96)
       IF(OUT)DEFINE FILE OUTFIL(13,ISIZE,U,OUTREC)
       KEEP=.NOT.OPT('D')
       IF(KEEP)GO TO 15
       PRINT 800
   800 FORMAT(' ENTER WAVELENGTHS TO DELETE')
       READ(5,810,END=13)(BAD(NBAD),NBAD=1,25)
   810 FORMAT()
       NBAD=26
    13 NBAD=NBAD-1
       IF(NBAD.EQ.0)KEEP=.TRUE.
    15 CALL FETCHS(ARG0,NA,LINE)
       READ(DFILE'1)NFMT,HEADER
       IF(NFMT.NE.TFMT)GO TO 97
       IF(OUT)WRITE(OUTFIL'1)OUTFMT,HEADER
       PRINT 820,HEADER
   820 FORMAT(1H1,12A6/1X,12A6)
       LINEP=2
C                   READ DATA FOR NEXT MONITOR INTENSITY
    20 READ(DFILE'DREC)BLOCK,NSHOT,LENGTH,INTEXP
```

****** THEORY ******

```
      NARG=NA
      DO 22 I=1,NARG
   22 ARG(I)=ARGQ(I)
      LINES(1)=LINE
      IF(INTMON.EQ.END)GO TO 10
C                    CHECK FOR ACCEPTABLE WAVELENGTH RANGE
      IF(ARG(2)+BASE.LT.2*LENGTH(1)-LENGTH(NU) .OR.
     -    ARG(2)+BASE.GT.2*LENGTH(NU)-LENGTH(1)) GO TO 92
      NU1=1
      NU2=NU
      IF(KEEP)GO TO 50
      NU1=0
      NU2=NU+1
   38 NU1=NU1+1
      IF(NU1.GE.NU2)GO TO 49
      DO 40 I=1,NBAD
      IF(ABS(LENGTH(NU1)-BAD(I)).LT. .001)GO TO 38
   40 CONTINUE
   42 NU2=NU2-1
      IF(NU1.GE.NU2)GO TO 49
      DO 44 I=1,NBAD
      IF(ABS(LENGTH(NU2)-BAD(I)).LT. .001)GO TO 45
   44 CONTINUE
      GO TO 42
   45 HOLD=LENGTH(NU1)
      LENGTH(NU1)=LENGTH(NU2)
      LENGTH(NU2)=HOLD
      N=MAX0(NSHOT(NU1),NSHOT(NU2))
      DO 48 KSHOT=1,N
      HOLD=INTEXP(NU1,KSHOT)
      INTEXP(NU1,KSHOT)=INTEXP(NU2,KSHOT)
   48 INTEXP(NU2,KSHOT)=HOLD
      N=NSHOT(NU1)
      NSHOT(NU1)=NSHOT(NU2)
      NSHOT(NU2)=N
      GO TO 38
   49 NU2=NU
C                    PRINT LABELING INFORMATION
   50 TOTAL=0
      BOTTOM=LENGTH(NU1)
      TOP=LENGTH(NU2)
      AVG=0.
      DO 51 KU=NU1,NU2
      BOTTOM=AMIN1(BOTTOM,LENGTH(KU))
      TOP=AMAX1(TOP,LENGTH(KU))
      N=NSHOT(KU)
      TOTAL=TOTAL+N
      DO 51 KSHOT=1,N
   51 AVG=AVG+INTEXP(KU,KSHOT)
      AVG=AVG/TOTAL
      IF(AVG.LT.1.E-5)GO TO 95
      LINEP=LINEP+13
      IF(LINEP.LT.57-3)GO TO 53
      PRINT 820,HEADER
      LINEP=15
   53 PRINT 830,TAVER,INTMON,TOTAL,BOTTOM,TOP
  830 FORMAT(1X/' TIME:',F6.3,'    MONITOR:',F6.4/
```

****** THEORY ******

```
     -     1X,I3,' POINTS,  WAVELENGTHS:',F8.2,' TO',F8.2)
      IF(ALL)GO TO 55
      IF(YESNO('FIT?',*96))GO TO 55
      LINEP=LINEP-11
      GO TO 20
C                     CHECK THAT THE SYSTEM ISN'T DEGENERATE
   55 I=NU2-NU1+1
      IF(I.LE.NARG+2)GO TO 93
C                     SET UP FOR SOLUTION
      NEVAL=0
      DO 60 ITER=1,6
      A1=ARG(1)
      ARG2(1)=9.9
      ARG2(2)=9.9
      CALL NEWS(ARG,NARG)
      LIMIT=10
C
C                     HAVE MINIMUM FOUND (USING ROUTINE FROM IMSL)
      CALL ZXPOWL(FUNCT3,CLOSE,NARG,ARG,VALUE,LIMIT,H,IER)
      IF(OPT('O'))PRINT 760,ARG(1),ARG(2),VALUE,IER
  760 FORMAT(' RESULTS:',3G13.6,I4)
C
C                     IF ELECTRON DENSITY CHANGED MUCH, REPEAT SOLUTION
      IF(ABS(ARG(1)-A1) .LT. .1*ARG(1))GO TO 65
   60 CONTINUE
      ITER=6
      A1=ARG(1)*1.E16
      PRINT 838,ITER,A1
  838 FORMAT(' DENSITY DIDN''T CONVERGE AFTER',I4,' ITERATIONS, HAVE',
     -     1PE11.3)
C
C                     REPEAT WITH CLOSER TOLERANCES
   65 ITER=ITER+1
      CALL NEWS(ARG,NARG)
      ARG2(1)=9.9
      CALL ZXPOWL(FUNCT3,CLOSER,NARG,ARG,VALUE,LIMIT,H,IER)
      IF(VALUE.LT..01*EST)GO TO 94
C
C                     UPDATE ESTIMATE OF MINIMUM VALUE
      EST=VALUE
C                     FIND ERRORS IN CALCULATED PARAMETERS
      CALL FUNCT2
C
C                     PRINT RESULTS
C
      PRINT 840,ITER,NEVAL,IER,HWIDTH,FO,VALUE
  840 FORMAT(' ITERATIONS:',I5,'   EVALUATIONS.',I7,'   ERROR CODE:',I4/
     -     ' HALF WIDTH:',F5.2,'   FIELD STRENGTH:',F5.0,'  SIGMA:',F9.4)
      II=IPCENT(SIG(1)/ARG(1))
      PRINT 845,ARG(1),SIG(1),II,COVAR(1,1)
  845 FORMAT(1H0,T13,'BEST FIT VALUES',T49,'CORRELATION MATRIX'/
     -      ' ELECTRON DENSITY=',1PE11.3,' +-',0PE8.3,I4,'%',T47,F6.2)
      A=ARG(2)+BASE
      PRINT 846,LABEL(2*LINES-1),LABEL(2*LINES),A,SIG(2),
     -      COVAR(1,2),COVAR(2,2)
  846 FORMAT(T2,2A6,'CENTER=',F9.2,' +-',F4.2,T47,2F6.2)
      II=IPCENT(E(1)/INT(1))
```

