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DATA ACQUISITION SYSTEM FOR CO_2 LINESHAPE AND LINEWIDTH ANALYSIS

by

(C)

MEENAKSHINATHAN PARAMESWARAN

A THESIS

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Supervisor

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Dedicated

To my Parents

ABSTRACT

The advances in methods and equipment for data acquisition have improved the accuracy in the results obtained from experiments. In the case of carbon dioxide laser linewidth analysis, the line parameters have been measured and computed by an indirect approach of measuring the absorption coefficient at the line center [27].

A better method of analysing the linewidth of the carbon dioxide laser transitions is to directly measure the lineshape and then compute the linewidth. This method poses a problem of manipulating voluminous data for analysis. With the advent of microprocessors, data acquisition systems can be constructed to handle the data.

One such data acquisition system for use in a single pass absorption experiment was proposed and conducted. The single pass absorption experiment uses a tunable diode laser as a radiation source to measure the lineshape and linewidth of carbon dioxide laser transitions as a function of temperature and pressure.

This thesis describes the experiment, construction of the data acquisition system and the analysis of data. The results obtained from this experiment includes the lineshape and linewidth of the P(16) carbon dioxide laser transition as a function of temperature and pressure.

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Table of Contents

List of Tables

List of Figures

Figure Page

List of Plates

1. INTRODUCTION

1.1 Carbon dioxide lasers

Carbon dioxide plays an important role as active medium in CO_2 lasers, amplifiers, and attenuators, as well as affecting atmospheric transmission of infrared radiation at 10μm. CO_2 lasers have numerous uses in the field of communications, medical and industrial applications, and fusion studies. The linewidth (bandwidth at half maximum of the lineshape function) of the radiative transition in CO_2 is an essential parameter which determines the laser efficiency, optical amplification, and absorption in the applications mentioned above. The knowledge of the variation of linewidth with temperature and the lineshape in the 0 to 100 Torr pressure range is necessary for more complete understanding of numerous effects in CO_2.

The objective of this research project is the systematic measurement of linewidth as function of temperature and pressure by determining the lineshape and then computing the bandwidth at half maximum. This approach will provide us much more accurate results than the results obtained from [3], [6] and [27].

1.2 Linewidth and Broadening

Laser action in a gas is obtained by subjecting the gas to an electric discharge. The energetic electrons produced by the discharge collide with gas molecules, exciting them to higher energy levels. These excited molecules then fall to lower energy levels, emitting the excess energy in the form of photons. The spectral analysis of the radiation emitted by spontaneous transitions shows that the radiation is not strictly monochromatic but occupies a finite frequency bandwidth. The function describing the distribution of emitted energy versus frequency is referred to as the lineshape function $g(\nu)$ of the transition. The scale factor is usually chosen so that the function is normalised according to

$$\int_{-\infty}^{+\infty} g(\nu)\,d\nu = 1 \qquad (1.1)$$

The bandwidth at half maximum of the lineshape function is called the linewidth of that particular transition. The linewidth is found to be a function of the temperature and pressure. A typical lineshape profile is shown in figure 1.1.

One method of determining $g(\nu)$ is to pass electromagnetic radiation through a sample containing CO_2 molecules and measure the amount of energy absorbed as a function of frequency [1].

From this we can determine the absorption coefficient of the gas using the formula

$$I=I_0e^{-kz} \qquad (1.2)$$

where

I_0 = Intensity of the E.M. source

I = Intensity after absorption

k = Absorption coefficient

z = Length of the absorbing medium

The absorption coefficient is proportional to the lineshape function $g(\nu)$, and the latter can be obtained from the measured absorption coefficient.

For accurate measurement of the lineshape, the spectral width of the electromagnetic source should be narrow compared to the linewidth of the absorber.

1.3 Broadening mechanisms

There are in general five processes that contribute to the broadening of an absorption line of a gas [2]. The five type of broadening are as follows:

1. Natural broadening, due to the finite life time of the excited states.
2. Doppler broadening, due to the motions of the atoms.
3. Lorentz broadening, due to collisions with foreign atoms.
4. Holtzmark broadening, due to the collisions with other absorbing atoms of the same kind.
5. Stark broadening, due to collisions with electrons and

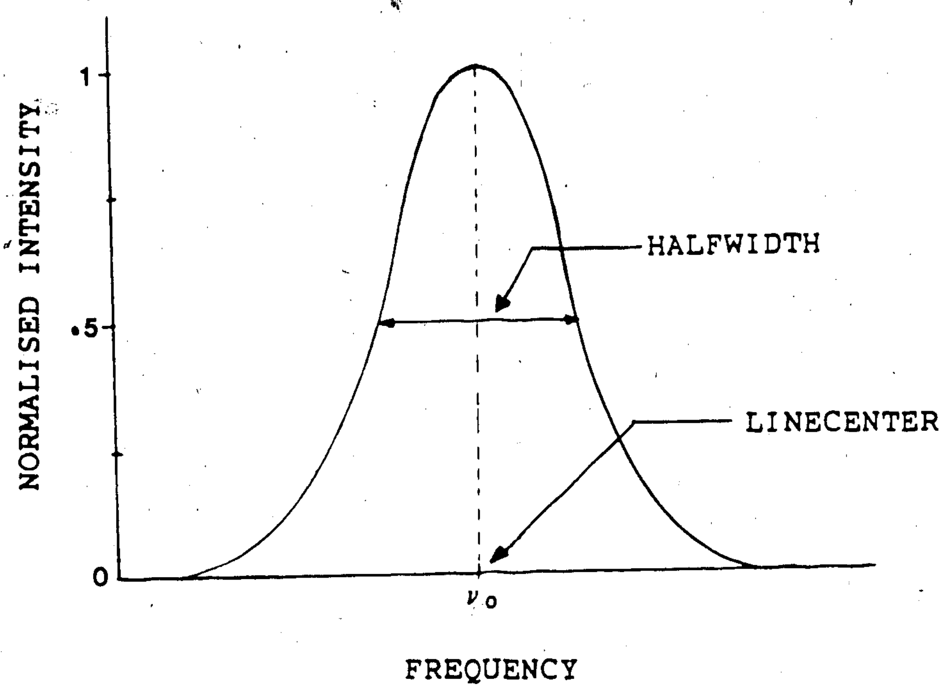


Figure 1.1 Profile of a transition line

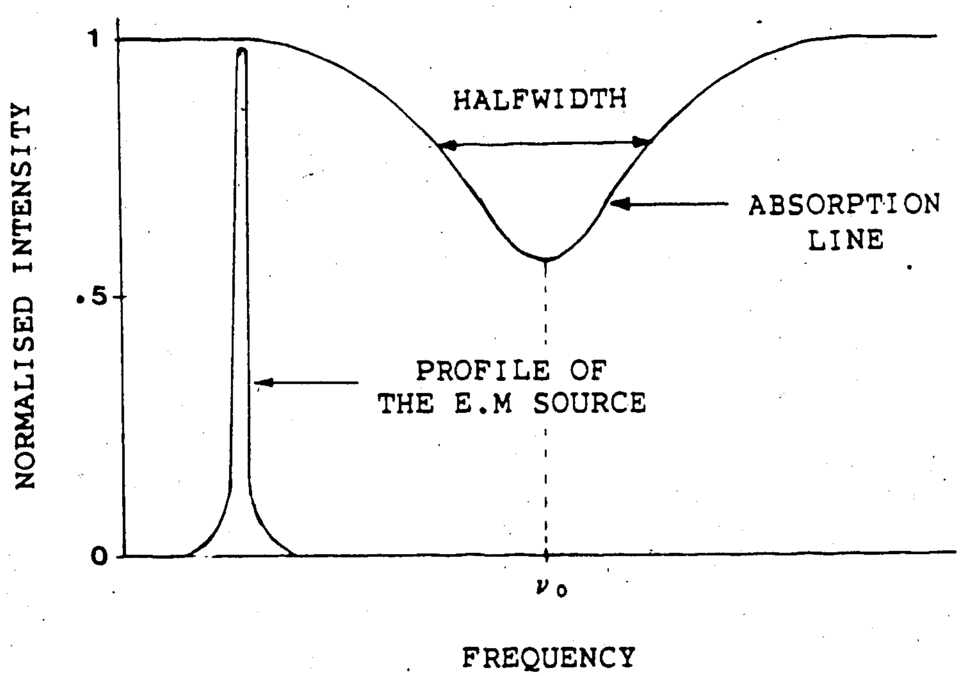


Figure 1.2 Profile of an absorption line and the relative spectral linewidth of the E.M. source

ions.

Both Lorentz and Holtzmark types of broadening are referred to as "pressure broadening" or "collisional broadening".

1.4 Thesis Objectives

Present day CO_2 lasers are operated in a pressure range of 10 Torr to 100 Torr and generally at temperatures between 350-500K. Ref [7] indicates that CO_2 lines exhibit a Voigt profile in the pressure range of 10 to 50 Torr and at 300 K. It is usually assumed that the pressure broadened linewidth

$$L\nu \sim p\,T^{-n} \qquad (1.4.1)$$

where,

p = Pressure

T = Absolute temperature

and n has been assumed or measured to have a value between 0.5 and 1.0 [3], [5], [7], [27], [28], [29].

Although measurements of linewidth have been made at room temperature [3], [7] and 384K [3], a systematic investigation of the lineshape and linewidth behaviour in the pressure range 10-100 Torr and at temperatures above 370K has not been performed before but, was conducted in the work described here. Also this systematic investigation will determine the the value of n with much higher accuracy.

The objective of the experiment is to determine the absorption coefficient as a function of frequency for a CO_2 transition line. From the measured lineshape, the linewidth is obtained by measuring the bandwidth at half maximum.

The variable frequency source for the absorption experiment is a tunable diode laser. The output frequency of the tunable diode laser is a function of the diode current. A Fabry-Perot etalon is used to calibrate the frequency of the diode laser. The lineshape function of CO_2 tansition lines is assumed to be a Voigt function, and a FORTRAN program is written to fit a theoretical Voigt function to the measured absorption coefficient.

1.4.1 Data Acquisition

Data acquisition forms an essential part of any experimentally oriented research. For efficient management and processing of data, in terms of good accuracy, high speed and handling of voluminous information, a digital processor is essential. Present day digital instruments are provided with a standard instrumentation bus such as IEEE-488, RS-232 and S-100. Acquiring data from these busses for analysis and storage requires a data acquisition interface. To assist the absorption experiment in fast and accurate data acquisition, a microprocessor-based data acquisition interface is constructed and is described in detail in chapter 3.

1.5 Thesis organization

Chapter 2 describes the experimental set-up, the averaging technique for improving signal-to-noise ratio and the calibration of the output frequency of the tunable diode laser. The design, construction and operation of the data acquisition interface is explained in chapter 3. The analysis of the absorption line and fitting the Voigt function to the experimental data is detailed in chapter 4. The results obtained are listed in chapter 5. The functional dependance of the pressure broadened linewidth with pressure and temperature are analysed in detail and the results are also included in chapter 5.

2. EXPERIMENT

2.1 Organization

The experimental arrangement is shown in figure 2.1. It consists of a tunable semiconductor diode laser (TDL), an absorption cell, a monochromator, a detector, an amplifier, and a signal averager. The TDL emits infrared radiation at a wavelength of approximately 10μm, which is the same wavelength region as the CO_2 laser transitions. The laser beam is directed through the absorption cell and monochromator and is finally focused on to the detector by the optical arrangement shown in figure 2.1. The output of the detector is amplified and fed to the signal averager.

The absorption cell is situated inside an oven whose temperature can be controlled. The absorption cell can also be filled with CO_2 gas to the required pressure.

Since the lineshape of the CO_2 transitions are measured in terms of the absorption suffered by the infrared laser beam, the infrared laser source must have a narrow spectral linewidth (see figure 1.2). One source of extremely narrow spectral width is the TDL. The TDL used for the experiment is a PbCdS diode laser manufactured by Laser Analytics [24]. The output of a typical TDL has a spectral width of 54 kHz [25]. In comparison, the doppler linewidth of CO_2 line is 50 MHz at 300K.

The output frequency of the TDL can be easily tuned by adjusting the current flowing through it. The current may also be modulated by applying an external signal. The output of the TDL is controlled by a Laser Control Module and a Cryogenic Temperature Stabilizer [19]. A periodic modulating ramp signal, of 0.3 volts amplitude and 3 seconds period, is applied to the modulating input of the Laser Control Module [3]. This enables the TDL to emit an infrared laser beam which is repetitively varying in frequency over a range determined by the amplitude of the modulating signal [16].

This periodic sweep of the TDL is used for averaging purposes to improve the signal-to-noise ratio at the final output of the experiment. The photograph of the experimental set-up and the instrument panel are shown in plates 2.1 and 2.2.

2.2 Procedure

The absorption cell is filled with CO_2 gas to the required pressure and the oven is set to the required temperature. The frequency of the TDL is swept over a range which is adjusted to include an absorption line. The output of the detector shows the absorption by the CO_2 transition, from which the absorption coefficient throughout the line is determined.

The optical throughput of the entire experimental set-up is small. Hence, the signal at the detector contains noise so that accurate determination of lineshape is difficult. In order to maximise the precision of the measurements, the output is measured for a number of sweeps and averaged for subsequent analysis.

For this purpose an EG&G Model 4203 signal averager is used [18]. The mode of averaging and the number of sweeps to be averaged are preset using the controls of the instrument [18]. Averaging will increase the signal-to-noise ratio by reducing the effect of the random noise appearing on the output signal.

2.3 Averaging Technique

As mentioned in section 2.2, the entire optical system has a low throughput. The signal averager gives three options of averaging the signal for the required number of sweeps:

1. Exponential averaging
2. Normalised averaging
3. Summation averaging

The normalised averaging technique is chosen for the experiment, because of its high signal-to-noise improvement ratio (SNIR). SNIR is the amount of additional signal-to-noise ratio obtained by the process of averaging.

The normalised averaging method is as follows:

$$A_k = A_{k-1} + (I_k - A_{k-1})/2^j \qquad (2.3.1)$$

where,

A_k = Average after k sweeps

A_{k-1} = Average after k-1 sweeps

I_k = Kth input signal

j = A positive integer, which ranges

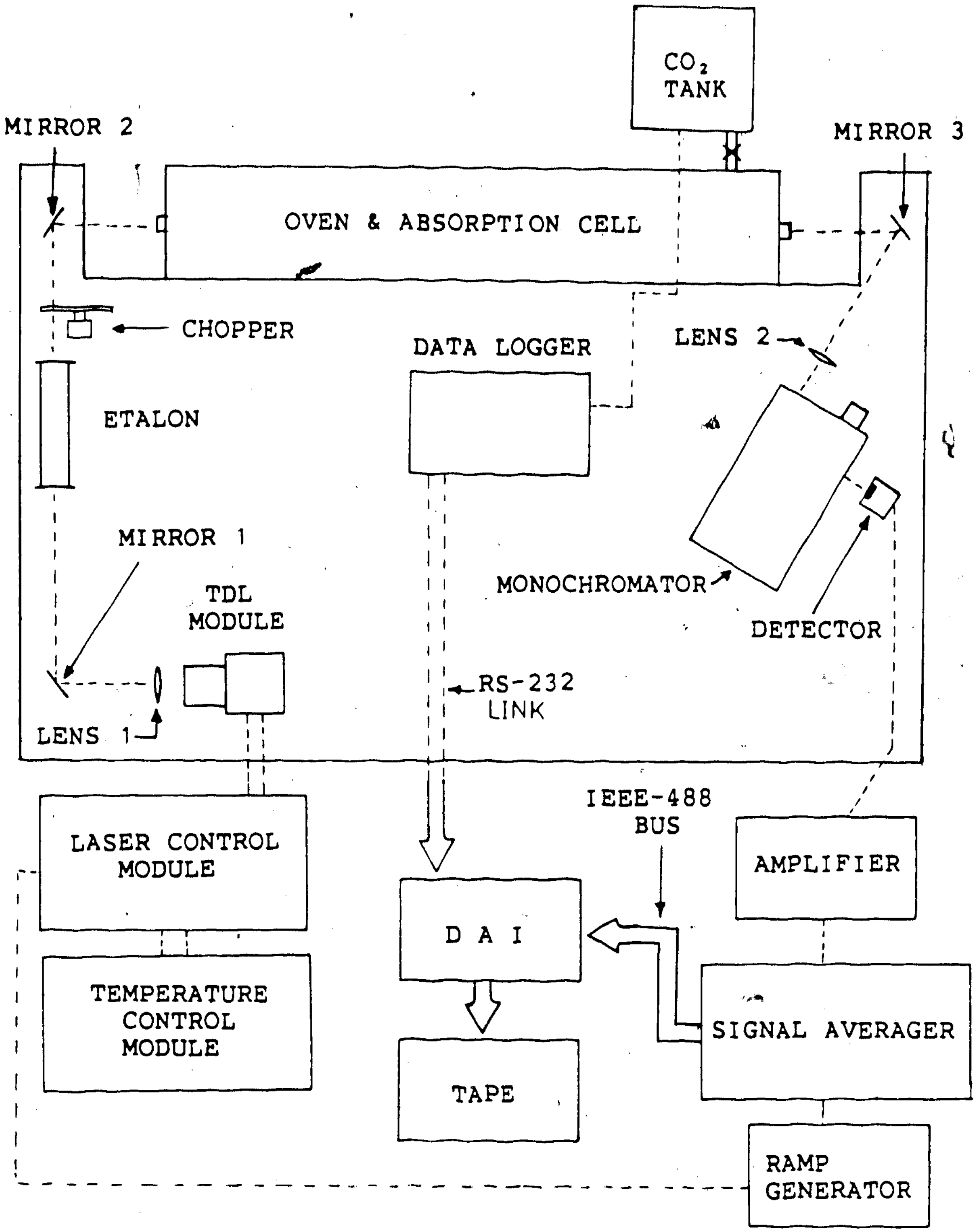


Figure 2.1 Experimental set-up

from 0 - 19

The selection of j is automatically done by the signal averager, and depends on the total number of sweeps selected.