```
                      ******  THEORY  ******
      PRINT 847,INT(1),E(1),II,(COVAR(I,3),I=1,3)
  847 FORMAT(T13,'INTENSITY=',F7.4,' +-',F6.4,I6,'%',T47,3F6.2)
      II=IPCENT(E(2)/INT(2))
      PRINT 848,INT(2),E(2),II,(COVAR(I,4),I=1,4)
  848 FORMAT(' BACKGROUND INTENSITY=',F7.4,' +-',F6.4,I6,'%',T47,
     -       4F6.2)
      IF(RATIO .LT. 1.E-5)GO TO 70
      II=IPCENT(ERATIO(1)/RATIO(1))
      PRINT 850,RATIO(1),ERATIO(1),II
  850 FORMAT(1H0,T13,'LINE:CONT=',F7.2,' +-',F6.2,I6,'%')
C                     IF LINE IS HE II 4686, FIND & PRINT TEMPERATURE
      IF(ABS(ARG(2)+BASE-4685.75) .GT. 10.)GO TO 70
      II=IPCENT(ETEMP/TEMP)
      PRINT 855,TEMP,ETEMP,II
  855 FORMAT(T11,'TEMPERATURE=',F7.2,' +-',F6.2,I6,'%')
      LINEP=LINEP+1
C                     WRITE RESULTS TO FILE IF DESIRED
   70 IF(OUT)WRITE(OUTFIL'OUTREC)BLOCK,NSHOT,LENGTH,INTEXP
      ARG(1)=1.E-16*ARG(1)
C                     PLOT NOW IF DESIRED
      IF(LATER)GO TO 20
      LINEP=LINEP+1
      IF(.NOT.YESNO('PLOT?9',$96))GO TO 20
      CALL TPLOT(IMAX,BOTTOM,TOP)
      PRINT 860,IMAX,BOTTOM,TOP
  860 FORMAT('      AXIS LABELS:',F7.4,2F8.1)
      LINEP=LINEP+1
      GO TO 20
C                     NOTIFY OF ERRORS
   92 A=BASE+ARG(2)
      PRINT 902,A,LENGTH(1),LENGTH(NU)
  902 FORMAT(' LINE CENTER OF',F9.2,' TOO FAR FROM EXP RANGE',F9.2,
     -       ' TO',F9.2)
      GO TO 96
   93 PRINT 903,I
  903 FORMAT(T6,'(ONLY',I2,' POINTS PRESENT)')
      GO TO 96
   94 PRINT 904
  904 FORMAT(' SIGMA SQUARED IS TOO SMALL')
      A=1.E16*ARG(1)
      S=0.
      PRINT 840,ITER,NEVAL,IER,VALUE,A,S,S
      A=ARG(2)+BASE
      PRINT 845,LABEL(2*LINES-1),LABEL(2*LINES),A,S,INT(1),S
      GO TO 20
   95 PRINT 905,AVG
  905 FORMAT('      (SIGNALS AVERAGE ONLY',E13.6,')')
      GO TO 20
   96 IF(OUT .AND. OUTREC.LT.13)WRITE(OUTFIL'OUTREC)END
      STOP
   97 PRINT 907,NFMT,TFMT
  907 FORMAT(' INPUT DATA FILE FORMAT IS',I7,' RATHER THAN',I4)
      STOP
      END
```

****** THEORY (DBANK) ******

```
205373JI*WORKSPACES(1).DBANK
      DBANK PROC
      C
      C      PROCEDURE NAME...
      C             DBANK
      C
      C      PURPOSE...
      C             TO TRANSMIT THEORETICAL, EXPERIMENTAL, AND CALCULATED
      C             INFORMATION PAST THE LIBRARY ROUTINE 'FMCG'
      C
      C
      C      PROGRAMS USING THIS PROCEDURE...
      C
      C             FETCHS,FUNCT1,FUNCT2,NEWS,NEWT,NEWU,SIGMA,SUMF,THEORY,TPLOT
      C
             PARAMETER LIMS=26
             PARAMETER LIMEXP=36
             PARAMETER LIMSH=8
             INTEGER TOTAL
             LOGICAL OPT
             REAL INTEXP,LENGTH
             COMMON KS,KU,NU1,NU2,KSHOT,TOTAL,NEVAL,ITER,IER,EPSI,EPSNE,HHW,
           -      NS1,NS2,F0,BASE,
           -      ALPH1(LIMS),SALPH1(LIMS),ALPH2(LIMS),SALPH2(LIMS),
           -      DEL(LIMS),TDEL(LIMS),
           -      NSHOT(LIMEXP),LENGTH(LIMEXP),INTEXP(LIMEXP,LIMSH),
           -      SUM(4,5),ERROR(4),P(20),Q(10)
             EQUIVALENCE (BRIGHT,SUM(1,3)),(BACKGD,SUM(2,3))
        END
```

****** THEORY (GROUP) ******

```
205373JIM*WORKSPACES(1).GROUP
      GROUP PROC
      C
      C      PROCEDURE NAME...
      C             GROUP
      C
      C      PURPOSE...
      C             TO COMMUNICATE PARAMETER ERROR ESTIMATES.
      C
      C      PROGRAMS USING THIS PROCEDURE...
      C
      C             THEORY,FUNCT2,NEWU
      C
             PARAMETER ISIZE=55+(2+LIMSH)*LIMEXP
             COMMON/GROUP/ INTMON,TAVER,NU,W1,W2,NARG,TEMP,ETEMP,
           -      LINES(10),
           -      VALUE,HWIDTH,
           -      ARG(4),SIG(4),INT(4),E(4),RATIO(3),ERATIO(3),COVAR(4,4)
             DIMENSION BLOCK(55)
             EQUIVALENCE (BLOCK(1),INTMON)
             REAL INTMON,INT
        END
```

****** THEORY (FETCHS) ******

```
20537301**DBANK*PACL$(1).FETCHS
          SUBROUTINE FETCHS(ARG,NARG,LINES)
C
C         NAME...
C                 FETCHS
C
C         PURPOSE...
C                 TO DETERMINE WHICH LINE HAS BEEN SCANNED, READ IN THE
C                 CORRESPONDING THEORETICAL PROFILE, AND INITIALIZE THE
C                 NONLINEAR PARAMETERS.
C
C         CALLING SEQUENCE...
C
C                 CALL FETCHS (ARG,NARG,LINES)
C
C                 ARG     R,O     ARRAY OF NONLINEAR PARAMETERS
C                                 ARG(1) IS THE ELECTRON DENSITY TIMES 1.E-16 .
C                                 ARG(2) IS THE DISTANCE FROM THEORETICAL
C                                 TO ACTUAL LINE CENTER.
C                 NARG    I,O     NUMBER OF NONLINEAR PARAMETERS
C                 LINES   I,O     LINE CODE NUMBER.
C                                 1  HE II 4686  (DENSITY 1.E17)
C                                 2  HE II 1640
C                                 3  HE II 1215
C                                 4  HE II 1025
C                                 5  HE II 4686  (DENSITY 1.E18)
C
C                 VARIABLES IN BLANK COMMON:
C                 NARG    I,O     # NONLINEAR ARGUMENTS
C                 NS1,NS2
C                         I,O     # ENTRIES IN ARRAYS ALPH1, SALPH1, AND
C                                 ALPH2, SALPH2, RESPECTIVELY
C                                 (PRESET POSITIONS)
C                 HHW     R,O     HALF HALF WIDTH OF INSTRUMENT FUNCTION
C                 BASE    R,O     THEORETICAL LINE CENTER MINUS 10 ANGSTROMS
C                 ALPH1,SALPH1
C                         R,O     ARRAYS OF VALUES OF ALPHA & S(ALPHA)
C
          INCLUDE DBANK,LIST
          DIMENSION ARG(4)
          INTEGER STHEO
          LOGICAL OPT
          DATA STHEO/29/,IFMT/o00/
          DEFINE FILE STHEO(10,2*LINS+2,U,NREC)
          READ(STHEO'1)NFMT
          IF(NFMT.NE.IFMT)GO TO 90
          NARG=2
C                         START WITH AN ELECTRON DENSITY OF 10**17
          ARG(1)=1.E-16*1.E17
          LINES=NUMBER('LINE NUMBER?0',1,9,$30)
          READ(STHEO'LINES+1)BASE,N,ALPH1,SALPH1
          NS1=N
          NS2=NS1+1
          ARG(2)=10.
          BASE=BASE-10.
          IF(BASE.LT.3000)GO TO 25
          HHW=.3
```

****** THEORY (FETCHS) ******

```
      IF(OPT('C'))HHW=.0001
      RETURN
   25 BASE=BASE-.58
      HHW=.336
      IF(OPT('C'))HHW=.0001
      RETURN
   30 STOP
   90 PRINT 906,NFMT,IFMT
  906 FORMAT(' S(ALPHA) FILE FORMAT IS',I5,' RATHER THAN',I4)
      STOP
      END
```

J.EJCT

****** THEORY (FUNCT3) ******