The signal-to-noise improvement ratio (SNIR) for the normalised averaging is given as

$$SNIR = \sqrt{S} \qquad (2.3.2)$$

where,

S = Total number of sweeps

2.4 Data Acquisition

After the preset number of sweeps are completed, the data representing the transmission through the absorption cell is stored in the memory of the signal averager. The size of the memory is 1024 locations, with each location containing the data in ASCII format. To retrieve the data for analysis the signal averager gives two options:

1. x - y recorder output. Through this output the data can be transferred to chart-paper.
2. IEEE-488 bus [20]. Using an intelligent computer interface the data can be transferred from memory of the signal averager to any I/O device in the form of ASCII codes.

The latter option is chosen for the experiment for the following reasons:

1. Fast data transfer can be implemented
2. Data from all the 1024 memory locations can be

transferred

In addition, the IEEE-488 bus provides the option of operating the signal averager remotely [8], [18].

The construction of the data acquisition interface for the purpose of data transfer from the signal averager to an I/O device is described in chapter 3.

2.5 Frequency Calibration

The frequency of the radiation output of the TDL is neither calibrated nor listed as a function of the sweeping current through it. From the obtained absorption data, only the line center frequency is known. To obtain a calibration for the sweep range, a Fabry-Perot etalon is introduced in the optical path [4].

The Fabry-Perot etalon is made of two plane parallel plates separated by a distance d. The parallel surfaces are well polished so that the plane surfaces act as partially reflecting and partially transmitting media [1]. When the laser beam passes through the etalon, the reflections of the two surfaces produces interference on the transmitted beam. As the frequency of the laser beam changes it produces an output pattern in the detector as shown in figure 2.2.

The frequency difference $\Delta\nu$ between any two adjacent peaks is given by the formula

$$\Delta\nu = c/(2\ n\ d) \qquad (2.5.1)$$

where,

c = Velocity of light

n = Refractive index of the medium

d = Thickness of the etalon

Since the frequency of the line center is known accurately, we can calculate the frequencies over the entire sweep range. The exact calculations are described in detail in section 4.3.2

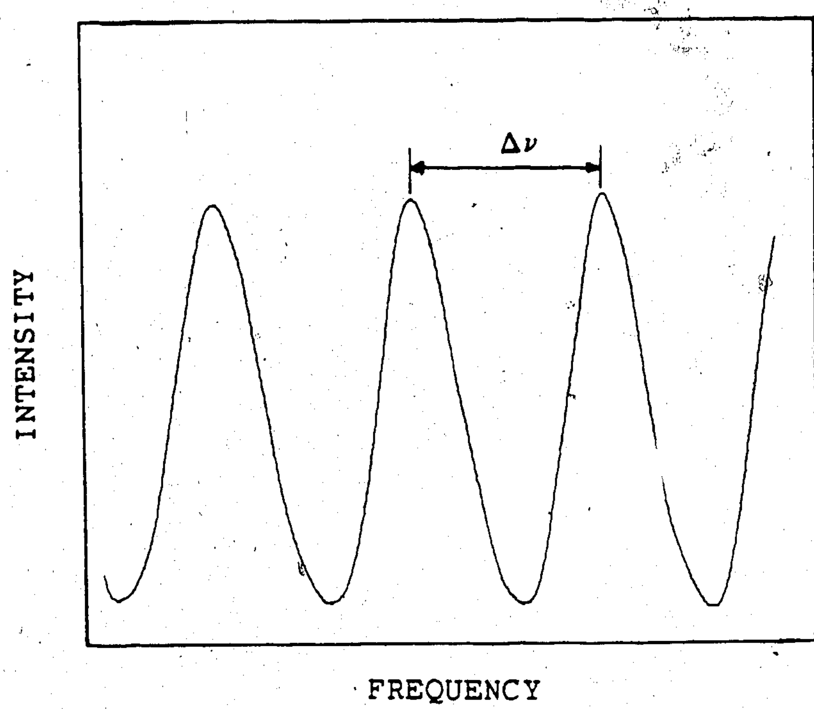


Figure 2.2 Output pattern produced by the etalon

Plate 2.1 Photograph of the experimental set-up

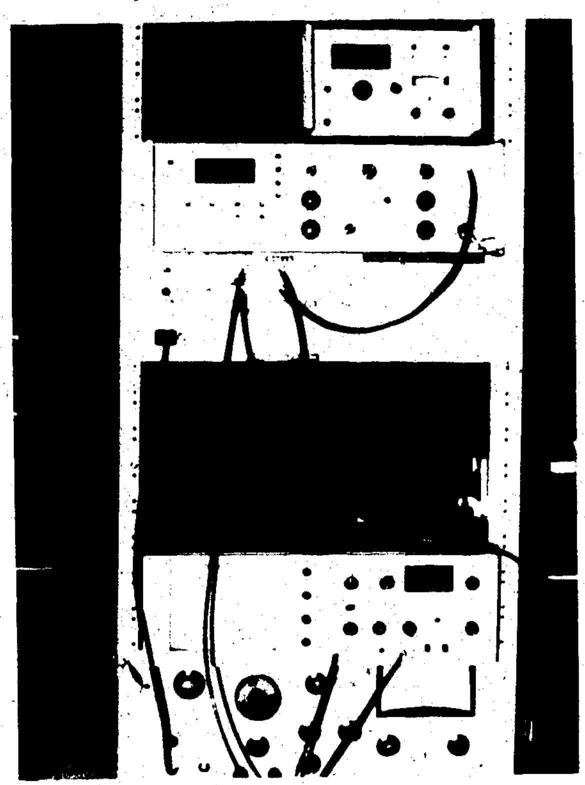


Plate 2.2 Photograph of the instrument panel

3. DATA ACQUISITION INTERFACE

3.1 Instrumentation Bus

Various instrumentation bus standards have been developed for transfer of data and remote and programmed control of smart instruments. These instrumentation busses allow more than one instrument to communicate with each other. The communication should be initiated by an intelligent interface or a computer. The instrument which transmits data over the bus is called the transmitting device or talker. The instrument which receives the data is called the receiver or listener. The computer or the interface has to initialize an instrument in order to make a particular instrument talk or listen.

Instrumentation busses are classified into parallel busses and serial links. With a parallel bus , each data block (8 bit information) is transfered through an eight line data bus. This configuration requires more hard wired lines interconnecting the instruments. Parallel busses provide high speed communication between instruments.

In serial links, each data block (8 bit information) is transfered serially, bit by bit, in one hard wired interconnecting line. Hence a serial link requires fewer number of interconnecting lines and the data communication can be made over a longer distance. Compared to parallel busses, the data transfer process in serial link is slow.

3.1.1 Handshake function

One of the salient features of any instrumentation bus is the handshaking function. Handshaking is responsible for reliable data transfer over the bus from one instrument to the other or to the computer and vice versa. Handshaking processes use two or more lines and perform pre-determined operations for the transfer of each data block, usually a byte (8 bit information). Furthermore, the handshake lines provide information to the computer about the nature and the status of data transfer at any time.

3.1.2 IEEE-488 Bus

The IEEE-488 bus is a parallel bus. It consists of 8 data lines, 8 control lines and 8 ground lines for the interconnection. Every IEEE-488 bus-incorporated instrument should be capable of performing one or more of the following functions:

1. Listener- An instrument capable of receiving data over the bus when addressed.
2. Talker- An instrument capable of transmitting data over the bus when addressed.
3. Controller- An instrument or device (usually the computer) capable of specifying the talker and listener for an information transfer (including itself).

The handshake operation is performed over three control lines and the handshake sequence is shown in figure 3.1.

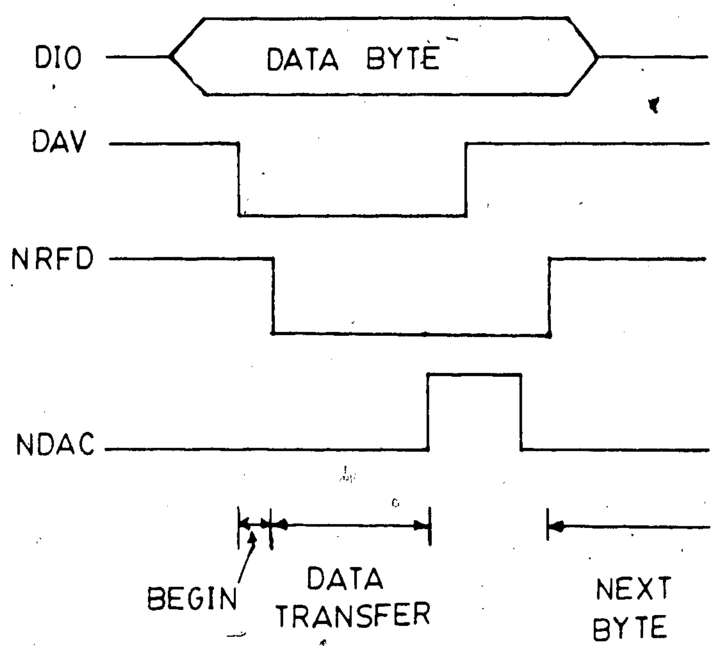


Figure 3.1 Handshake operation of IEEE-488 bus

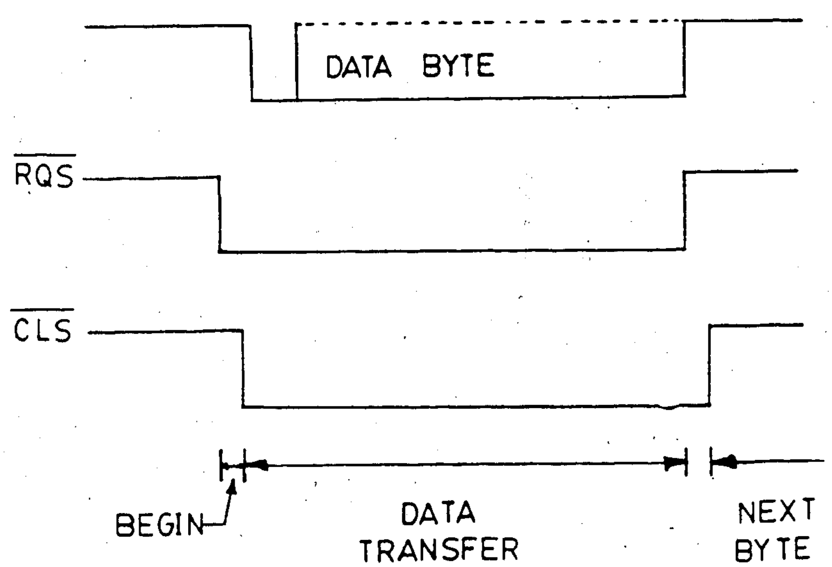


Figure 3.2 Handshake operation of RS-232 bus

3.1.3 RS-232 Link

The RS-232 link is a 20 line serial interconnection. It uses one line for transmitting data in serial format and another line for receiving data in serial format. The RS-232 uses a two wire handshake and is shown in figure 3.2. Any RS-232 incorporated instrument can be configured to transmit-only mode or receive-only mode by ignoring the handshake process. The transmit-only or receive-only mode is also called the 'dumb' mode.

The signal averager has an IEEE-488 bus and it is capable of talking and listening when it is addressed by a controller. The data logger (Fluke 2240B) samples the temperature of the absorption cell using six thermocouples, and the pressure of the absorption cell using a capacitive pressure gauge. The sampled data is transmitted through an RS-232 link in the transmit-only mode. The magnetic cassette tape recorder (Tektronix 4923), which records the data on the tape, has an RS-232 link in receive-only mode. Taking these things into account the requirements of the Data Acquisition Interface (DAI) are as follows:

1. The DAI should have an IEEE-488 controller to provide communication link between the signal averager and the DAI,
2. An RS-232 receive-only port is necessary to receive data from the data logger, and
3. An RS-232 transmit-only port to write data into the cassette tape.

The DAI is built with the above-mentioned features and is described below.

3.2 Architecture of the DAI

The intelligent Data Acquisition Interface (DAI) is based on a Z-80 microprocessor (CPU) [16] (see figure 3.3). IEEE peripheral devices manufactured by Intel (Intel 8291, 8292, 8293) are interfaced to the microprocessor, enabling the DAI to communicate with the signal averager. An asynchronous communication interface adapter (Motorola 6850) is also interfaced with the microprocessor for the DAI to communicate with the data logger and the cassette tape.

The required command sequence to be executed by the microprocessor is stored in a Read Only Memory (ROM). The program is so written that during the data transfer process the interface fetches one byte of data at a time from the signal averager and transfers it to the serial port [23].

To ensure proper data transfer, the processor is also programmed to check and perform handshake functions [20]. The program listing is shown in Appendix A.

3.2.1 Hardware organization

The Z-80 CPU has a 16 bit address bus and an 8 bit data bus. Since the address bus is 16 bits, it is capable of addressing 65535 (64 K) external memory locations. Apart from this, the CPU can address 256 external Input/Output (I/O) locations while executing I/O instructions.

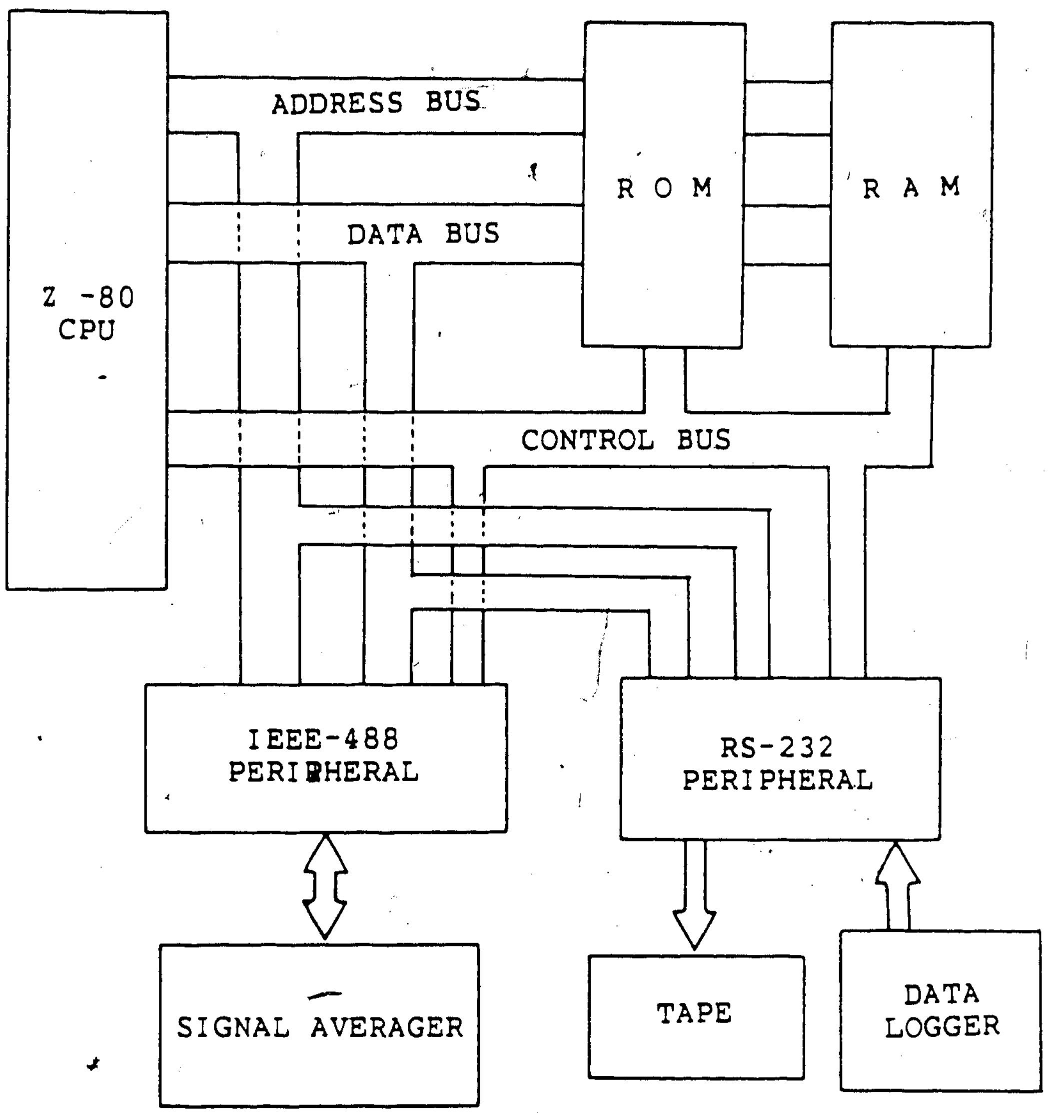


Figure 3.3 Hardware organization of the Data Acquisition Interface

The address bus, data bus and control bus of the CPU are connected to other devices through line buffers. This prevents the external devices overloding the CPU. Provision is also made to tristate the line buffers in order to isolate the CPU from the external devices. An optional step-execution circuit is incorporated with the CPU. This step-execution circuit helps the user to execute the program with one instruction at a time. This is essential for program and hardware de-bugging. The step-execution circuit can be disconnected from the CPU and the program can be executed continuously.