```
205373JIA*.ORKSPACE.(1).FUNCT3
      FUNCTION FUNCT3 (ARG)
C
C     PURPOSE...
C             TO FIND THE MEAN SQUARE DEVIATION OF THE DATA FROM THE
C             THEORY USING CURRENT PARAMETERS.
C
      INCLUDE DBANK,LIST
      INTEGER ERRCT/0/
      DIMENSION ARG(1)
      LOGICAL OPT
      COMMON/F3COM/A(2),OLDVAL,OLDANG
C                       NEEDN'T CALL NEWT UNLESS DENSITY CHANGED
      IF(A(1).NE.ARG(1).OR.A(2).NE.ARG(2))
     -     ANGLE=57.296*ATAN2(ARG(2)-A(2),ARG(1)-A(1))
      IF(ABS(A(2)-10.).GT.20.)ERRCT=ERRCT+1
      IF(ABS(ARG(1)-A(1)) .LT. 1.E-7*ARG(1))GO TO 10
      IF(A(1).LT.1. .OR. A(1).GT.100.)ERRCT=ERRCT+1
C     IF(ERRCT.GE.8)GO TO 90
      IF(BRIGHT .LT. -1.E-5)GO TO 90
      CALL NEWT(ARG,2)
      A(1)=ARG(1)
   10 CALL NEWU(ARG,2)
      FUNCT3=SIGMA(ARG)
      IF(ANGLE.LE.0.)ANGLE=ANGLE+180.
      IF(OPT('Z') .AND. ABS(ANGLE-OLDANG).GT..4)
     -     PRINT 701,A,OLDVAL,OLDANG
      IF(OPT('Y'))
     -     PRINT 701,ARG(1),ARG(2),FUNCT3,ANGLE,BRIGHT,BACKGD
  701 FORMAT(3G15.8,F5.0,1P2G9.3)
      A(2)=ARG(2)
      OLDVAL=FUNCT3
      OLDANG=ANGLE
      NEVAL=NEVAL+1
      RETURN
   90 PRINT 703
  703 FORMAT(' ''FUNCT3'' FINDS UNREASONABLE ARGUMENTS (8TH TIME).')
      PRINT 701,A,OLDVAL,OLDANG
      PRINT 707,ARG(1),BASE,ARG(2),F0,BRIGHT,BACKGD
  707 FORMAT(' NOW:  NE=1.E16*',1PG9.3,'  CFN=',G9.3,'+',G13.6,'  F0=',
     -     G9.3/'  BRIGHT,BACKGD=',2G9.3)
      DO 92 KU=NU1,NU2
      XX=LENGTH(KU)
      YY=VALUE(DEL,TDEL,NS2,XX-BASE-ARG(2),0)
      Y2=0.
      N=NSHOT(KU)
      DO 91 KSHOT=1,N
   91 Y2=Y2+INTEXP(KU,KSHOT)
      Y2=Y2/N
   92 PRINT 724,XX,Y2,YY
  724 FORMAT(1PG14.6,2G10.2)
      STOP
      END
```

****** THEORY (FUNCT2) ******

```
205373JIH*WORKSPACES(1).FUNCT2
      SUBROUTINE FUNCT2
C
C     NAME...
C           FUNCT2
C
C     PURPOSE...
C           TO FIND THE EXPECTED ERRORS IN THE BEST-FIT PARAMETERS.
C
C     CALLING SEQUENCE...
C
C           CALL FUNCT2
C
C           VARIABLES IN BLANK COMMON:
C
C           TOTAL  I,I    # DATA POINTS
C           EPSI   R,I    STEP IN WAVELENGTH
C           EPSNE  R,I    STEP IN ELECTRON DENSITY = ARG(1)
C           F0     R,0    HOLTSMARK FIELD STRENGTH
C           BASE   R,I    THEORETICAL LINE CENTER MINUS 10 ANGSTROMS
C
C           VARIABLES IN COMMON /GROUP/*
C
C           NARG   I,I    NUMBER OF ELEMENTS IN ARG
C           ARG    R,I    ARRAY OF NONLINEAR PARAMETERS
C           VALUE  R,IO   INPUT: SUM OF SQUARES OF DEVIATIONS
C                         FOR THE BEST-FIT PARAMETERS. OUTPUT: SQUARE
C                         ROOT OF SUM OF SQUARES.
C           SIG    R,0    ARRAY OF EXPECTED ERRORS IN THE NONLINEAR
C                         PARAMETERS
C           LIN    R,0    ARRAY OF LINEAR PARAMETERS
C           E      R,0    ARRAY OF EXPECTED ERRORS OF LINEAR PARAMETERS
C           COVAR  R,0    UPPER TRIANGLE IS SET TO A NORMALIZED
C                         VARIANCE-COVARIANCE MATRIX.
C           RATIO  R,0    LINE TO (100 ANGSTROM) CONTINUUM RATIO
C           ERATIO R,0    EXPECTED ERROR IN RATIO
C           TEMP   R,0    TEMPERATURE FROM THE LINE:CONTINUUM RATIO
C           ETEMP  R,0    EXPECTED EXPERIMENTAL ERROR IN TEMP
C           HWIDTH R,0    HALF HALF WIDTH OF EXPERIMENTAL LINE
C                         (ANGSTROMS)
C
C     METHOD...
C
C           THE VARIANCE-COVARIANCE MATRIX IS NORMALIZED BY DIVIDING
C           EACH ROW AND EACH COLUMN BY THE SQUARE ROOT OF THE ORIGINAL
C           DIAGONAL ELEMENT, THE CALCULATIONS OF ERATIO AND ETEMP MAKE
C           USE OF THE APPROXIMATELY KNOWN COVARIANCE MATRIX ELEMENTS.
C           THE TEMPERATURE IS FOUND USING THE THEORETICAL RESULTS OF
C           DELCROIX AND VOLONTE.
C
C     SUBPROGRAMS REQUIRED...
C
C           NEWT,NEWU,SUMF,SIGMA,SYMINV
C
      DIMENSION ARGUM(4)
      LOGICAL OPT
      DIMENSION TATTLE(6)
```

ORIGINAL PAGE IS
OF POOR QUALITY

****** THEORY (FUNCT2) ******

```
      DATA BIGI/10./,BIGNE/10./
      REAL INT
      INCLUDE JBANK,LIST
      INCLUDE GROUP,LIST
C                   GET THE FINAL VALUES OF THE SUM OF SQUARES & ERROR
C                   MATRIX ELEMENTS
      CALL NEWT(ARG,NARG)
      CALL NEWU(ARG,NARG)
      V1=SIGMA(ARG)
      IF(OPT('O'))PRINT 701,ARG(1),ARG(2),V1
  701 FORMAT('0     ',2G13.6,'  FIND',G12.6)
      V1=FUNCT3(ARG)
      IF(OPT('O'))PRINT 701,ARG(1),ARG(2),V1
      MARKER=0
      BEPSI=BIGI*EPSI
      BEPSNE=BIGNE*EPSNE
      DO 10 I=1,NARG
   10 ARGUM(I)=ARG(I)
      CALL NEWT(ARGUM,NARG)
      CALL NEWU(ARGUM,NARG)
      CALL SUMF(ARGUM,NARG,SF,SFD,VALUE)
      TATTLE(4)=VALUE
      INT(1)=SUM(1,3)
      INT(2)=SUM(2,3)
      V=VALUE
      ARGUM(2)=ARG(2)-BEPSI
      S1=SIGMA(ARGUM)
      IF(S1.LE.VALUE)MARKER=1
      TATTLE(3)=S1
      ARGUM(2)=ARG(2)+BEPSI
      CALL SUMF(ARGUM,NARG,SF2,SFD2,S2)
      IF(S2.LE.VALUE)MARKER=1
      TATTLE(5)=S2
      COVAR(2,2)=.5*(TOTAL-4)*(S1-2*VALUE+S2)/BEPSI**2
      ARGUM(1)=ARG(1)+BEPSNE
      CALL NEWT(ARGUM,NARG)
      S1=SIGMA(ARGUM)
      IF(S1.LE.VALUE)MARKER=1
      TATTLE(2)=S1
      ARGUM(2)=ARG(2)
      CALL SUMF(ARGUM,NARG,SF3,SFD3,S3)
      IF(S3.LE.VALUE)MARKER=1
      TATTLE(1)=S3
      COVAR(1,2)=.5*(TOTAL-4)*(VALUE+S1-S2-S3)/(BEPSI*BEPSNE)
      ARGUM(1)=ARG(1)-BEPSNE
      CALL NEWT(ARGUM,NARG)
      S1=SIGMA(ARGUM)
      IF(S1.LE.VALUE)MARKER=1   ←CALL NEWT(ARG,NARG)
      TATTLE(6)=S1
      IF(MARKER.EQ.1)PRINT 702
  702 FORMAT(' *****  LEAST SQUARE SOLUTION NOT FOUND...NEARBY VALUES',
     -      ' FOLLOW  *****')
      IF(MARKER.EQ.1 .OR. OPT('Q'))PRINT 707,TATTLE
  707 FORMAT(13X,2G13.6/3G13.6/13X,G13.6/)
      COVAR(1,1)=.5*(TOTAL-4)*(S1-2.*VALUE+S3)/BEPSNE**2
      COVAR(1,3)=(SFD3-SFD)/BEPSNE
      COVAR(1,4)=(SF3-SF)/BEPSNE
```

```
****** THEORY (FUNCT2) ******
      COVAR(2,3)=(SFD2-SFD)/DEPSI
      COVAR(2,4)=(SF2-SF)/DEPSI
C                   COVAR(3,3), COVAR(3,4), AND COVAR(4,4) ARE SET BY
C                   PROGRAM 'MENU'
C
C                   INVERT TO FIND THE VARIANCE-COVARIANCE MATRIX
      DO 15 J=1,4
   15 IF(OPT('O'))PRINT 715,(COVAR(I,J),I=1,J)
  715 FORMAT(1X,4G13.6)
      CALL SYMINV(COVAR,4,4,0,$60)
      DO 18 J=1,4
   18 IF(OPT('O'))PRINT 715,(COVAR(I,J),I=1,J)
      DO 20 J=1,4
      DO 20 I=1,J
   20 COVAR(I,J)=COVAR(I,J)*V
C                   RESCALE ELECTRON DENSITY
      ARG(1)=1.E16*ARG(1)
C                   CORRECT REFERENCES TO DENSITY
C                   DENSITY ACTUALLY VARIES LIKE  (LINE WIDTH)**1.2
      R=1.
      IF(ABS(ARG(2)+BASF-4635.75) .GT. 10.)GO TO 25
      R=(1.2/1.5)*(ARG(1)/1.E17)**(1.2/1.5-1.)
      ARG(1)=1.E17*((ARG(1)/1.E17)**(1.2/1.5))
C                   WE MUST RECALCULATE THE HOLTSMARK FIELD STRENGTH
C                   WITH THE NEW DENSITY
      F0=1.2503E-9*ARG(1)**.6666666667
   25 COVAR(1,1)=1.E32*COVAR(1,1)*R**2
      COVAR(1,2)=1.E16*COVAR(1,2)*R
      COVAR(1,3)=1.E16*COVAR(1,3)*R
      COVAR(1,4)=1.E16*COVAR(1,4)*R
C                   EXTRACT THE VARIANCES OF THE INDIVIDUAL PARAMETERS
      SIG(1)=SIGN(SQRT(ABS(COVAR(1,1))),COVAR(1,1))
      SIG(2)=SIGN(SQRT(ABS(COVAR(2,2))),COVAR(2,2))
      E(1)=  SIGN(SQRT(ABS(COVAR(3,3))),COVAR(3,3))
      E(2)=  SIGN(SQRT(ABS(COVAR(4,4))),COVAR(4,4))
C                   FIND THE LINE-CONTINUUM RATIO & ERROR
      RATIO=INT(1)/(INT(2)*100.)
      ERATIO=RATIO*SQRT(ABS( COVAR(3,3)/INT(1)**2
     -     +COVAR(4,4)/INT(2)**2
     -     -2.*COVAR(3,4)/(INT(1)*INT(2))  ))
C                   IF LINE IS HE II 4686, FIND TEMPERATURE & ERROR
      IF(RATIO.LT..001 .OR. ABS(ARG(2)+BASE-4685.75).GT.10.)GO TO 30
      TEMP=.208*ALOG(ARG(1))+.209*ALOG(RATIO(1))-5.10
      TN=.208/ARG(1)
      TL=.209/INT(1)
      TC=-.209/INT(2)
      ETEMP=SQRT(ABS( TN*TN*COVAR(1,1)
     -     +TL*TL*COVAR(3,3)
     -     +TC*TC*COVAR(4,4)
     -     +2.*TN*TL*COVAR(1,3)
     -     +2.*TN*TC*COVAR(1,4)
     -     +2.*TL*TC*COVAR(3,4) ))
C                   NORMALIZE THE VARIANCE-COVARIANCE MATRIX
   30 COVAR(1,2)=COVAR(1,2)/(SIG(1)*SIG(2))
      COVAR(1,3)=COVAR(1,3)/(SIG(1)*E(1))
      COVAR(1,4)=COVAR(1,4)/(SIG(1)*E(2))
      COVAR(2,3)=COVAR(2,3)/(SIG(2)*E(1))
```

****** THEORY (FUNCT2) ******

```
      COVAR(2,4)=COVAR(2,4)/(SIG(2)*E(2))
      COVAR(3,4)=COVAR(3,4)/(E(1)*E(2))
      DO 40 J=1,4
   40 COVAR(J,J)=1.
C                    FIND HALF INTENSITY POINT OF EXPERIMENTAL PROFILE
      HALF=TDEL(2)/2.
      DO 45 KS=2,NS2
      IF(TDEL(KS).LT.HALF)GO TO 48
   45 CONTINUE
      KS=NS2
   48 X1=DEL(KS)
      Y1=TDEL(KS)
      X2=DEL(KS-1)
      Y2=TDEL(KS-1)
      DO 50 J=1,4
      X=((Y2-HALF)*X1-(Y1-HALF)*X2)/(Y2-Y1)
      X2=X1
      Y2=Y1
      X1=X
   50 Y1=VALUE(DEL,TDEL,NS2,X,Q)
      HWIDTH=((Y2-HALF)*X1-(Y1-HALF)*X2)/(Y2-Y1)
      VALUE=SQRT(V)
      RETURN
   60 PRINT 908
  908 FORMAT(' INVERSION FAILURE FINDING COVARIANCE MATRIX')
      RETURN
      END
```

W.EJECT

****** THEORY (TPLOT) ******