The memory map or the memory organization is shown in figure 3.4. The first 2K memory locations (in hexadecimal notation $0000-07FF) is alloted for ROM and the next 1K ($0800-0BFF) is alloted for Read-Write Memory (RAM). RAM is used for the stack and storing data temporarily within the DAI. The stack is a few read-write memory locations, which the CPU uses to remember its status before executing a jump or interrupt instructions. The IEEE peripheral devices are interfaced to the CPU in the memory mapped mode. In the memory mapped mode, the peripheral devices are treated exactly as a memory. To operate a memory mapped I/O device, the same instructions that are used for operating the memory can be used. The memory locations used for the Intel 8291 are $7000-7007 and for the Intel 8292 are $7800-7801.

A pair of seven segment displays and a switch are interfaced to the CPU in memory mapped mode at location

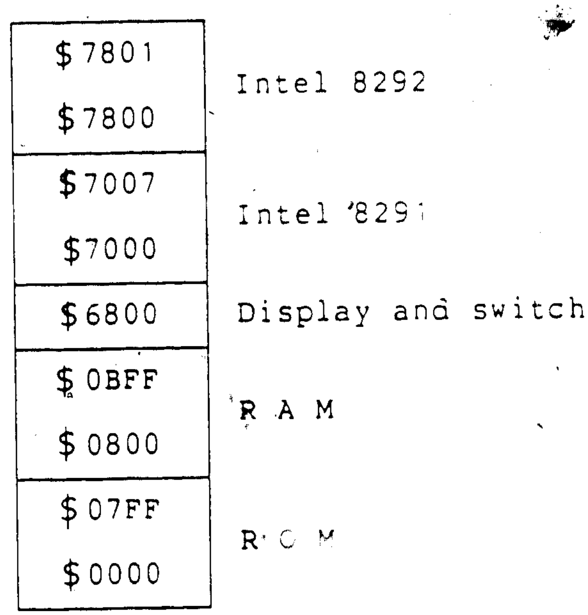


Figure 3.4 Memory organization

$6800. By closing the switch (key) the user can activate the DAI to transfer data to the tape (see figure 3.8). When the DAI is ready to transfer data to the tape, it so indicates to the user by flashing the seven segment displays. The seven segment displays were also used for de-bugging during the construction of the DAI.

The RS-232 peripheral is interfaced to the CPU in isolated I/O mode. The peripheral devices interfaced to the CPU in isolated I/O mode are treated separately from the memories. This also helps to distinguish between the IEEE peripherals and the RS-232 peripheral. I/O locations used for the RS-232 peripheral are $0001-0002. The schematics of the DAI are shown in figures 3.5-3.7.

3.3 Operation

The flow chart for the operation of the DAI is shown in figure 3.8. The power-on or hardware reset signal enables the CPU to initialize the peripherals. The DAI then performs the memory-clear operation on the signal averager and enters a stand-by state.

During this stand-by state the user can choose and set the pressure, temperature and the proper TDL current for analysing a particular line.

After the pressure, temperature and the TDL current are set, the required number of sweeps are preset using the thumbwheel switches provided on the front panel of the signal averager. The periodic ramp voltage is supplied to

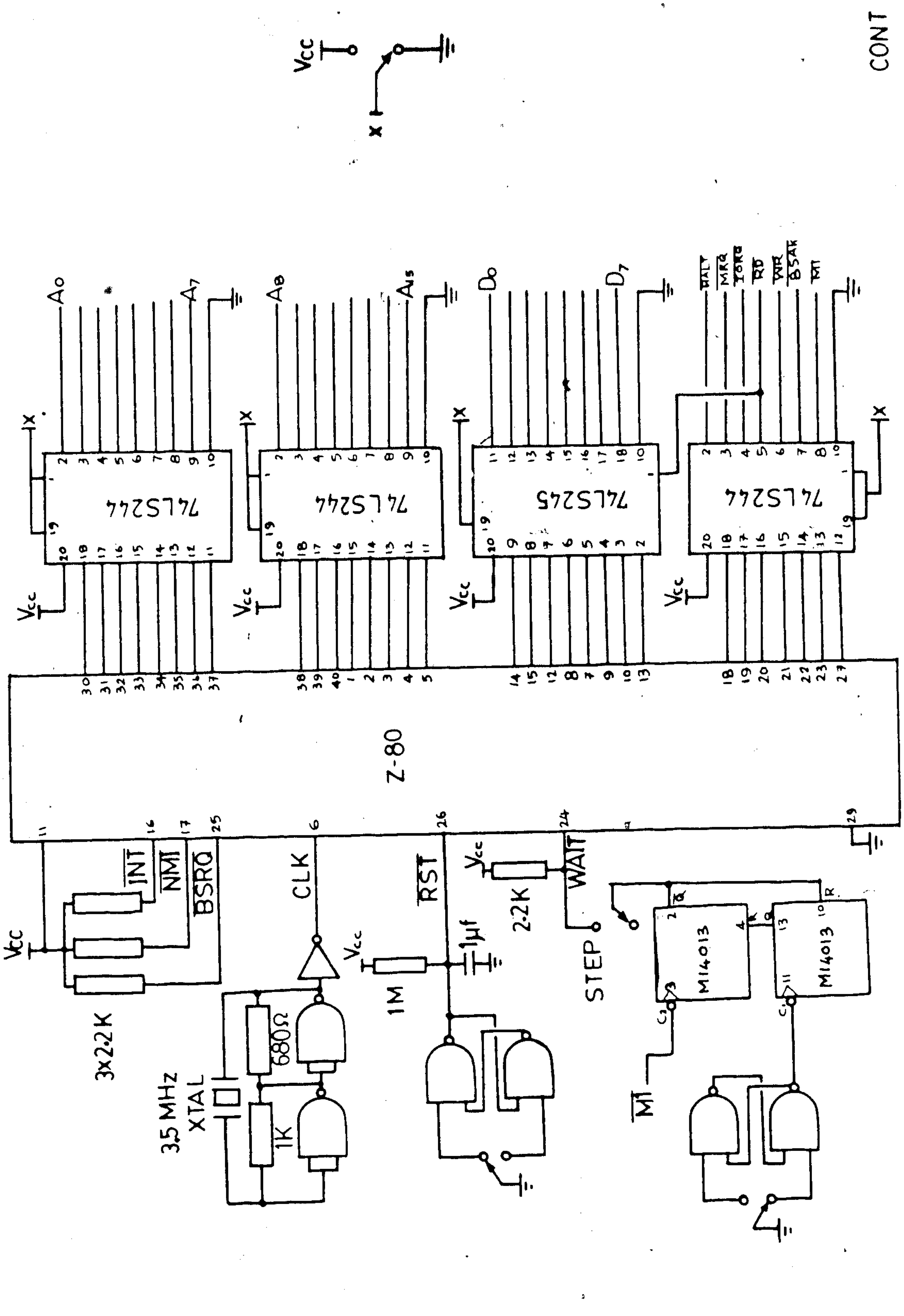
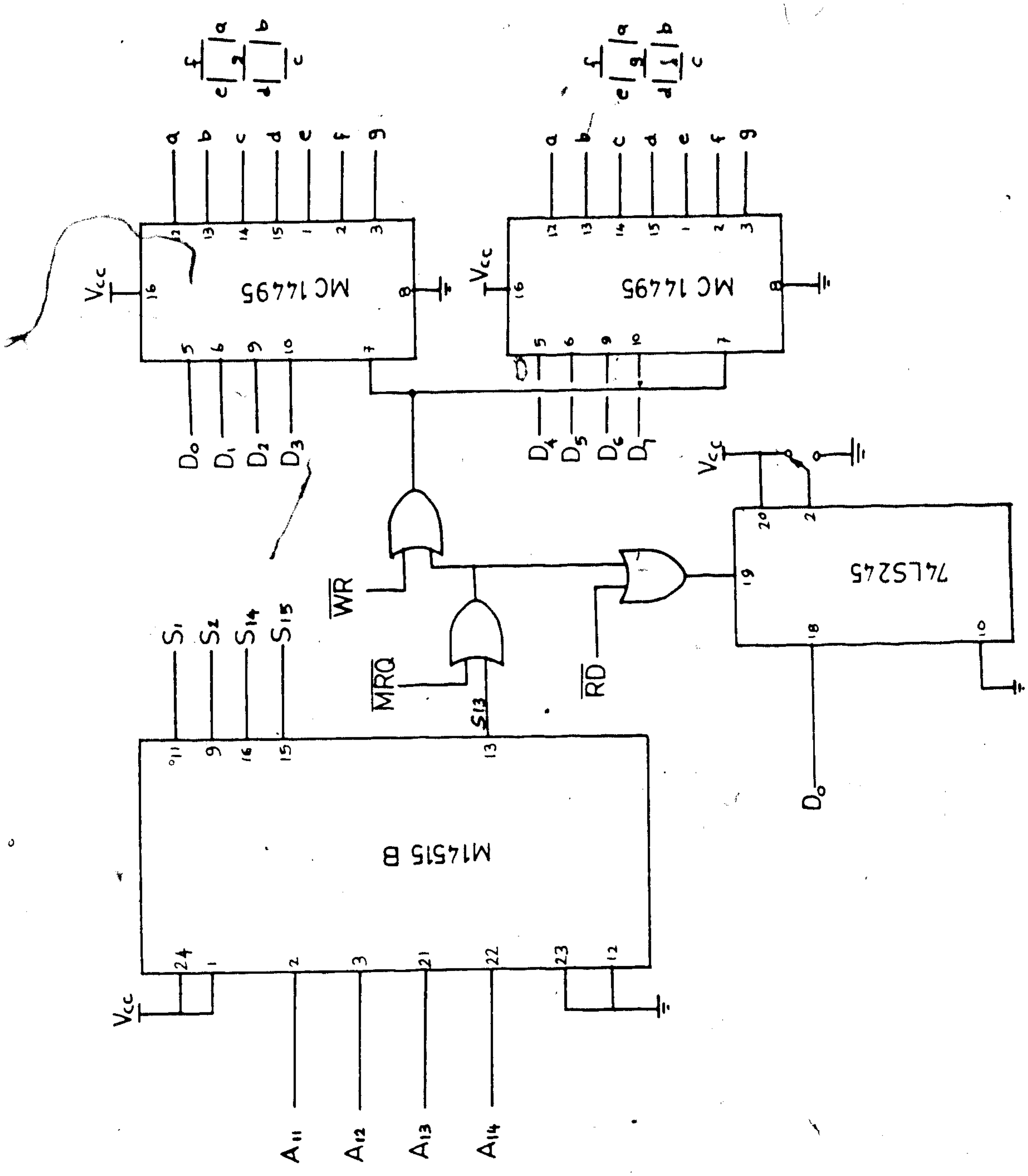


Figure 3.5 Schematic of clock, step circuit and line buffer



CONT

Figure 3.6 Schematic of decoding and I/O interfacing

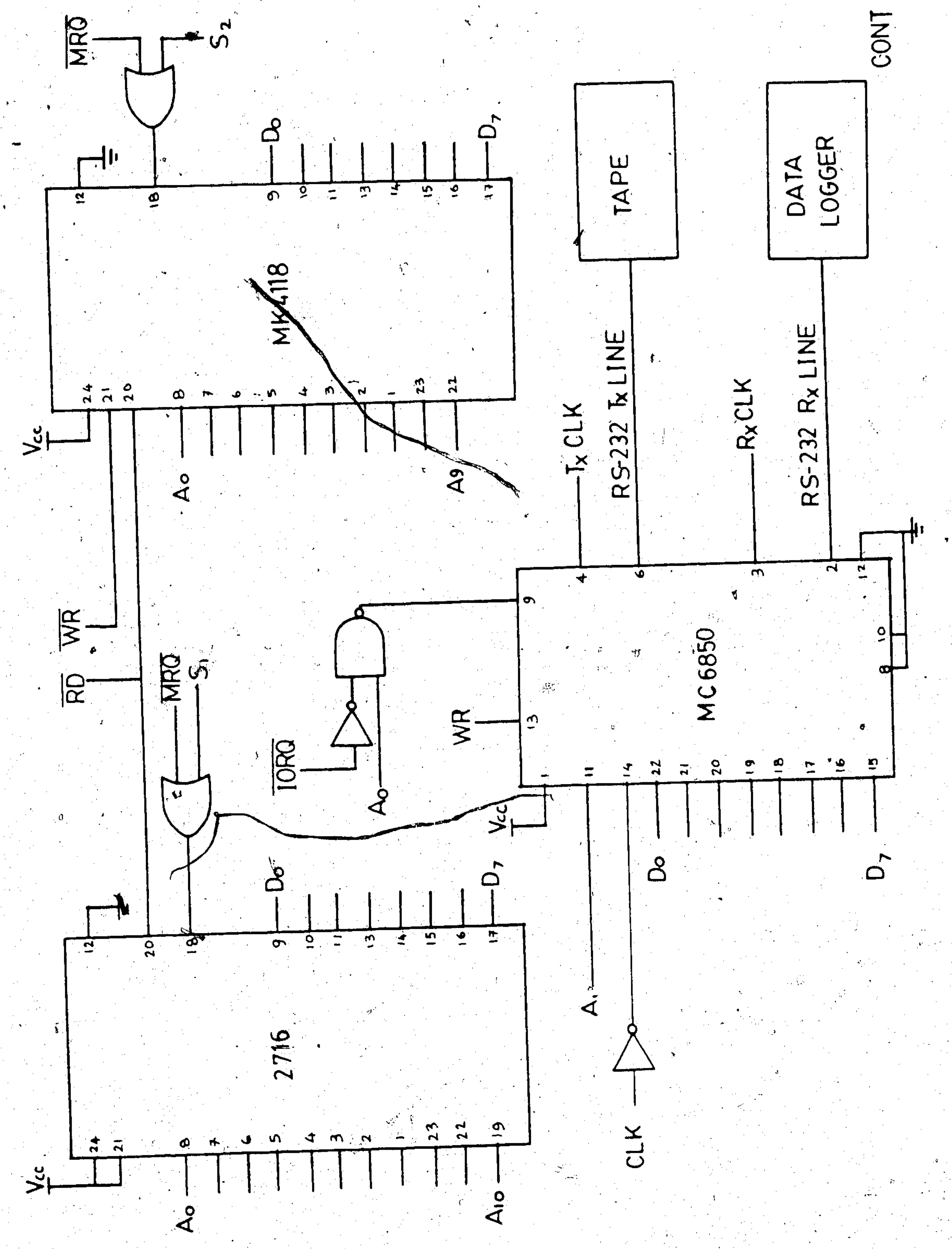


Figure 3.7 Schematic of ROM, RAM and ACIA

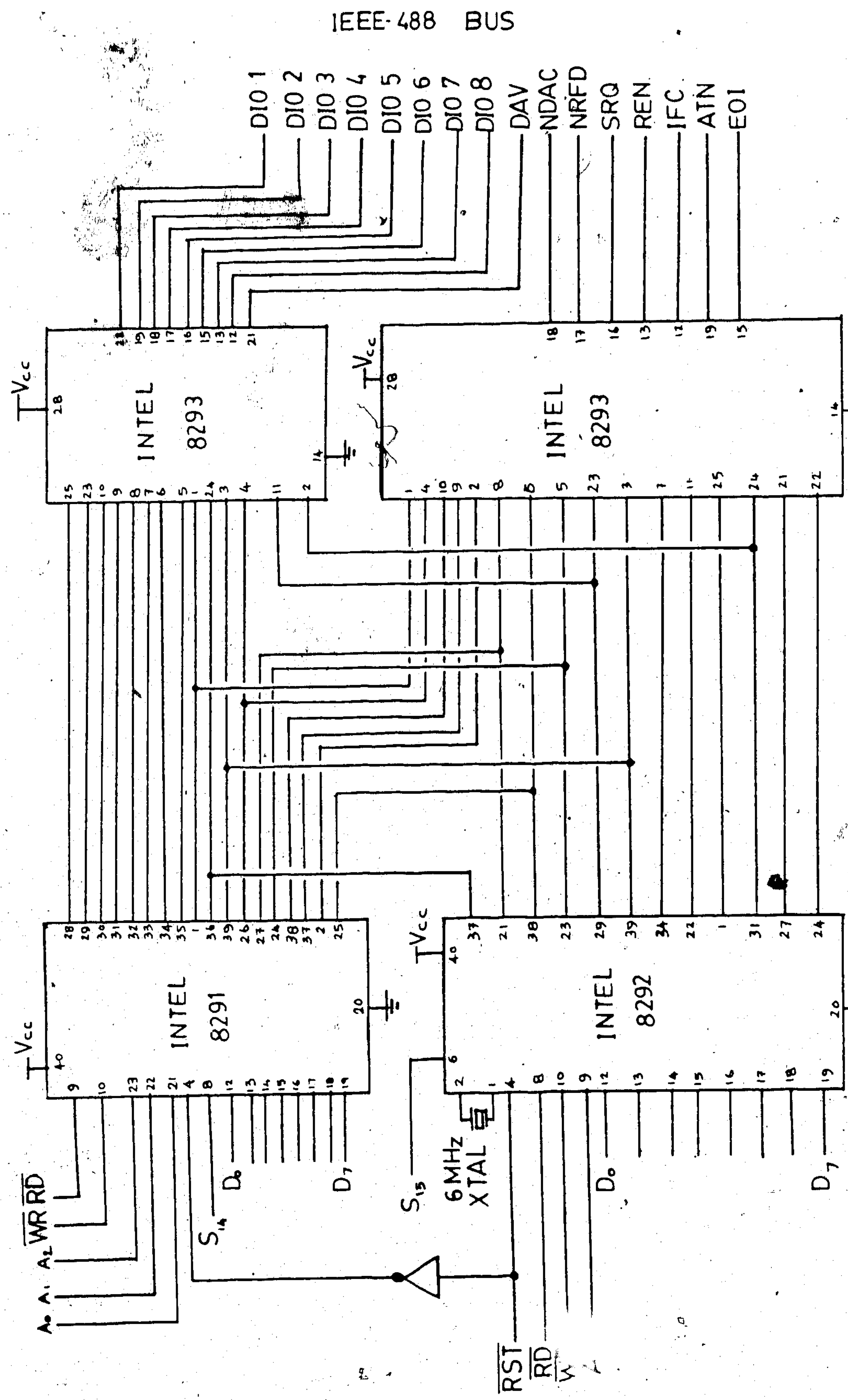


Figure 3.8 Schematic of IEEE-488 peripheral interfacing

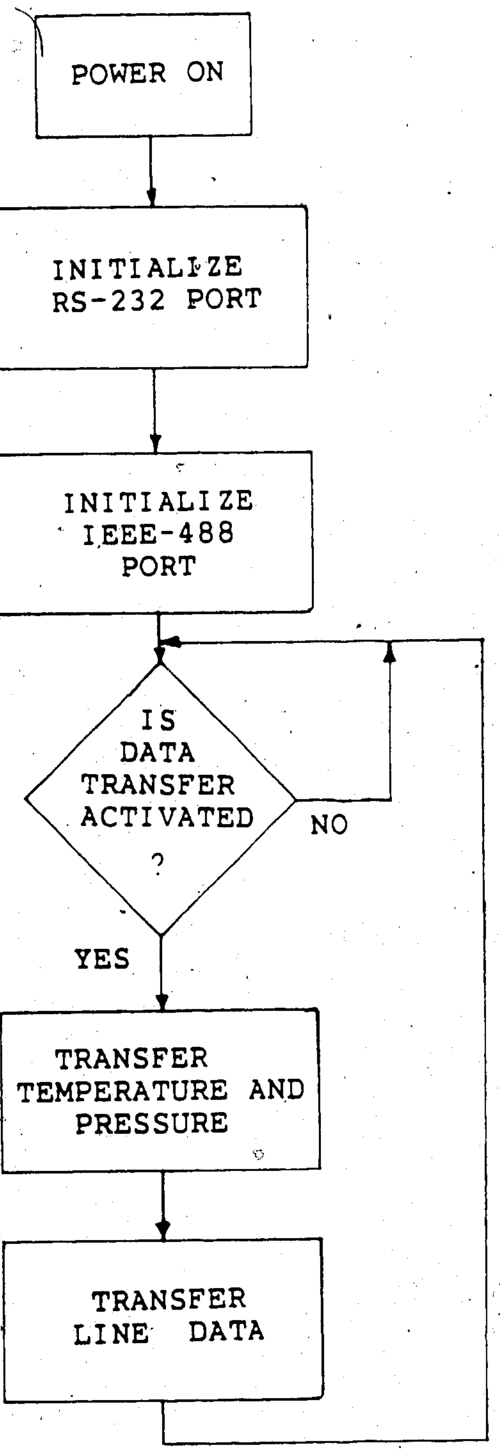


Figure 3.9 Operation Flow Chart of the Data Acquisition Interface

the Laser Control Module and the TDL is set to sweep. The output is averaged by the signal averager according to equation 2.3.1 and stores the 1024 values in its memory.

The CRT screen provided in the signal averager helps the user to view the absorption line as the signal averager receives the signal from the detector.

After obtaining the data, the DAI can be activated by a key for transfering the data for analysis. Since online transfer of data from interface to the University computer (MTS) requires excessively long MTS CPU time, the data is momentarily transfered to a cassette magnetic tape.

Since the tape recorder has an RS-232 port for communication with the outside world, the serial port in the DAI is used to transfer the data from the signal averager to the tape. The exact transfer process is shown by the flowchart of figure 3.9.

When the DAI is activated for data transfer, it also samples the pressure and temperature of the absorption cell via the RS-232 bus of the data logger and includes them along with the transferred line data. Once the transfer is complete the DAI re-enters the stand-by state awaiting the next set of data to be transferred.

The data from the tape is transferred later to MTS for analysis. The photograph of the DAI is shown in plate 3.1.

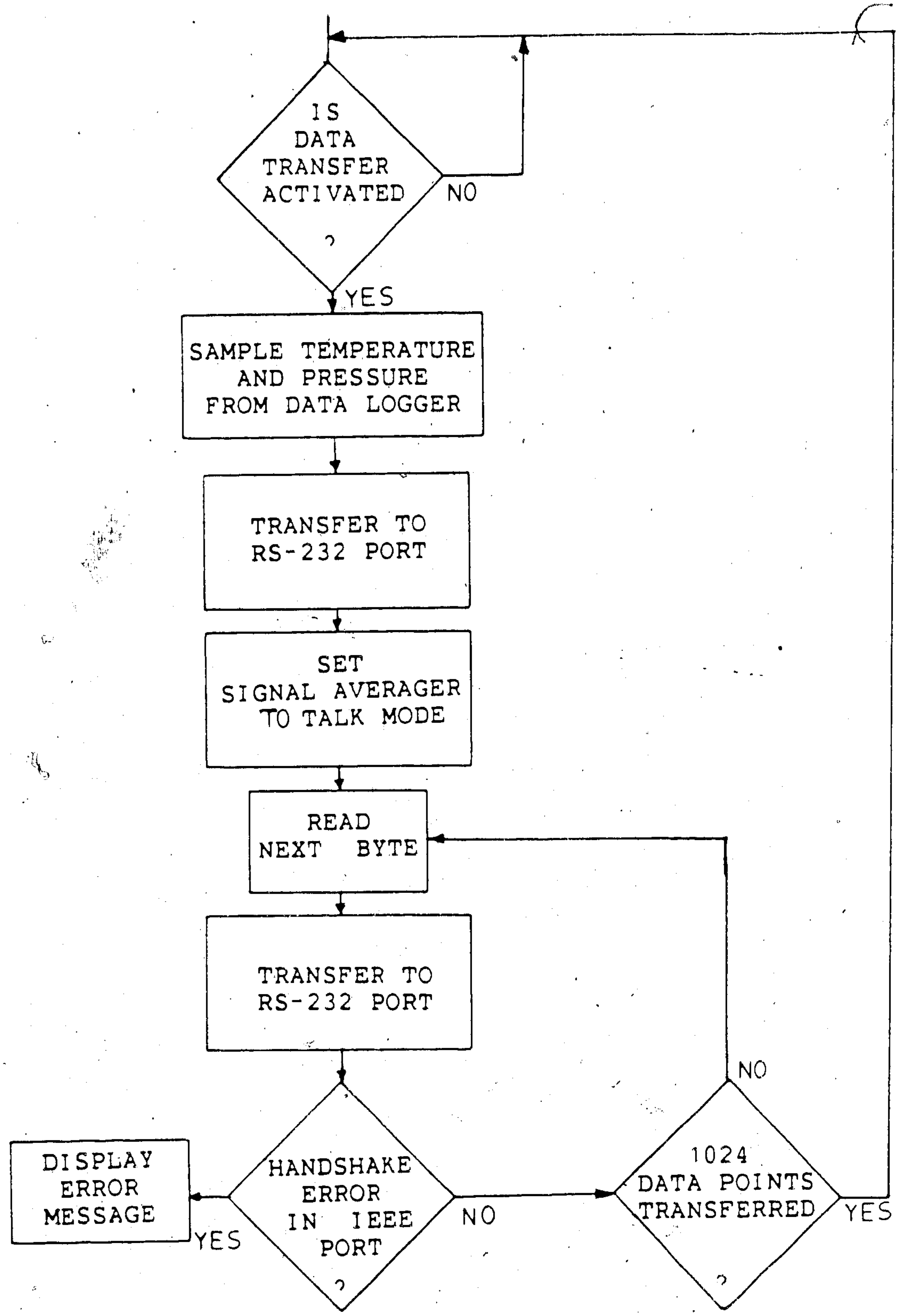


Figure 3.10 Data Transfer Flow Chart

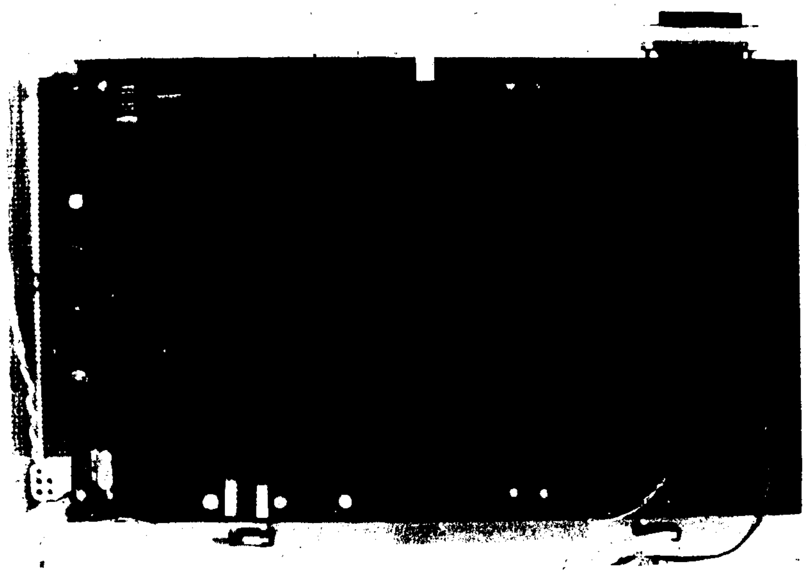


Plate 3.1 Photograph of the data acquisition interface

4. ANALYSIS

4.1 Doppler and Lorentz broadening

The spectrum of spontaneous emission in CO_2 shows a frequency spread or broadening. In a gas, broadening can be explained in terms of two phenomena:

1. Each molecule or atom at a slightly different transition frequency.
2. The finite lifetime of the excited state in an atom or molecule.

In CO_2 at low pressures (≤1 Torr), The broadening is due to the doppler-shift of the transition frequency of the molecules. The doppler-shifting occurs due to the finite velocity of the molecules. The doppler-broadened line shape function is given as

$$g(\nu) = 2\sqrt{\ln 2}/((D\nu)\sqrt{\pi})\ \exp-[4\ln 2\ (\nu-\nu_0)^2/(D\nu)^2] \quad \ldots(4.1.1)$$

where,

$$(D\nu) = 2\nu_0\ \sqrt{(2\ k\ T\ \ln 2/m\ c^2)} \quad \ldots\ldots\ldots\ldots(4.1.2)$$

ν = Frequency

ν_0 = Line center frequency

k = Boltzmann's constant

T = Absolute temperature

m = Mass of the molecule

c = Velocity of light

$D\nu$ is known as the doppler halfwidth. The functional dependance of $g(\nu)$ is referred to as gaussian [1] and the doppler linewidth is a function of absolute temperature.

When CO_2 is at high pressure ($\geq$100 Torr) the molecular density becomes higher and collisions between molecules becomes quite frequent. The classical view of an emitting or absorbing molecule is that the collisions interrupt the relative phase of the molecular oscillation and that of the field, causing a broadening [1]. This gives rise to the lineshape function, whose functional dependance is referred to as Lorentzian.

$$g(\nu) = (L\nu)/2\pi[(\nu-\nu_0)^2 + ((L\nu)/2)^2] \quad \text{.........(4.1.3)}$$

where,

$$(L\nu) = 1/(\pi\tau) \quad \text{.............................(4.1.4)}$$

ν = Frequency

ν_0 = Line center frequency

τ = Mean uninterrupted interaction time

$L\nu$ is the halfwidth of the lorentz line and is proportional to the pressure of the active medium.

When the CO_2 pressure p is in the range $1\leq p \leq 100$ Torr the broadening becomes a combination of Lorentz and Doppler broadening. Usually the combination of the Lorentz and

Doppler broadening function is expressed in terms of the absorption coefficient $k(\nu)$

$$k(\nu) = (k_0 y/\pi)\int_{-\infty}^{+\infty}[\exp(-t^2)/(y^2+(x-t)^2)]\,dt \quad \ldots(4.1.5)$$

where,

$k_0 = (S/(D\nu))\sqrt{\ln 2/\pi}$

$y = (L\nu/D\nu)\sqrt{\ln 2}$ ....(4.1.5.1)

$x = ((\nu-\nu_0)/D\nu)\sqrt{\ln 2}$ ....(4.1.5.2)

S = Line strength

ν_0 = Frequency at line center

ν = Frequency at which $k(\nu)$ is to be measured

The function $k(\nu)$ is known as the Voigt function [3], [15].

4.2 Analysis of the Voigt function

4.2.1 Classification of the regions

The Voigt function shown in equation 4.1.5 is the real part of the complex probability function [11]

$$W(z) = i/\pi\int_{-\infty}^{+\infty}[\exp(-t^2)/(z - t)]\,dt \quad \ldots\ldots\ldots\ldots(4.2.1)$$

where,

$$i = \sqrt{-1}$$

$$z = x + iy$$

This function is not easy to integrate analytically and numerical methods are used to evaluate it.

In order to achieve fast convergence and good accuracy, four different numerical methods are used for four different regions [10]. The four different regions are shown graphically in figure 4.1. In each region W(z) is evaluated and the real part of the solution is taken. The four different numerical methods used are described in detail below.