```
2U5373J1H*.ORKSPACE$(1).TPLOT
          SUBROUTINE TPLOT(YMAX,BOTTOM,TOP)
    C
    C     NAME...
    C            TPLOT
    C
    C     PURPOSE...
    C            TO PLOT THE EXPERIMENTAL DATA AND THEORETICAL BEST-
    C            FIT PROFILE.
    C
    C     USAGE...
    C
    C            CALL TPLOT (AMAX,BOTTOM,TOP)
    C
    C            AMAX   R.O    LABEL FOR END OF Y AXIS
    C            BOTTOM R.O    LABEL FOR ORIGIN OF X AXIS
    C            TOP    R.O    LABEL FOR END OF X AXIS
    C
    C            VARIABLES IN COMMON: ALMOST EVERYTHING
    C
    C     SUBROUTINES USED...
    C
    C            PLOTC  STANDARD PLOT SUBROUTINE, USED TO POSITION THE PEN
    C            NSCALE FINDS PLOT SCALING PARAMETERS FOR EASILY INTERPRETED
    C                   AXIS LABELS
    C            AXISN  DRAWS AN AXIS
    C            'SYMBOL' DRAWS A SYMBOL AT THE DESIRED POSITION
    C            PAGEUP COMPLETES THE PLOT AND REPOSITIONS THE PEN ONTO
    C                   THE NEXT PAGE
    C
    C     METHOD...
    C            NOTE THAT THE AXES USED IN THIS ROUTINE ARE ROTATED 90
    C            DEGREES CCW FROM THOSE USED BY THE SYSTEM ROUTINES. THUS,
    C            MY '+Y' DIRECTION IS THEIR '-X', AND MY '+X' IS THEIR '+Y'.
    C
          DIMENSION ARG(4),INT(4)
          INCLUDE DBANK,LIST
          INCLUDE GROUP,LIST
          REAL L,INT,LBOUND
          DATA  WIDTH,HEIGHT,    NY,    NX
         -    /    8.,    5.5,    5,    15/
    C
    C                  BEST FIT CURVE
          FIT(Z)=INT(1)*VALUE(DEL,TDEL,NS2,Z,Q)+INT(NARG)
    C
    C                  FIND LARGEST & SMALLEST VALUES ALONG EACH AXIS
          BOTTOM=LENGTH(1)
          TOP=LENGTH(NU)
          YMAX=FIT(0.)
          CENTER=ARG(2)+BASE
          UBOUND=CENTER+10.*HWIDTH
          LBOUND=CENTER-10.*HWIDTH
          DO 15 KU=1,NU
    C                  DON'T PLOT POINTS FURTHER THAN 10 HHW TO EITHER SIDE
          IF(LENGTH(KU).GE.LBOUND)BOTTOM=AMIN1(BOTTOM,LENGTH(KU))
          IF(LENGTH(KU).LE.UBOUND)TOP=AMAX1(TOP,LENGTH(KU))
          N=NSHOT(KU)
```

****** THEORY (TPLOT) ******

```
      DO 15 KSHOT=1,N
   15 YMAX=AMAX1(YMAX,INTEXP(KU,KSHOT))
C                     PLOT AT LEAST 4 HHW TO EACH SIDE
      BOTTOM=AMIN1(BOTTOM,CENTER-4.*HWIDTH)
      TOP=AMAX1(TOP,CENTER+4.*HWIDTH)
C
C                     FIND SCALING PARAMETERS
      NTICX=NX
      CALL NSCALE(BOTTOM,TOP,NTICX,WIDTH,DX)
      DX=1./DX
      NTICY=NY
      ZERO=0.
      CALL NSCALE(ZERO,YMAX,NTICY,HEIGHT,DY)
      DY=-1./DY
C
      CALL PLOTC(7.5,1.0,-3)
C
C                     DRAW AXES
      CALL AXISN(0.,0.,NTICY,HEIGHT,-.1,180.)
      CALL AXISN(0.,0.,NTICX,WIDTH,.1,90.)
C
C                     DRAW A DOTTED LINE FOR THE CONTINUUM LEVEL
C                     (IF POSITIVE)
      IF(INT(NARG).LT.0.)GO TO 20
      U=DY*INT(NARG)
      L=DX*(TOP-BOTTOM)
      DL=-L/69.
      DO 18 KU=1,35
      CALL PLOTC(U,L,3)
      CALL PLOTC(U,L+DL,2)
   18 L=L+DL+DL
      CALL PLOTC(U,L,3)
C
C                     PLOT THE EXPERIMENTAL POINTS
   20 NSYMB=4
      DO 30 KU=1,NU
      IF(KU.EQ.NU1)NSYMB=0
      IF(LENGTH(KU).LT.BOTTOM .OR. LENGTH(KU).GT.TOP) GO TO 30
      U=0.
      N=NSHOT(KU)
      DO 25 KSHOT=1,N
   25 U=U+INTEXP(KU,KSHOT)
      CALL SYMBOL(DY*U/N,DX*(LENGTH(KU)-BOTTOM),.1,NSYMB,90.,-1)
   30 IF(KU.EQ.NU2)NSYMB=4
C
C                     DRAW THE THEORETICAL CURVE
      L=TOP
      DL=-(TOP-BOTTOM)/250.
      NPEN=3
      DO 40 KU=1,251
      U=FIT(CENTER-L)
      CALL PLOTC(DY*U,DX*(L-BOTTOM),NPEN)
      NPEN=2
   40 L=L+DL
      CALL PAGEUP
      RETURN
      END
```

****** THEORY (AXISN) ******

```
205373JIM*WORKSPACE.(1).AXISN
      SUBROUTINE AXISN (XX,YY,NTIC,ALNTH,TIC,ANGLE)
C
C     NAME...
C             AXISN
C
C     PURPOSE...
C             TO DRAW ONE AXIS FOR A 2-DIMENSIONAL GRAPH
C
C     USAGE...
C
C             CALL AXISN (X,Y,NTIC,ALNTH,TIC,ANGLE)
C
C             X,Y     R,I     POSITION OF START OF AXIS (INCHES FROM PAPER
C                             ORIGIN)
C             NTIC    I,I     NUMBER OF LINE SEGMENTS BETWEEN TIC MARKS
C             ALNTH   R,I     LENGTH OF AXIS (INCHES)
C             TIC     R,I     LENGTH OF TIC MARKS (INCHES)
C                             TIC.GT.0 FOR MARKS ON CLOCKWISE SIDE
C                             TIC.LT.0 FOR MARKS ON COUNTER-CLOCKWISE SIDE
C             ANGLE   R,I     ANGLE OF AXIS FROM X-AXIS (DEGREES)
C
      A=ALNTH/NTIC
      X=XX
      Y=YY
      C=COS(.0174533*ANGLE)
      S=SIN(.0174533*ANGLE)
      AX=C*A
      AY=S*A
      TX=-S*TIC
      TY=C*TIC
      CALL PLOTC(X+TX,Y+TY,3)
      DO 10 I=1,NTIC
      CALL PLOTC(X,Y,2)
      X=X+AX
      Y=Y+AY
      CALL PLOTC(X,Y,2)
   10 CALL PLOTC(X+TX,Y+TY,2)
      CALL PLOTC(X+TX,Y+TY,3)
      RETURN
      END


@.EJCT
```

****** THEORY (NEWS) ******

```
2U53730IM*,ORKSPACE$(1).NEWS
          SUBROUTINE NEWS(ARG,NARG)
C
C         NAME...
C                NEWS
C
C         PURPOSE...
C                TO CONVOLVE THE THEORETICAL AND THE INSTRUMENT PROFILES.
C
C         CALLING SEQUENCE...
C
C                CALL NEWS(ARG,NARG)
C
C                ARG     R,I     ARRAY OF NONLINEAR PARAMETERS
C                                ARG(1) IS THE ELECTRON DENSITY TIMES 1.E-16 .
C                NARG    I,      NUMBER OF NONLINEAR PARAMETERS PRESENT
C
C         METHOD...
C                THE HOLTZMARK FIELD STRENGTH IS CALCULATED, AND USED TO
C                FIND THE AMOUNT OF BROADENING NEEDED IN (S(ALPHA),ALPHA)
C                SPACE. THIS IS ACCURATE IF THE FINAL ELECTRON DENSITY IS
C                CLOSE TO THE ORIGINAL ESTIMATE USED HERE. THE GAUSSIAN
C                HERMITE QUADRATURE FORMULA USED HERE IS EXACT FOR THE
C                INTEGRAL OF A GAUSSIAN INSTRUMENTAL PROFILE AND A FIFTH ORDER
C                CURVE FOR THE THEORETICAL PROFILE.
C
          INCLUDE DBANK,LIST
          DIMENSION ARG(4)
C                       WE USE THE HOLTZMARK NORMAL FIELD STRENGTH
C                       F0=2.603*Z*4.8035E-10*NE**(2/3)
          F0=1.2503E-9*(1.E16*ARG(1))**.66666666667
C                       WE USE THE ORDINATE FOR THE 3 POINT GAUSSIAN
C                       HERMITE QUADRATURE FORMULA
C                       DELTA=(HHW/F0)*SQRT(3/(2*ALOG(2)))
          DELTA=1.4710685*HHW/F0
          N=NS1
          DO 10 KS=2,N
          ALPH2(KS+1)=ALPH1(KS)
       10 SALPH2(KS+1)=.166666666*
     -         (VALUE(ALPH1,SALPH1,NS1,ALPH1(KS)-DELTA,0)
     -         +4.*SALPH1(KS)
     -         +VALUE(ALPH1,SALPH1,NS1,ALPH1(KS)+DELTA,0))
          ALPH2(1)=-ALPH2(3)
          SALPH2(1)=SALPH2(3)
          SALPH2(2)=.6666666666*SALPH1(1)
     -         +.3333333333*VALUE(ALPH1,SALPH1,NS1,DELTA,0)
          ALPH2(2)=0.
          RETURN
          END
```

@.EJCT

****** THEORY (NEWT) ******