4.2.2 Taylor series expansion method

In region I, a Taylor series expansion method is used [10]. Equation 4.2.1 can be expressed in the form

$$W(z) = \exp(-z^2) + (2i/\sqrt{\pi})\, F(z) \qquad (4.2.2)$$

where,

$$F(z) = \exp(-z^2)\int_0^z [\exp t^2]\, dt \qquad (4.2.3)$$

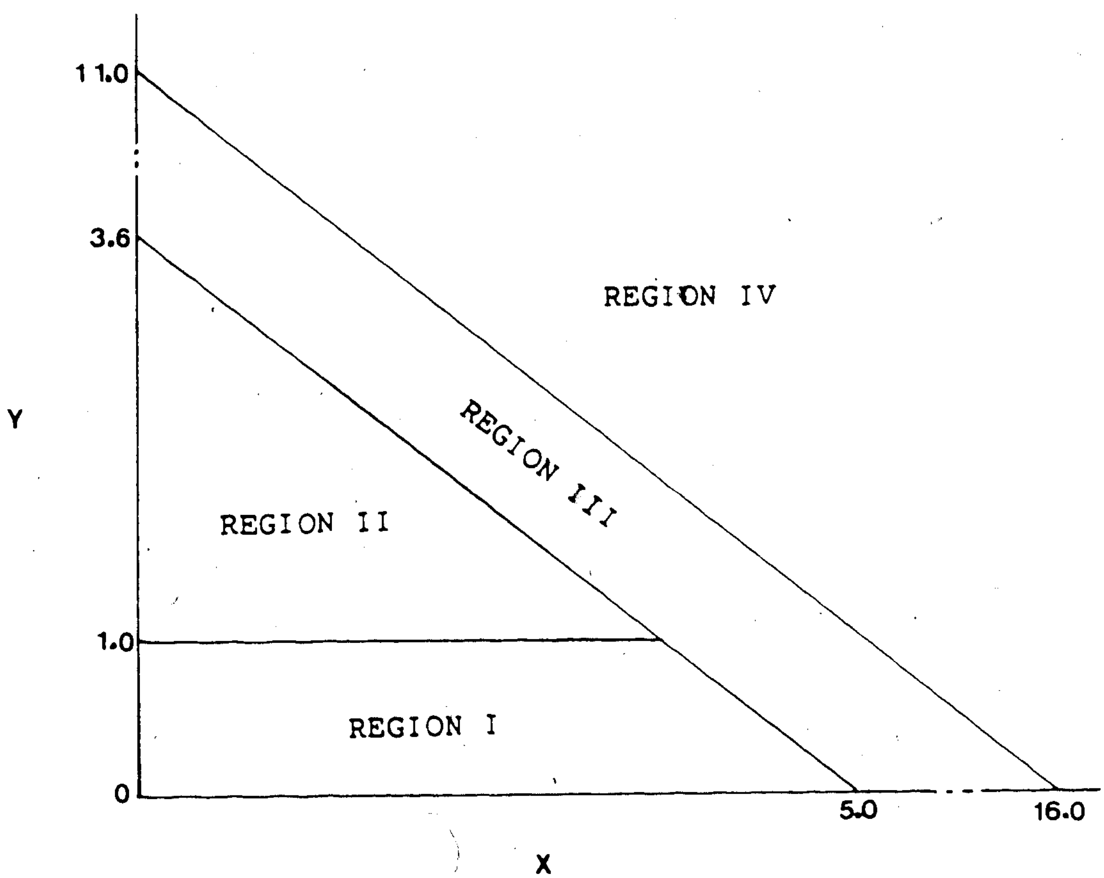


Figure 4.1 Computational regions used for different numerical methods

F(z) is known as Dawson's function [13]. Dawson's function on the real axis can be calculated using the Chebyshev expansion formula [14]

$$F(x) = \sum_{n=0}^{20} a_n(5)\ T_{2n+1}(x) \quad \text{.......................(4.2.4)}$$

where

$a_n(5)$ = Chebyshev coefficients

T_{2n+1} = Chebyshev polynomial

T_{2n+1} are calculated using the three term recurrence relationship

$T_0(x) = 1$

$T_1(x) = x$

$T_n(x) = 2\ x\ T_{n-1}(x) - T_{n-2}(x)$............(4.2.5)

In order to achieve rapid computation, Dawson's function F(x) is calculated for 25 values of x, equally spaced in the range 0 to 5. Taylor coefficients are also calculated at these 25 points using the relations

$d_0 = F(x)$

$d_1 = 1 - 2\ x\ d_0$

$d_{n+1} = -(2/(n+1))\ (x\ d_n + d_{n-1}) \quad n=1, 2, \ldots$

After obtaining the Taylor coefficients, F(x) at any x is found by another Taylor series and W(z) is evaluated using the formula

$$W(z) = \exp(-z^2)+(2i/\sqrt{\pi})\ (F(x)+ F'(x)y+...) \quad ..(4.2.6)$$

where

F'(x) = First derivative of F(x)

F''(x) = Second derivative of F(x)

The real part of W(z) gives the value of the Voigt function. Four terms are used for the expansion in equation 4.2.6.

4.2.3 Continued fraction method

In region II, W(z) can be evaluated using the continued fraction method [9], [12]

$$W(z) = 1/\sqrt{\pi}\left\{\frac{1}{z+}\ \frac{.5}{z+}\ \frac{1}{z+}\ \frac{1.5}{z+}\ \frac{2}{z+}\ ...\right\} \quad ....(4.2.7)$$

Ninteen terms are used in equation 4.2.7 to obtain sufficient accuracy.

4.2.4 Four-point and two-point gaussian quadrature

In region III and IV the Voigt function is asymptotic to the x axis. One of the best numerical integration methods for asymptotic functions is gaussian quadrature [11]. In region III, W(z) is evaluated using four-point gaussian quadrature

$$W(z) = \sum_{k=1}^{4} a_k/(z - t_k) \quad \text{.......................(4.2.8)}$$

where,

a_k are the gaussian quadrature weights associated with the points t_k.

In region IV, two-point gaussian quadrature is used to evaluate $W(z)$

$$W(z) = \sum_{k=1}^{2} a_k/(z - t_k) \quad \text{.......................(4.2.9)}$$

(Please refer to the program listing in Appendix A for the numerical values of a_k and t_k)

A FORTRAN program is written to compute the normalised absorption coefficients, $k(\nu)/k(\nu_0)$, for any x and y.

4.3 Computation of experimental absorption coefficient

The data transfered by the DAI consists of the temperature and pressure of the absorption cell and three sets of 1024 memory data points representing the transmitted intensity when the absorption cell is filled with CO_2 gas, when the absorption cell is empty and when the etalon is introduced in the optical path. Figure 4.2 shows these three data in graphical form. The absorption coefficient k is calculated using equation 1.2 for all the 1024 memory data points.

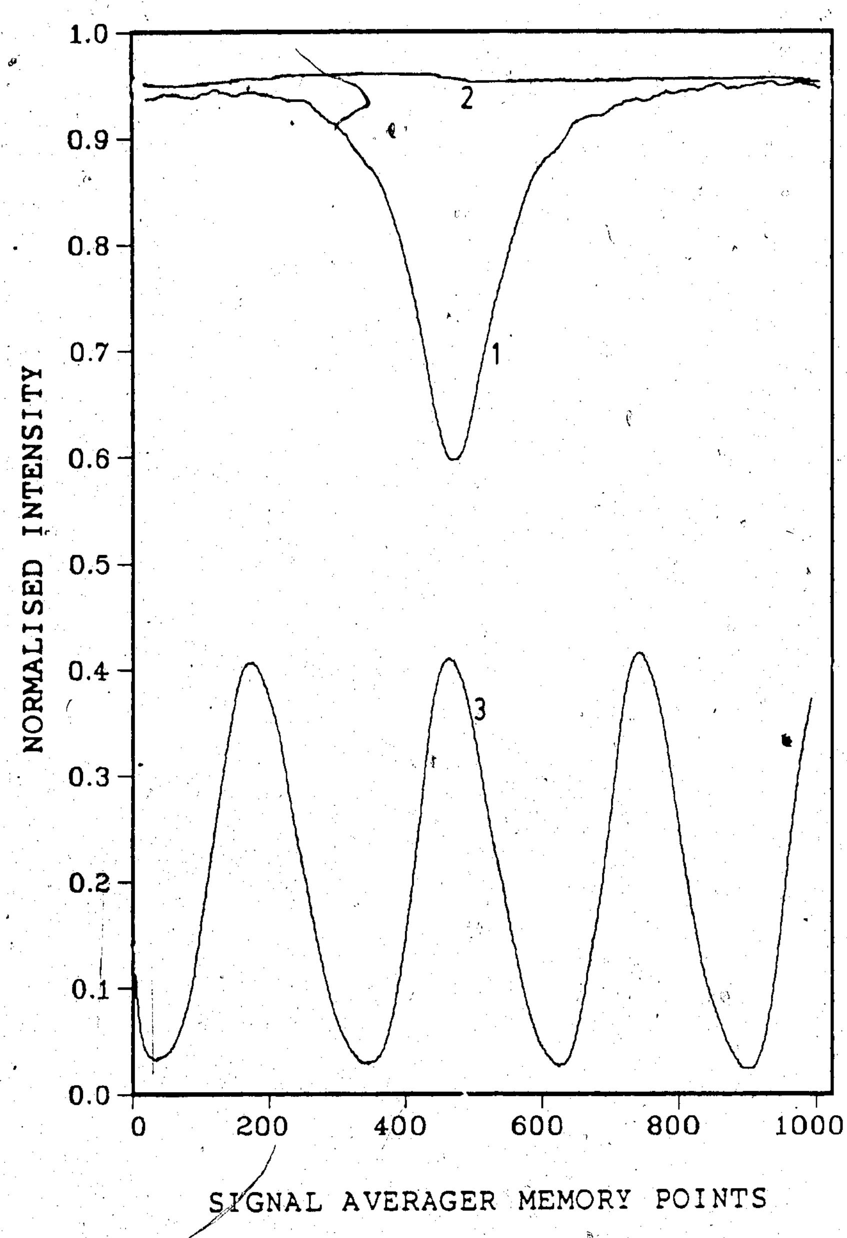


Figure 4.2 The data obtained from the experiment in graphical form 1.Absorption cell filled with CO_2 2.Absorption cell empty 3.Etalon introduced in the optical path

4.3.1 Determination of line center

The maximum absorption coefficient appears at the line center. But it cannot be assumed that the memory point corresponding to the maximum absorption coefficient is the line center, because of the random noise appearing in the system. In order to determine the line center with more accuracy a least squares fit is done.

The maximum absorption coefficient value and its memory point are first determined and the absorption coefficient values of 100 memory points in the neighbourhood (50 memory points on either side of the maximum value) of the maximum value are selected. A parabola is fitted to these 100 values using least squares curve fitting and the peak of the parabola is taken as the maximum absorption coefficient and its corresponding memory point is taken as the line center frequency.

4.3.2 Frequency calibration using the etalon

Once linecenter has been determined, the frequency distribution for the rest of 1023 memory points must be calculated. The etalon produces an output trace with at least three peaks when introduced in the optical path (see figure 4.2). The least squares fit of the parabola is used to locate the coordinates of the peaks and the frequency difference between adjacent peaks is given by equation 2.5.1. From the coordinates of the peaks the number of memory points between the peaks is calculated which is then equated to the frequency difference obtained from equation 2.5.1. The number of memory points on the etalon trace between the first and the second peak and the number of memory points between second peak and the third peak was always found to be equal, within one memory point. Hence the output of the TDL is assumed to be linear with respect to the sweeping current. Since we know the frequency of the line center and its corresponding memory point, the entire range of 1024 memory points is now calibrated in terms of x as in equation 4.1.5.2 [26].

The absorption coefficients are normalised with respect to the peak value. Figure 4.3 shows the normalised absorption coefficient versus x for the P(16) line of the 10.4μm CO_2 laser transition obtained from the experiment.

4.4 Fitting the Voigt function to the experimental data

4.4.1 Initial fitting

The two variables associated with the Voigt function(4.1.5) are x and y. Since x is now known, the theoretical function which gives the best fit of the experimental data determines a y value. From equation 4.1.5.1, $L\nu$ can then be calculated.

In order to save computer time, initially an approximate y is calculated using a successive approximation method near the half maximum points (where the value of the normalised absorption coefficient is $\simeq$0.5). The iteration is

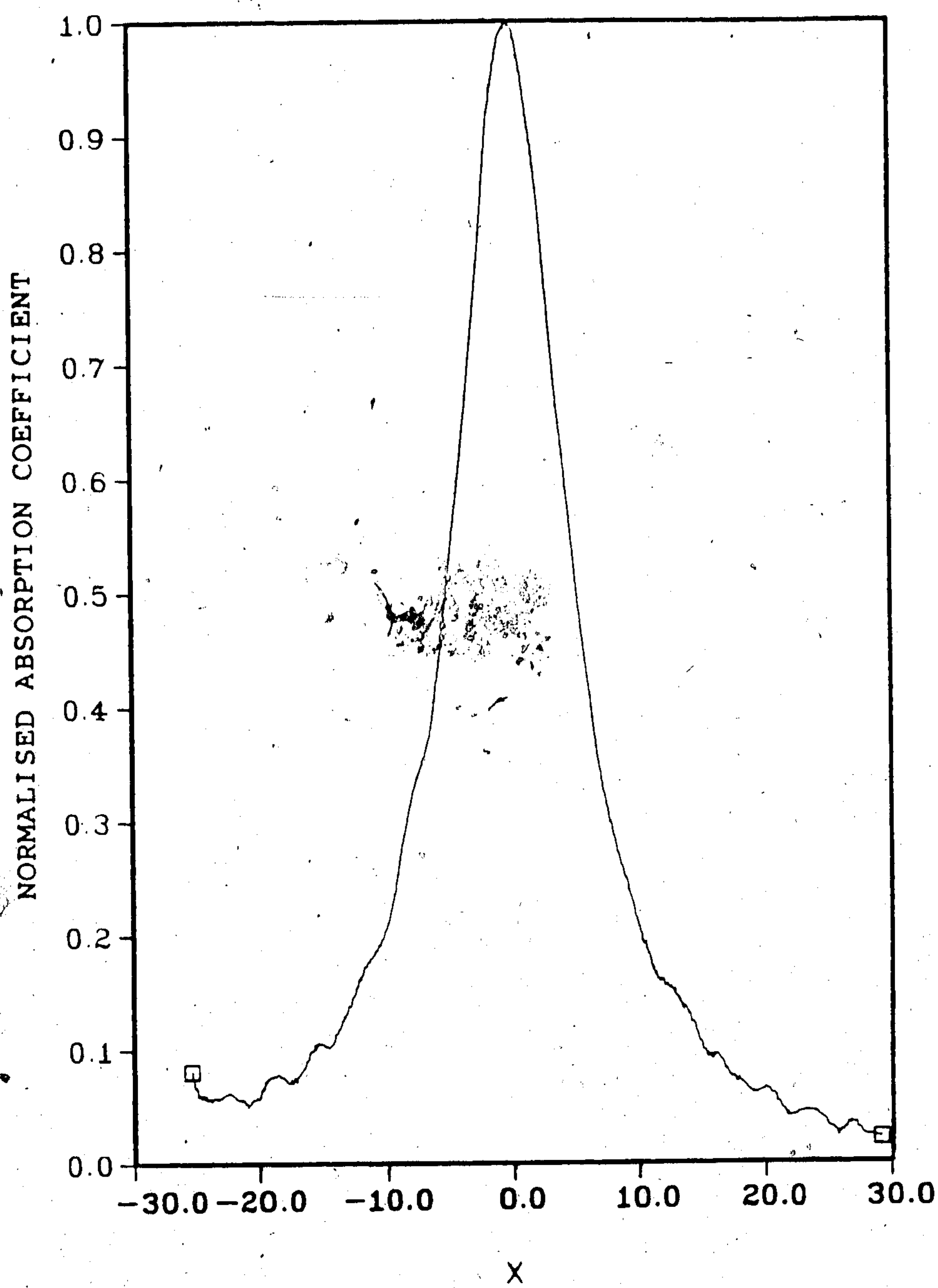


Figure 4.3 Absorption coefficient calculated with respect to x. CO_2 P(16)line at 50 Torr and 380K.

terminated when the obtained y value gives a theoretical normalised coefficient within 0.002% of the experimental value. This particular y makes the theoretical Voigt function to pass through at least three experimental values-the two half maximum points and the peak.

4.4.2 Fitting using sum of squared errors

To obtain an optimum y which gives the best fit, the sum of the squared errors between the theoretical and the experimental values is used. With the y value obtained from the general fitting, the squared error is computed at each of the 1024 points and summed. Using the successive approximation method, an optimum y is computed by minimising the sum of squared errors. For all set of data the minimum value (sum of squared error) was found to be within 0.140. The sets of data which could not produce a minimum error within 0.140 is rejected. Figure 4.4 shows the Voigt function fitted to the experimental data.

Figure 4.5 - 4.8 shows the voigt fitting for the experimental data obtained for different pressures at 418K.

With the optimum y, the Lorentz width responsible for the broadening is calculated using equation 4.1.5.1. Using equation 1.4.1 the dependancy of $L\nu$ on temperature and pressure is determined, and this comparison is outlined in the following chapter.

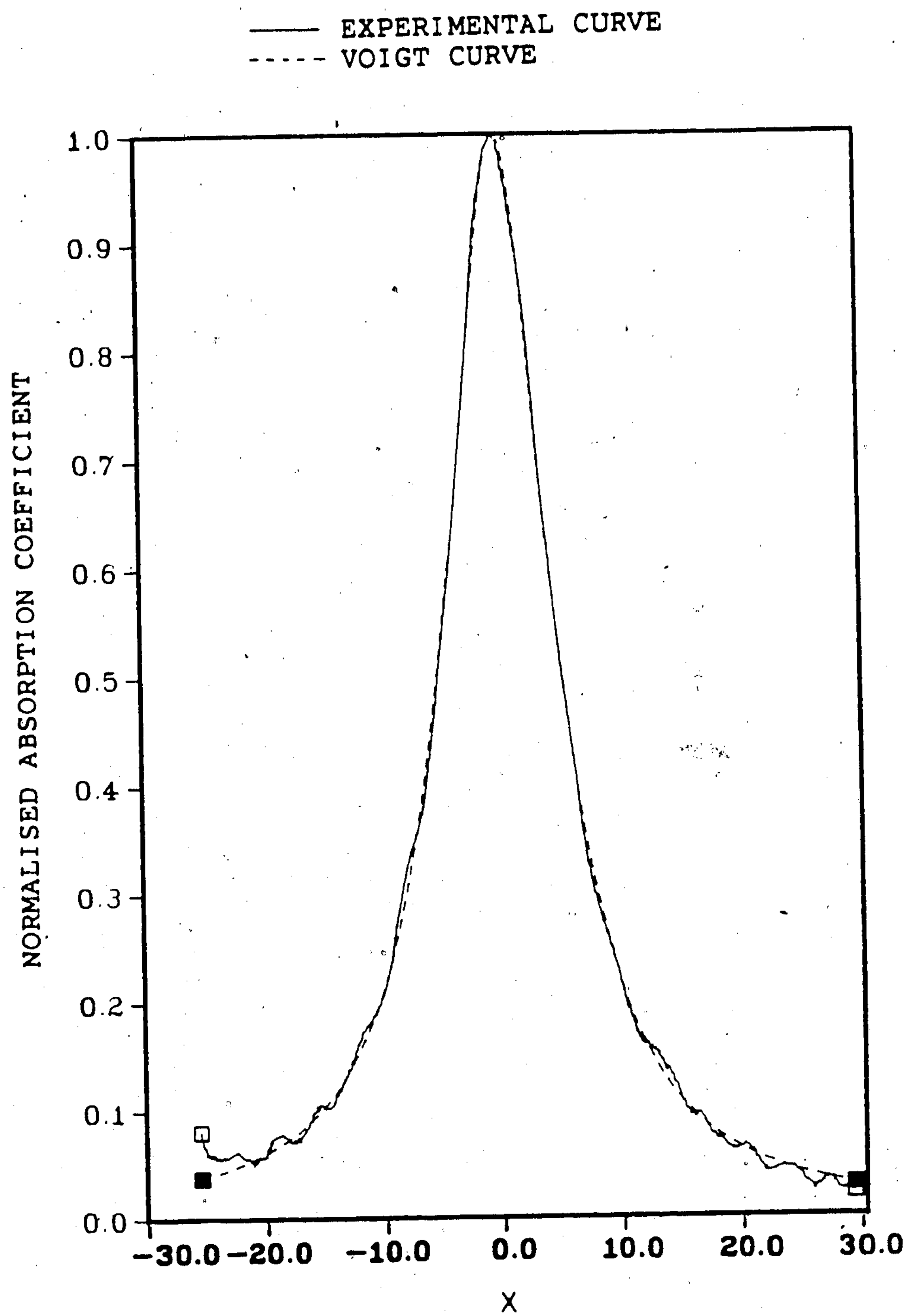


Figure 4.4 Theoretical Voigt function fitted to the experimental data. CO_2 P(16)line at 50 Torr and 380K

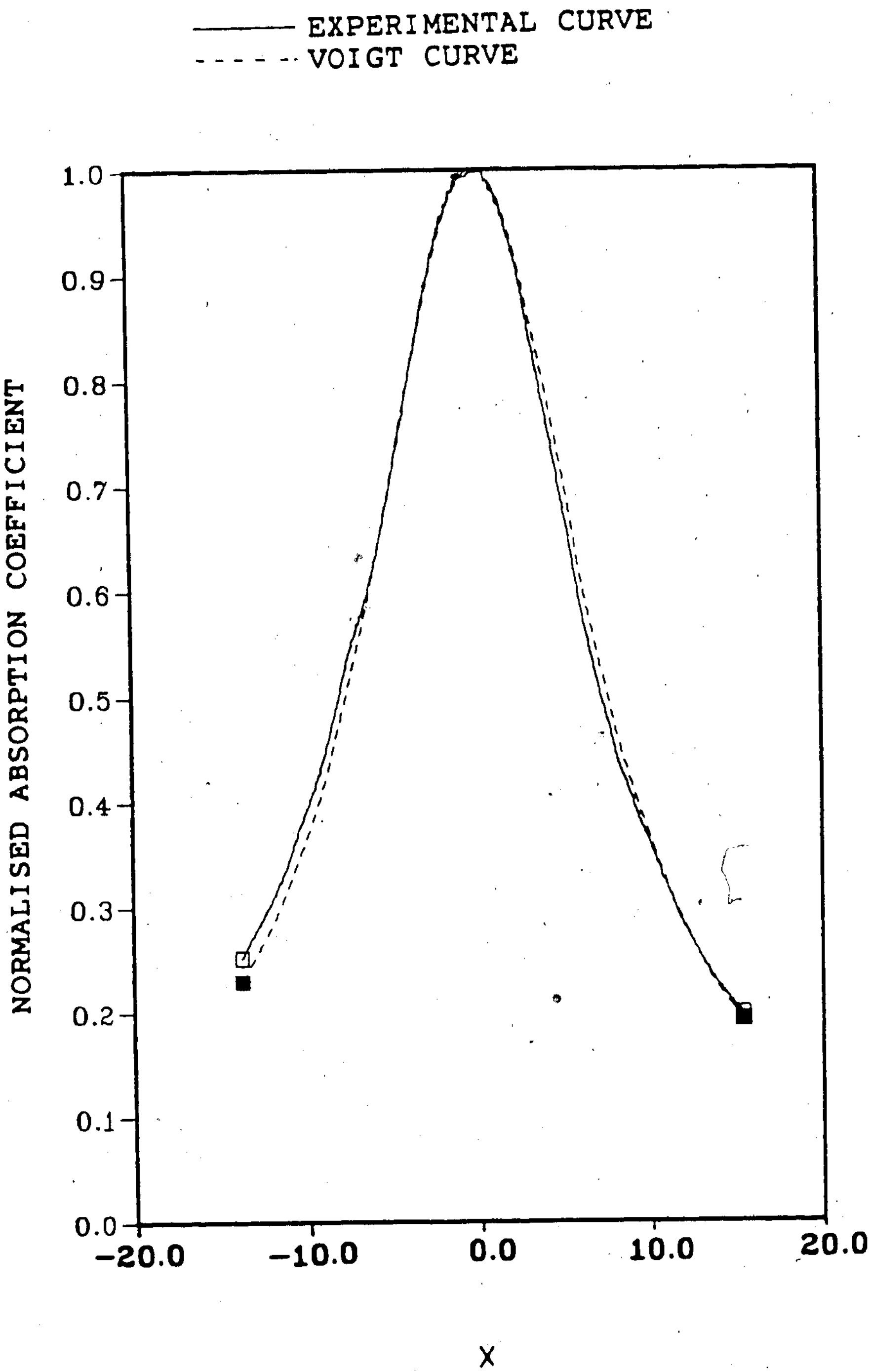


Figure 4.5 Voigt fitting for CO_2 P(16) line at 101 Torr and 418K

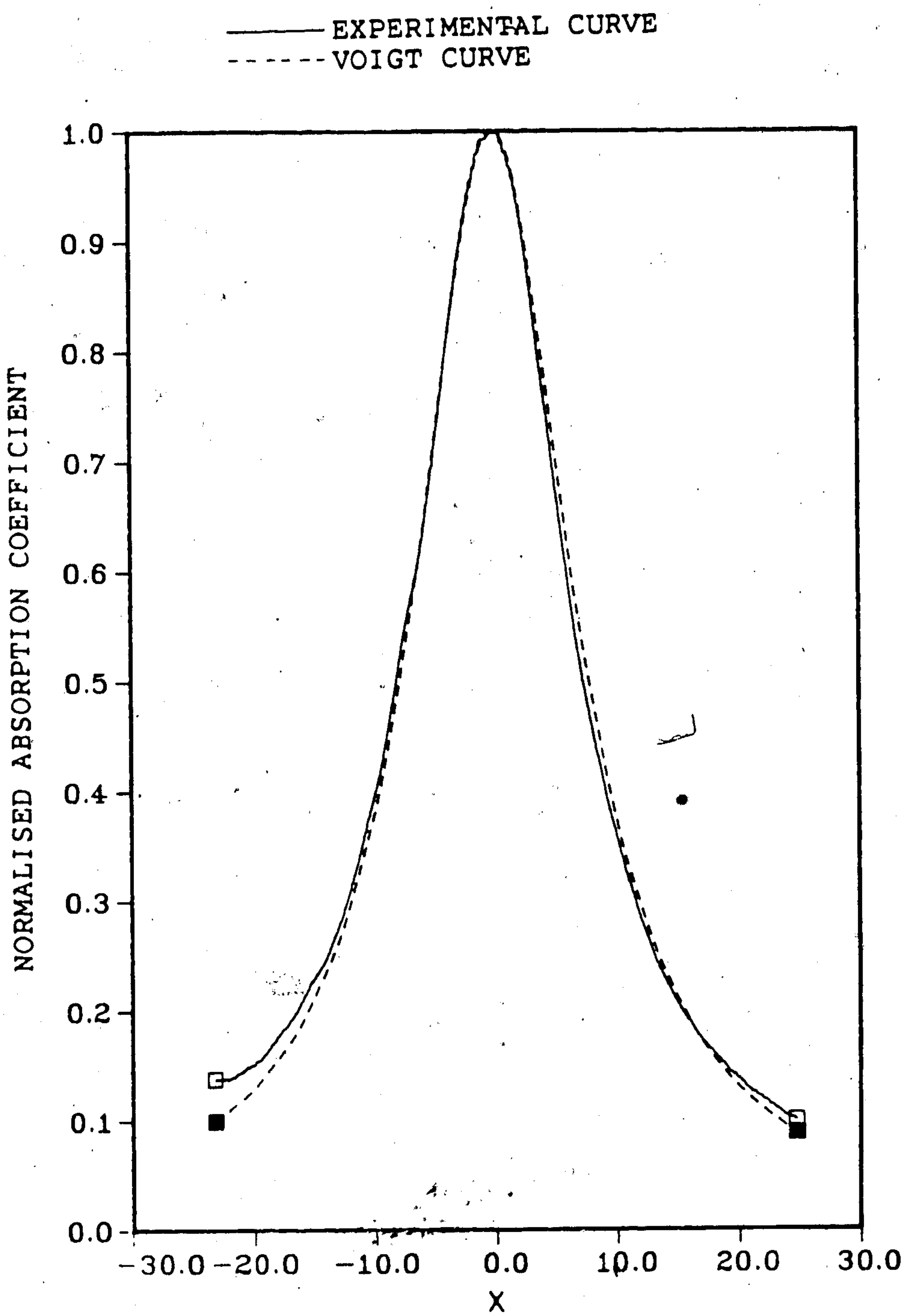


Figure 4.6 Voigt fitting for CO_2 P(16) line at 80 Torr and 418K

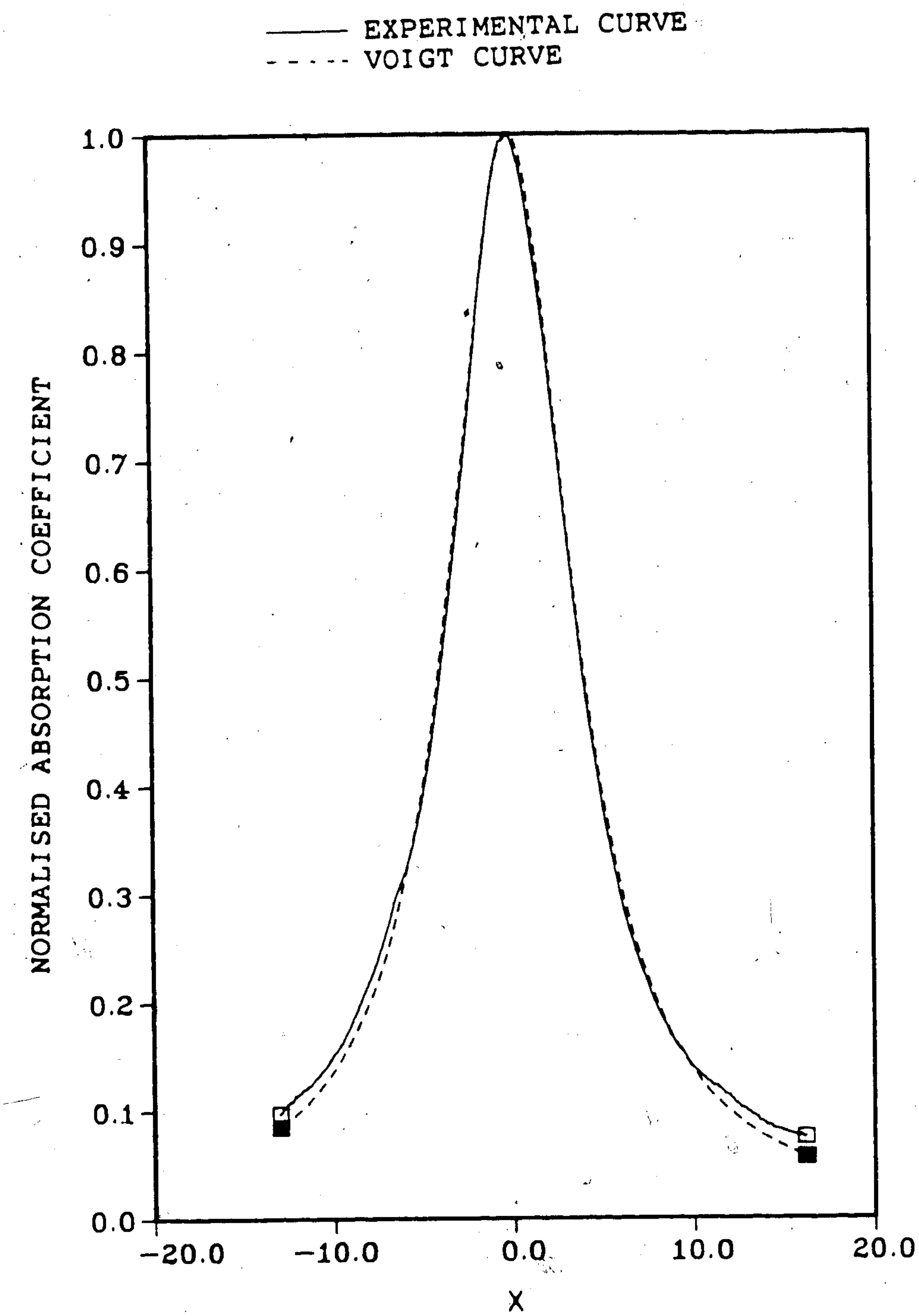


Figure 4.7 Voigt fitting for CO_2 P(16) line at 49 Torr and 418K

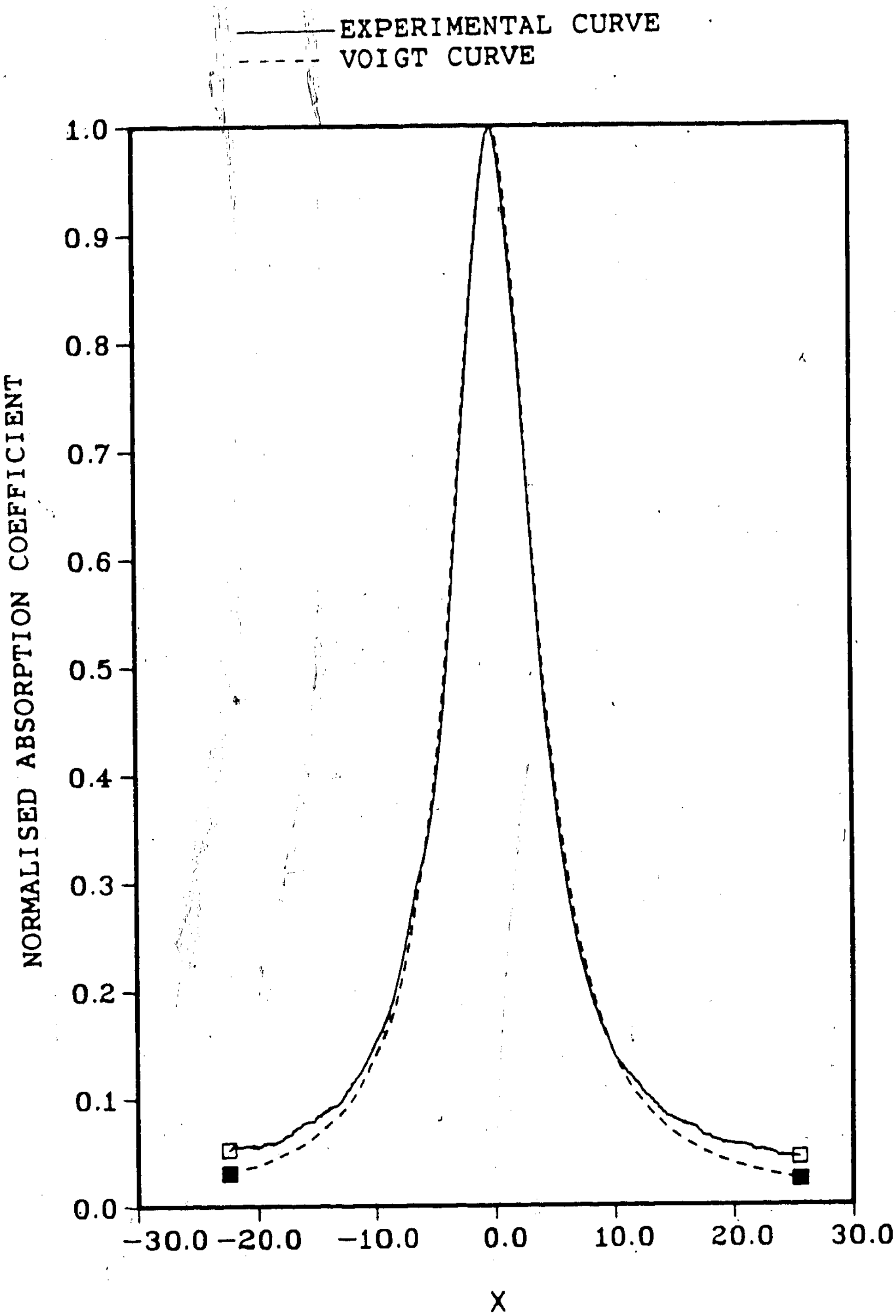


Figure 4.8 Voigt fitting for CO_2 P(16) line at 29 Torr and 418K

5. RESULTS AND CONCLUSIONS

5.1 Obtained results

Table 5.1 shows the experimental and the fitted Voigt function halfwidths for the P(16) line. The experimental Voigt halfwidth is obtained from the halfwidth of the experimental absorption lineshape. The fitted Voigt halfwidth is computed from the theoretical Voigt function which gives the best fit for the experimentally obtained absorption lineshape. Table 5.1 lists the pressure and temperature conditions of the absorption cell at the time of data acquisition. It also shows the value of y and $L\nu$ calculated for each case, from equation 4.1.5.1.