```
2053730IN*,ORKSPACES(1).NEWT
      SUBROUTINE NEWT(ARG,NARG)
C
C     NAME...
C            NEWT
C
C     PURPOSE...
C            TO CALCULATE THE PROFILE IN WAVELENGTH SPACE, KNOWING
C            THE ELECTRON DENSITY AND THE PROFILE IN (S(ALPHA),ALPHA)
C            SPACE
C
C     CALLING SEQUENCE...
C
C            CALL NEWT (ARG,NARG)
C
C            ARG     R,I     ARRAY OF NONLINEAR ARGUMENTS
C                            ARG(1) IS ELECTRON DENSITY TIMES 1.E-16 .
C            NARG    I,I     NUMBER OF NONLINEAR ARGUMENTS
C
      INCLUDE DBANK,LIST
      DIMENSION ARG(5)
C                    WE USE THE HOLTZMARK NORMAL FIELD STRENGTH
C                    F0=2.603*Z*4.803E-10*NE**(2/3)
      IF(ARG(1).LE.0.)GO TO 90
      F0=1.2503E-9*(1.E16*ARG(1))**.6666667
      F0INV=1./F0
      N=NS2
      DO 20 KS=2,N
      TDEL(KS)=F0INV*SALPH2(KS)
   20 DEL(KS)=F0*ALPH2(KS)
      TDEL(1)=TDEL(3)
      DEL(1)=-DEL(3)
      RETURN
   90 PRINT 901,ARG(1)
  901 FORMAT(' NEWT: DENSITY OF',G9.3,' *1.E16 ?')
      STOP
      END
```

@.EJCT

****** THEORY (NEWU) ******

```
205373J1**,)RASPACES(1).NEWU
C
C      NAME...
C              NEWU
C
C      PURPOSE...
C              TO SOLVE THE LINEAR PART OF THE LEAST SQUARE FIT.
C
C      USAGE...
C
C              CALL NEWU(ARG,NARG)
C
C              ARG     R,I     ARRAY OF NONLINEAR ARGUMENTS
C              NARG    I,I     NUMBER OF NONLINEAR ARGUMENTS
C
C              VARIABLES IN COMMON:
C
C              SUM     R,O     SUM(1,3) IS THE LINE INTENSITY
C                              SUM(2,3) IS THE BACKGROUND INTENSITY
C              COVAR   R,O     COVAR(3,3), COVAR(3,4), AND COVAR(4,4) ARE
C                              INSERTED FOR LATER USE BY PROGRAM 'FUNCT2'
C
       SUBROUTINE NEWU(ARGUM,NARGUM)
       INCLUDE DBANK,LIST
       INCLUDE GROUP,LIST
       DIMENSION ARGUM(4)
       A=ARGUM(2)+BASE
       DO 15 I=1,NARGUM
       DO 15 J=I,NARGUM+1
    15 SUM(I,J)=0.
       DO 25 KU=NU1,NU2
       T=VALUE(DEL,TDEL,NS2,A-LENGTH(KU),0)
       N=NSHOT(KU)
       SUM(1,1)=SUM(1,1)+T*T*N
       SUM(1,2)=SUM(1,2)+T*N
       DO 25 KSHOT=1,N
       SUM(1,3)=SUM(1,3)+INTEXP(KU,KSHOT)*T
       SUM(2,3)=SUM(2,3)+INTEXP(KU,KSHOT)
    25 CONTINUE
       SUM(2,2)=TOTAL
C                      SAVE ELEMENTS FOR CALCULATION OF VARIANCE-
C                      COVARIANCE MATRIX
       COVAR(3,3)=SUM(1,1)
       COVAR(3,4)=SUM(1,2)
       COVAR(4,4)=SUM(2,2)
C                      HAVE THIS SYMMETRIC SYSTEM SOLVED
       CALL SYMSLV(SUM,SUM(1,NARGUM+1),NARGUM,4,0,$40)
       RETURN
    40 PRINT 908
   908 FORMAT(' SINGULAR MATRIX!')
       STOP
       END
```

@.EJCT

****** THEORY (SIGMA) ******

```
2053730IV*WORKSPACES(1).SIGMA
            FUNCTION SIGMA(ARG)
      C
      C     PURPOSE...
      C            TO FIND THE MEAN SQUARE DEVIATION OF THE DATA FROM THE
      C            VALUES PREDICTED USING THE CURRENT PARAMETERS.
      C
            INCLUDE DBANK.LIST
            DIMENSION ARG(4)
            LOGICAL OPT
            SIGMA=0.
            A=ARG(2)+BASE
            DO 20 KU=NU1,NU2
            T=VALUE(DEL,TDEL,NS2,A-LENGTH(KU),0)
            U=SUM(1,3)*T+SUM(2,3)
            N=NSHOT(KU)
            DO 20 KSHOT=1,N
         20 SIGMA=SIGMA+(INTEXP(KU,KSHOT)-U)**2
            SIGMA=SIGMA/(TOTAL-4)
            RETURN
            END
```

0.EJCT

****** THEORY (SYMSLV) ******

```
205373JIM*WORKSPACES(1).SYMSLV
      SUBROUTINE SYMSLV(A,B,N,NN,IT,S)
C
C     NAME...
C
C            SYMMETRIC LINEAR EQUATION SOLVER
C
C     CODE NAME...
C
C            SYMSLV
C
C     PURPOSE...
C
C            TO SOLVE A LINEAR SYSTEM AX=B WHEN THE MATRIX A IS
C            SYMMETRIC AND POSITIVE DEFINITE. THE ROUTINE CAN BE
C            CALLED SUBSEQUENTLY TO PERFORM THE SOLUTION FOR
C            A NEW RIGHT HAND SIDE WITHOUT DECOMPOSING AGAIN.
C
C     CALLING SEQUENCE...
C
C            CALL SYMSLV(A,B,N,NN,IT,$60)
C
C            ARGUMENTS ON ENTRY:
C            A       MATRIX OF COEFFICIENTS. SINCE IT IS SYMMETRIC,
C                    ONLY ELEMENTS NEEDED ARE A(I,J), 1.LE.I.LE.J.LE.N .
C            B       ARRAY OF ELEMENTS FROM RIGHT HAND SIDE
C            N       DIMENSION OF MATRIX AND B.
C            NN      MAXIMUM NUMBER OF ROWS IN A (FIRST DIMENSION)
C            IT      SWITCH...IT=1 IF MATRIX A WAS DECOMPOSED ON A
C                    PREVIOUS CALL TO SYMSLV, AND ONLY THE ARRAY B
C                    IS DIFFERENT THIS TIME.  IT.NE.1 IF A IS NEW.
C            $60     CONTROL WILL BE PASSED TO THIS STATEMENT IF
C                    A PIVOT ELEMENT IS FOUND OF ABSOLUTE VALUE
C                    LESS THAN 1.E-10.
C
C            ARGUMENTS ON RETURN:
C            A       ORIGINAL MATRIX IS DESTROYED. LOWER TRIANGLE HOLDS
C                    LOWER TRIANGLE OF MATRIX L. (DIAGONAL ELEMENTS OF L
C                    ARE 1'S.) DIAGONAL ELEMENTS HOLD MATRIX D.
C            B       SOLUTION ARRAY X.
C
C     METHOD...
C
C            SYMMETRIC FACTORIZATION IS USED TO FIND A LOWER
C            TRIANGULAR MATRIX L AND A DIAGONAL MATRIX D SUCH
C            THAT A=LDU, WHERE U IS L TRANSPOSED. THE UNKNOWN
C            VECTOR IS CALCULATED BY BACK SOLVING THESE TRIANGULAR
C            SYSTEMS: UZ=B , DY=Z , LX=Y .
C
      DIMENSION B(5),A(25)
      IF(N.GT.1)GO TO 10
      B(1)=B(1)/A(1)
      RETURN
   10 IF(IT.EQ.1)GO TO 28
      DO 25 K=1,N-1
      IF(ABS(A(K+NN*K-NN)) .LT. 1.E-10)RETURN 6
      DO 25 J=K+1,N
```