Reference [30] gives an approximate expression relating the Voigt halfwidth to Doppler halfwidth and Lorentz halfwidth. This expression can be modified and written as

$$L\nu = A\left(B - \sqrt{C + D}\right) \qquad (5.1.1)$$

where,

$A = 1/0.198 \ln 2$

$B = (1 + 0.099 \ln 2)V\nu$

$C = (1 - 0.099 \ln 2)^2 V\nu^2$

$D = 0.396 \ln 2 \, D\nu^2$

$V\nu$ = Voigt halfwidth

$L\nu$s calculated using the equation 5.1.1 agree closely with the $L\nu$s calculated using the equation 4.1.5.1.

The Voigt function fit (fig 4.4) indicates that the lineshape of the CO_2 P(16) line closely exhibits a Voigt lineshape for the pressure range 10-100 Torr and temperatures above 370K.

Figures 5.1-5.4 are the graphs showing the linear relationship of $L\nu$ with pressure. The straight line functions are least square fits of the calculated $L\nu$s, constrained to pass through the origin. The confidence interval of $L\nu$, for each pressure at which the measurements are taken, is calculated using the relationship described in [31] and [32]. From that the maximum and minimum $L\nu$ is calculated using the formula

$$\overleftrightarrow{L\nu} = \bar{L}\nu \pm 2.132\ (sd) \qquad (5.1.2)$$

where,

$\bar{L}\nu$ = $L\nu$ calculated from the fitted straight line equation at a pressure

$\overleftrightarrow{L\nu}$ = is the maximum and minimum $L\nu$

sd = standard deviation of $L\nu$

Figure 5.5 shows the behaviour of $L\nu$ with respect to temperature. The values of $L\nu$ were obtained from the straight line plots of figures 5.1-5.4 at 50 Torr pressure. From the points so obtained , a straight line is fitted to the plot of $\ln(L\nu)$ versus $\ln(T)$. the slope of this straight line is the exponent of T in equation 1.4.1. The straight line fit is also made for the two sets of $\overline{L\nu}$s obtained from equation 5.1.2. The slopes of these two fittings give the two extreme values of the exponent, which is taken for the error estimate of the exponent. Reference [27] indicates a value around 0.5 for the exponent and [3] gives a value of 0.75. The experiment conducted here yields a maximum value of 0.56 , an average value of 0.48 and a minimum value of 0.41. The average value of 0.48 is in close agreement with [27].

The fit in the wings of the absorption profile shows more error that at other points (see figure 4.3). This error is caused because of the noise appearing in the system. Since the absolute value of the absorption coefficient is small in the wings, the noise introduces more error than it does at the line center. Also the fly-back of the ramp signal used for sweeping the TDL is suspected to introduce error at the leading wing of the profile. In order to investigate the amount of error these wings could have caused, the calculation of the $L\nu$s is made by fitting the Voigt function for the measured absorption coefficient values above 10% of the maximum. The results were very close to the $L\nu$s calculated from fitting the Voigt function for all the data points, differing at most by 4 MHz. Table 5.2 lists the results obtained for the calculation made for absorption coefficient values above 10% of the maximum.

5.2 Further Research

The potential of the DAI can be expanded by providing extra operating memory. The processor can also be programmed to control many of the experimental conditions such as pressure, temperature and sweep-control. The absorption experiment can be used for further research in the analysis of CO_2 lines, such as linewidths and lineshapes of other CO_2 transitions, optical broadening coefficients due to CO_2 and foreign gases such as N_2 and He, and lineshape measurement of other gases absorbing in the infrared.

5.3 Conclusions

The data acquisition system was constructed and used for the CO_2 laser transition lineshape and linewidth experiment. Interfacing the IEEE-488 peripheral chips (Intel 8291, 8292, 8293) to the Z-80 CPU was simple forward because Intel and Zilog family of chips have many hardware features in common. Interfacing the RS-232 peripheral chip (Motorola ACIA 6850) to the CPU initially appeared to be difficult. After a series of analysis and testing of the hardware features of the ACIA, the interfacing became possible with fewer chips for decoding and controlling.

The Voigt lineshape for CO_2 laser transitions at the pressure range 10-100 Torr has been confirmed by this experiment. This systematic experiment also shows that the Lorentz halfwidth varies as $T^{-0.48}$ which is in close aggrement with the theoretically proposed model [27].

It is hoped that the work and results reported in this thesis will be useful for further research in the analyis of CO_2 transition lines and in developing microprocessor-based data acquisition systems.

Table 5.1 Experimentally calculated line parameters and the line parameters obtained from Voigt function fitting for the CO_2 P(16) line

Temp K	Pressure Torr	Experimental Voigt halfwidth MHz	Fitted Voigt halfwidth MHz	Calculated Lorentz halfwidth MHz	y
380	80.0	294.5	271.1	267.5	7.5
	69.8	258.8	251.5	247.5	7.0
	59.0	216.4	211.5	207.0	5.8
	50.1	188.1	182.8	177.2	5.0
	38.9	152.8	143.3	136.5	3.8
	30.3	127.1	116.0	113.1	3.2
418	101.0	346.3	357.1	345.4	9.1
	80.0	283.8	282.0	278.7	7.3
	69.4	242.9	244.6	240.3	6.3
	49.8	180.2	161.7	153.7	4.0
	39.4	149.3	137.0	137.2	3.6
	29.0	117.5	105.1	100.5	2.6
449	105.5	342.8	347.2	334.8	8.8
	68.7	229.6	228.7	224.0	5.8
	59.1	198.7	205.5	198.1	5.2
	49.3	169.6	171.1	164.3	4.3
	45.7	147.5	147.8	140.0	3.6
	29.8	107.7	103.8	98.2	2.5
526	101.4	307.4	311.3	307.3	7.6
	79.4	242.9	247.0	242.0	6.0
	70.9	210.2	212.7	207.0	5.1
	55.3	167.9	164.1	157.2	3.9
	45.9	140.4	136.5	132.7	3.3
	30.1	114.9	110.6	104.8	2.6

Table 5.2 Line parameters obtained from the Voigt function fitting for absorption coefficient values above 10% for the CO_2 P(16) line

Temp K	Pressure Torr	Experimental Voigt Halfwidth MHz	Fitted Voigt Halfwidth MHz	Calaulated Lorentz Halfwidth MHz	y
380	80.0	294.5	271.2	267.5	7.5
	69.8	258.8	250.1	246.1	6.9
	59.0	216.4	211.5	207.0	5.8
	50.1	118.1	182.8	177.2	5.0
	38.9	152.8	143.3	136.5	3.8
	30.3	127.1	116.0	113.1	3.2
418	101.0	346.3	345.0	342.3	9.0
	80.0	283.8	274.6	270.3	7.1
	69.4	242.9	238.7	234.3	6.1
	49.8	180.2	161.7	153.7	4.0
	39.4	149.3	136.0	135.7	3.5
	29.0	117.5	106.5	101.3	2.6
449	105.5	342.8	339.1	335.4	8.8
	68.7	229.6	226.3	221.7	5.8
	59.1	198.7	202.6	195.9	5.1
	49.3	169.6	168.1	161.2	4.2
	45.7	147.5	145.5	137.8	3.6
	29.8	107.7	103.8	98.2	2.5
526	101.4	307.4	307.4	303.3	7.5
	79.4	242.9	244.8	238.8	5.9
	70.9	210.2	210.0	204.6	5.1
	55.3	197.9	163.1	155.6	3.8
	45.9	140.4	136.0	131.9	3.2
	30.1	114.9	109.0	104.0	2.5