```
                         ******  THEORY (SYMSLV)  ******
      S=A(K+NN*J-NN)/A(K+NN*K-NN)
      DO 20 I=J,N
   20 A(J+NN*I-NN)=A(J+NN*I-NN)-S*A(K+NN*I-NN)
   25 A(J+NN*K-NN)=S
   28 DO 30 J=2,N
      DO 30 I=1,J-1
   30 B(J)=B(J)-A(J+NN*I-NN)*B(I)
      DO 40 J=1,N
   40 B(J)=B(J)/A(J+NN*J-NN)
      DO 50 J=N-1,1,-1
      DO 50 I=J+1,N
   50 B(J)=B(J)-A(I+NN*J-NN)*B(I)
      RETURN
      END

@.EJCT
```

****** THEORY (VALUE) ******

```
205373JIH*WORKSPACE$(1).VALUE
      FUNCTION VALUE(X,Y,N,XB,P)
C
C     NAME...
C             VALUE
C
C     PURPOSE...
C             TO INTERPOLATE IN A TABLE TO FIND INTENSITIES FROM
C             THE THEORETICAL LINE PROFILE.
C
C     CALLING SEQUENCE...
C
C             CALL VALUE(WAVE,INT,N,WANT,P)
C
C             WAVE    R,I     ARRAY OF WAVELENGTHS (DISPLACEMENTS FROM
C                             LINE CENTER)
C             INT     R,I     ARRAY OF CORRESPONDING LINE INTENSITIES
C             N       I,I     NUMBER OF ENTRIES IN WAVE OR INT
C             WANT    R,I     WAVELENGTH AT WHICH INTENSITY IS DESIRED
C             P       R,IO    WORK ARRAY OF LENGTH 4. P(1) IS USED TO STORE
C                             A POINTER BETWEEN CALLS, SO EACH SEARCH OF
C                             WAVE BEGINS WHERE THE PRECEDING SEARCH ENDED.
C
C     METHOD...
C             BEYOND THE END OF THE TABLE, A 5/2 POWER LAW IS USED TO
C             EXTRAPOLATE. WITHIN THE TABLE, AITKEN'S PROCEDURE IS
C             APPLIED USING 4 POINTS. SINCE AN EVEN NUMBER OF POINTS
C             IS USED, THE INTERPOLATING FUNCTION IS CONTINUOUS.
C
C
      DIMENSION X(N),Y(N),P(4)
      EQUIVALENCE(SAVEJ,J)
      XBAR=ABS(XB)
C                     IF ON FAR WING OF LINE, USE ASYMTOTIC FORMULA
      IF(XBAR.GE.X(N))GO TO 90
C                     RETRIEVE POINTER FROM LAST CALL
      SAVEJ=P(1)
C                     ENSURE 1 .LE. J .LE. N
      J=MAX0(MIN0(J,N),1)
C                     DECIDE WHETHER TO SEARCH UP OR DOWN
      IF(XBAR-X(J))10,80,20
C                     SEARCH DOWN
   10 IF(J.LE.1)GO TO 50
      JSTART=J
      DO 12 J=JSTART,2,-1
      IF(XBAR-X(J-1))12,75,40
   12 CONTINUE
      J=1
      GO TO 50
C                     SEARCH UP
   20 IF(J.GE.N)GO TO 30
      JSTART=J+1
      DO 22 J=JSTART,N,1
      IF(XBAR-X(J))40,80,22
   22 CONTINUE
   30 J=N-3
      GO TO 50
```

```
                         ****** THEORY (VALUE) ******
C                       SAVF THIS POINTER
   40 S=SAVEJ
C                       SET J TO POINT TO FIRST OF THE 4 POINTS
C                       IN X NEAREST XBAR
      J=MINO(MAXO(J-2,1),N-3)
C                       APPLY AITKEN'S PROCEDURE USING 4 POINTS
   50 P(1)=Y(J)
C                       THE GROUP OF STATEMENTS TO FOLLOW IS EQUIVALENT TO:
C     DO 60 I=2,4
C     P(I)=Y(J+I-1)
C     DO 60 L=2,I
C     P(I)=(P(L-1)*(X(J+I-1)-XBAR)-P(I)*(X(J+L-2)-XBAR))/
C    -      ((X(J+I-1)-XBAR)-(X(J+L-2)-XBAR))
C  60 CONTINUE
C                       ...BUT (WITHOUT LOOP CONTROL) WILL EXECUTE FASTER
      P(2)=Y(J+2-1)
      P(2)=(P(2-1)*(X(J+2-1)-XBAR)-P(2)*(X(J+2-2)-XBAR))/
     -      ((X(J+2-1)-XBAR)-(X(J+2-2)-XBAR))
      P(3)=Y(J+3-1)
      P(3)=(P(2-1)*(X(J+3-1)-XBAR)-P(3)*(X(J+2-2)-XBAR))/
     -      ((X(J+3-1)-XBAR)-(X(J+2-2)-XBAR))
      P(3)=(P(3-1)*(X(J+3-1)-XBAR)-P(3)*(X(J+3-2)-XBAR))/
     -      ((X(J+3-1)-XBAR)-(X(J+3-2)-XBAR))
      P(4)=Y(J+4-1)
      P(4)=(P(2-1)*(X(J+4-1)-XBAR)-P(4)*(X(J+2-2)-XBAR))/
     -      ((X(J+4-1)-XBAR)-(X(J+2-2)-XBAR))
      P(4)=(P(3-1)*(X(J+4-1)-XBAR)-P(4)*(X(J+3-2)-XBAR))/
     -      ((X(J+4-1)-XBAR)-(X(J+3-8)-XBAR))
      P(4)=(P(4-1)*(X(J+4-1)-XBAR)-P(4)*(X(J+4-2)-XBAR))/
     -      ((X(J+4-1)-XBAR)-(X(J+4-2)-XBAR))
      VALUE=P(4)
C                       SAVF THE POINTER IN THE WORK ARRAY
      P(1)=S
      RETURN
C                       XBAR APPEARS IN THE TABLE, SO WE USE THE
C                       CORRESPONDING TABLE ENTPY
   75 J=J-1
   80 VALUE=Y(J)
      P(1)=SAVEJ
      RETURN
   90 VALUE=Y(N)*(X(N)/XBAR)**2.5
      RETURN
      END
```

B.EJCT

REFERENCES

1. H. F. Berg, A. W. Ali, R. Lincke and H. R Griem, "Measurement of Stark Profiles of Neutral and Ionized Helium and Hydrogen Lines for Shock-Heated Plasmas in Electromagnetic T-Tubes", Phys. Rev. 125, 199 (1962).

2. H. F. Berg, "Plasmaeffekte an einer ionisierten Heliumlinie", Z Physik 191, 503 (1966).

3 J. R. Greig, H. R. Griem, L. A. Jones and T. Oda, "Observation of a Plasma Polarization Shift for the Resonance Line of Ionized Helium", Phys. Rev. Letters 24, No. 1, 3 (1970).

4. A. H Gabriel and S. Volonte, "Measurement and Interpretation of Plasma Polarization Shift for Members of the Resonance Series of Ionized Helium", J. Phys. B 6, 2684 (1973)

5. T. Goto and D. D. Burgess, "Plasma Polarization Shifts of He II Resonance Lines", J Phys B 6, 857 (1974).

6. M. Neiger and H. R. Griem,"Experimental Investigation of Stark Broadening and Plasma Polarization Shift of Ionized Helium Resonance Lines", to be published.

7 H. R. Griem, M. Baranger, A. C. Kolb, and G Oertel, "Stark Broadening of Neutral Helium Lines in a Plasma", Phys. Rev 125, 177 (1962).

8. S. Volonte, J. Phys B 8, 1170 (1975).

9. P. C. Kepple, "Improved Stark-Profile Calculations for the He II Lines at 256, 304, 1085, 1216, 1640, 3203, and 4686 Å", Phys. Rev. A [3] 6, 1 (1972); "Stark Profile Calculations for Ionized Helium Lines", Rep 72-018, Univ. of Maryland, College Park, Md. (1971).

10. H. R. Griem, Spectral Line Broadening by Plasmas, Academic Press, New York (1974).

11. W. Wiese, H. F. Berg, and H. R. Griem, "Measurements of Temperatures and Densities in Shock-Heated Hydrogen and Helium Plasmas", Phys. Rev. 120, 1079 (1960).

12. W. Wiese, H. F. Berg, and H. R. Griem, "Measurement of the Structure of Strong Shocks in Helium Filled T-Tubes", Phys. Fluids 4, 250 (1961).

13. H. R. Griem, Plasma Spectroscopy, McGraw-Hill, New York (1964).

14. N. A. Krall and A. W. Trivelpiece, Principles of Plasma Physics, McGraw-Hill, New York (1973).

15. W. L. Wiese, M. W. Smith, and B. M. Glennon, Atomic Transition Probabilities, Vol. 1, U. S. Gov't. Printing Office, Wash., D. C. (1966).

16. F. Cabannes and J. Chapelle, "Spectroscopic Plasma Diagnostics", in Reactions Under Plasma Conditions, M. Venugopalan, ed., Wiley, New York (1971).

17. W. J. Karzas and R. Latter, "Electron Radiative Transitions in a Coulomb Field", Astrophys. J. Suppl. VI, no. 55, 167 (1961).

18. D. R. Bates, Mon. Not. Roy. Astr. Soc., 106, 432 (1946).

19. A. Burgess and J. Seaton, Mon. Not. Roy. Astr. Soc. 120, 121 (1959).

20. N. A. Doughty and P. A. Fraser, in Atomic Collision Processes, North-Holland, Amsterdam (1964).

21. D. R. Inglis and E. Teller, "Ionic Depression of Series Limit in One-Electron Spectra", Astrophys. J., 90, 439 (1939).

22. E. U. Condon and G. H. Shortly, The Theory of Atomic Spectra, Cambridge, Cambridge (1951).

23. L. H. Aller, Astrophysics: The Atmospheres of the Sun and Stars, Ronald, New York (1963), 2nd. ed.

24. B. W. Shore and D. H. Menzel, Principles of Atomic Spectra, Wiley, New York (1968).

25. W. Heitler, The Quantum Theory of Radiation, 3rd ed., Clarendon Press, Oxford (1954).

26. J. W. Strutt (Baron Rayleigh), Phil. Mag. 27, 298 (1889).

27. H. Bethe and E. E. Salpeter, Quantum Mechanics of One- and Two-Electron Atoms, Academic, New York (1957).

28. J. Holtzmark, "Über die Verbreiterung von Spektrallinien", Ann. Physik 58, 577 (1919).

29. A. C. Kolb, "Production of High-Energy Plasmas by Magnetically Driven Shock Waves", Phys Rev. 107, 345 (1957).

30. A. C. Kolb, Proc. of the 4th Intern. Conf. on Ionization Phenomena in Gases, North-Holland Publish. Co., Amsterdam, 1021 (1960).

31. R. C. Elton, U. S. Naval Research Laboratory Report No. 5967 (1963).

32. R. C. Elton and H. R. Griem, "Measurement of Stark Profiles of the Lyman-α and Lyman-β Lines of Hydrogen in an Electromagnetic Shock Tube", Phys. Rev. 135, A1550 (1964).

33. J. D. Hey and H. R. Griem, "Central Structure of Low-n Balmer Lines in Dense Plasmas", Phys. Rev. A, 12, 169 (1975).

34. L. A. Jones, "Stark Profile Measurement for the First Four n-α Lines of Ionized Helium", University of Maryland Technical Report No. 71-090 (1971).

35. R. Lincke and H. R. Griem, "Method for Determination of Atomic-Resonance Line-Oscillator Strengths from Widths of Optically Thick Emission Lines in T-Tube Plasmas", Phys. Rev. 143, 66 (1966).

36. J. D. E. Fortna, R. C. Elton, and H. R. Griem, "Measurements of the Electron-Impact Broadening of Ionized Nitrogen and Carbon Resonance Lines in a High-Pressure Electric Shock Tube", Phys. Rev. A 2, 1150 (1970).

37. A. H. Gabriel and S. Volonte, "Plasma Polarization Shift for Members of the Resonance Series of Ionized Helium", Phys. Lett. 43A, 372 (1973).

38. T. N. Lie, M. U. Rhee, and E. A. McLean, "Validity of Local Thermal Equilibrium Assumption in Electromagnetic Shock Tubes", Phys. Fluids 13, 2492 (1970).

39. M. Brunet, M. Cantin, C. Julliot, and J. Vasseur, J. Phys. 24, (Suppl. 3), 53A (1963).

40. D. Heath and P. Sacher, "Effects of a Simulated High-Energy Space Environment to the Ultraviolet Transmittance of Optical Materials Between 1050 Å and 3000 Å", Applied Optics 5, 937 (1966).

41. A. Delcroix and S. Volonte, "Temperature Determination from the Relative Line-to-Continuum Intensity of the He II 4686 and 3203 Lines", J. Phys. B6, L4 (1963).

42. H. R. Griem, private communication.

43. D. D. Burgess, Astrophys J. 139, 776 (1964).

44. H. W. Drawin, "Thermodynamic Properties of the Equilibrium and Nonequilibrium States of Plasmas", in Reactions Under Plasma Conditions, M. Venugopalan, ed., Wiley, New York (1971).

45. D. D. Burgess and N. J. Peacock, "Reduced Limits on the Magnitude of Possible Plasma Polarization Shifts", J. Phys. B 4, L94 (1971).

46. A. Eberhagen and R. Wunderlich, "Profile Measurements of Pressure Broadened He II-Lines", Z. Physik 232, 1 (1970).

47. W. A. Cilliers, R. U. Datla, and H. R. Griem, "Spectroscopic Measurements on Vacuum Spark Plasmas", Phys. Rev. A 12, 1408 (1975).

48. J. Orear, Notes on Statistics for Physicists, University of California Radiation Laboratory Report 8417, (1958).

49. Standard Mathematical Tables, 19th Ed., Chemical Rubber Company, (1971).

50. "IBM System/360 Disc Operating System FORTRAN IV Programmer's Guide", IBM (1970).

51. "Univac 1100 Series FORTRAN V Programmer Reference", Sperry Univac (1973).

52. M. Abramowitz and I. A. Stegun, Handbook of Mathematical Functions, Dover, New York (1964).

53. "International Mathematical and Statistical Library, Library 2 Reference Manual", IMSL, Houston (1974).

54. W. Zangwill, "Minimizing a Function Without Calculating Derivatives", Computer Journal 10, 293 (1967).

55. M. J. D. Powell, "An Efficient Method for Finding the Minimum of a Function of Several Variables without Calculating Derivatives", Computer Journal 7, 155 (1964).