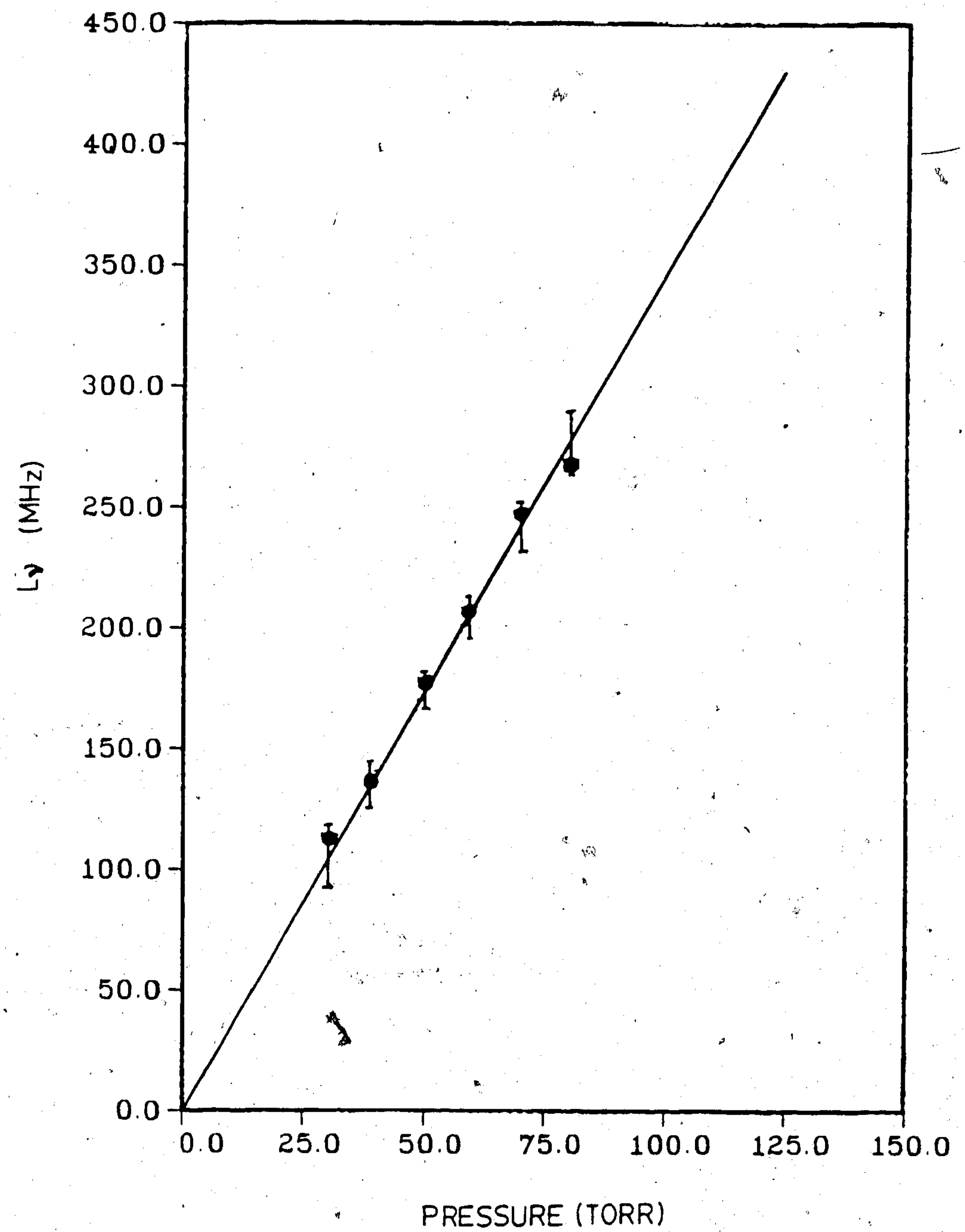


Figure 5.1 Linewidth dependance on pressure at 380K; P(16)line

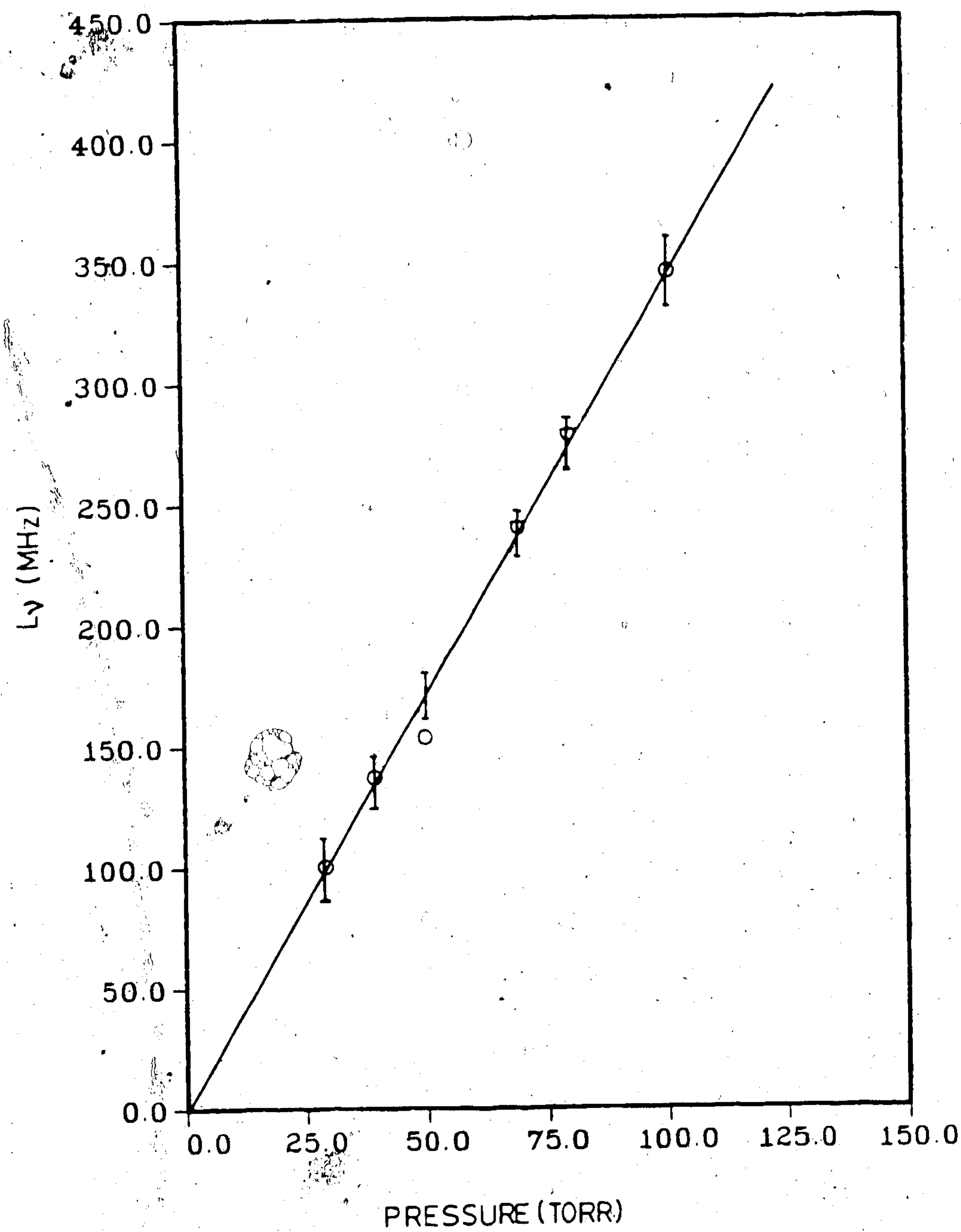


Figure 5.2 Linewidth dependance on pressure at 418K; P(16) line

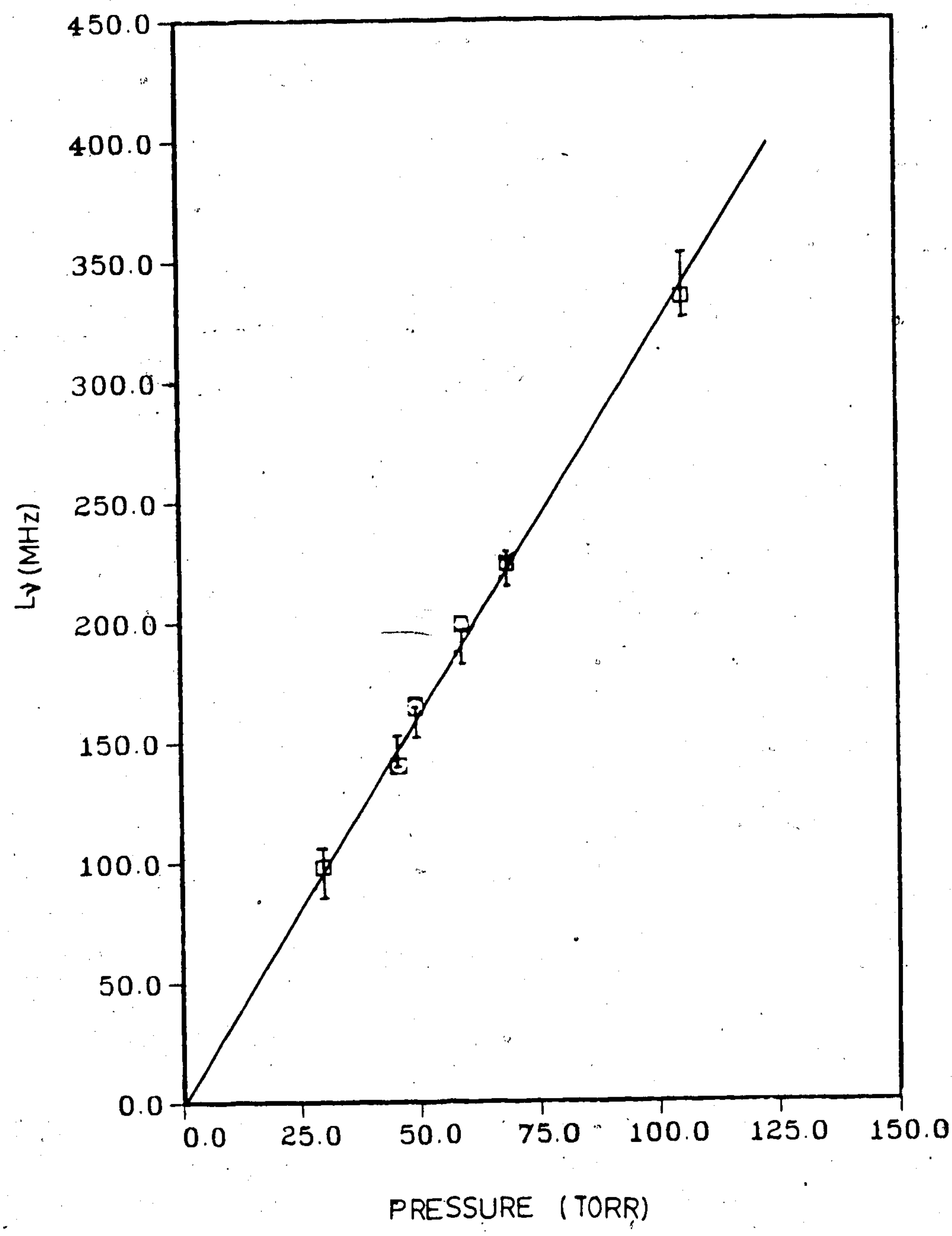


Figure 5.3 Linewidth dependance on pressure at 449K; P(16) line

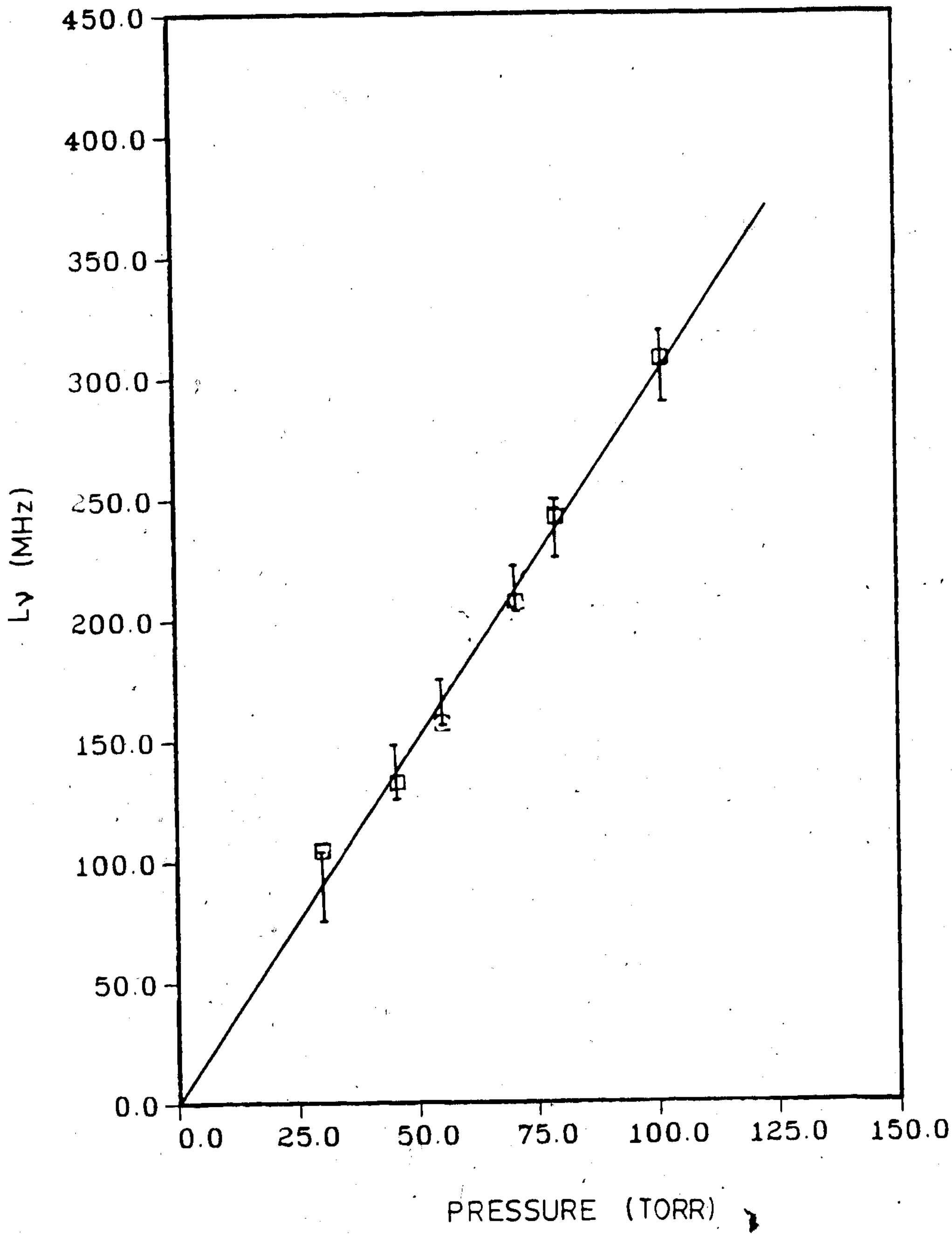


Figure 5.4 Linewidth dependance on pressure at 526K; P(16) line

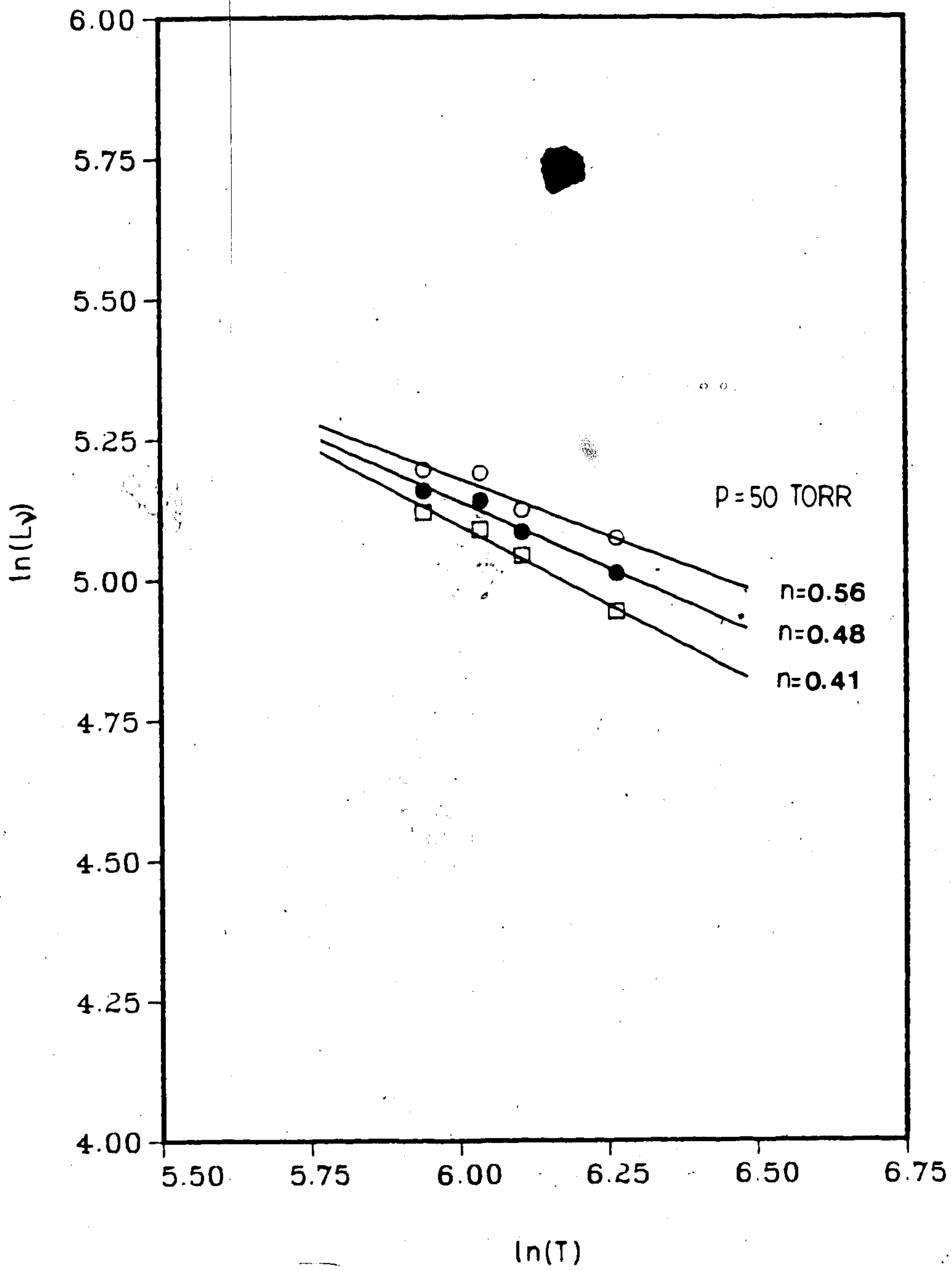


Figure 5.5 Linewidth dependance on temperature

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FORTRAN PROGRAM FOR DATA TRANSFER AND VOIGT FIT

```
      INTEGER DATA1(1024), DATA2(1024),
     1 J(1024), IE(1024)

      DOUBLE PRECISION DAT1(1024), DAT2(1024),
     1 ANS(1024), T1(7), T2(7), FE(1024),
     1 X(1024), Y(1024), EI(1024), YA(50),
     1 DVT(10,1024), ERR(1024), SR(50), SQR(50)


      N = 100

C     LINE CENTER FREQUENCY
      FE0=(3.0E+10*947.74197894)/1.0E+06

C     CONSTANTS FOR DOPPLER WIDTH
C         CALCULATION

      BK = 1.38062 E-23
      CM = 73.0 E-27
      VC = 3.0 E+08
      GN = 0.8325545

      TT=0.0
      DO 3 I=1, 6
      CALL FREAD(5, 'R:', T1(I))
      CALL FREAD(7, 'R:', T2(I))
      TT=TT+T1(I)+T2(I)
    3 CONTINUE

      TEM= (TT/12.0)+273.0

C     CALCULATION OF DOPPLER WIDTH
      RT = SQRT((2.0*BK*TEM)/(CM*VC*VC))
      DDW = 2.0*FE0*RT
      DDL = DDW*GN


      CALL FREAD(5, 'R:', P1)
      CALL FREAD(7, 'R:', P2)
      PRS= P2*10.0


      DO 10 I = 1, 1024
      CALL FREAD(5, 'I:', DATA1(I))
      CALL FREAD(7, 'I:', DATA2(I))
```

```
      CALL FREAD(8, 'I:', IE(I))
C     OFFSET ADJUSTMENT
      DAT1(I)=DATA1(I)*1.0 + 4080.0
      DAT2(I)=DATA2(I)*1.0 + 4080.0
      EI(I) =(IE(I)*1.0+4080.0)/10.0
 10   CONTINUE

      DO 2 I=1, 1024
      ANS(I)=-(DLOG(DAT2(I)/DAT1(I)))
 2    CONTINUE

C     TO FIND THE PEAK POINT AND 100 POINTS
C     IN THE NEIGHBOURHOOD OF THE PEAK

      BIG=0.0
      DO 11 I=1, 1024
      IF(ANS(I).LE.BIG) GOTO 11
      BIG= ANS(I)
      IP = I
 11   CONTINUE
      IPA= IP-51
      DO 12 I=1, N
      J(I)=IPA+I
      X(I)=J(I)*1.0
      Y(I)= ANS(IPA+I)
 12   CONTINUE


      CALL CORPEK(X, Y, N ,PX, PY)

      IP1X = PX/1
      P1Y = PY
      TAD = ANS(IP1X)

C     TO CALCULATE THE PEAK OF THE
C     ETALON TRACES

C     TO LOCATE THE FIRST PEAK

      BIG = 0.0
      DO 21 I =80, 300
      IF(EI(I).LT.BIG) GOTO 21
      BIG = EI(I)
      IP1 = I
 21   CONTINUE

C     TO LOCATE THE SECOND PEAK
```

```
22    BIG = 0.0
      JP=IP1+200
      DO 23 I =400, 550
      IF(EI(I).LT.BIG) GOTO 23
      BIG = EI(I)
      IP2 = I
23    CONTINUE
C     TO LOCATE THE THIRD PEAK

      BIG = 0.0
      JP=IP1+200
      DO 24 I =650, 800
      IF(EI(I).LT.BIG) GOTO 24
      BIG = EI(I)
      IP3 = I
24    CONTINUE

C     TO FIND THE COORDINATES
C     OF THE FIRST PEAK

      IPA= IP1-51
      DO 25 I=1, N
      J(I)=IPA+I
      X(I)=J(I)*1.0
      Y(I)= EI(IPA+I)
25    CONTINUE

      CALL CORPEK(X, Y, N, PX, PY)
      P2X = PX
      P2Y = PY

C     TO FIND THE COORDINATES
C     OF THE SECOND PEAK

      IPA = IP2-51
      DO 26 I = 1, N
      J(I)=IPA+I
      X(I)=J(I)*1.0
      Y(I)=EI(IPA+I)
26    CONTINUE

      CALL CORPEK(X, Y, N, PX, PY)
      P3X = PX
      P3Y = PY

C     TO FIND THE COORDINATES
C     OF THE THIRD PEAK

      IPA = IP3-51
      DO 27 I = 1, N
      J(I)=IPA+I
      X(I)=J(I)*1.0
```

```
      Y(I)=EI(IPA+I)
 27   CONTINUE

      CALL CORPEK(X, Y, N, PX, PY)
      P4X = PX
      P4Y = PY

      DF1 = P4X-P3X
      DF2 = P3X-P2X

      AVG = (DF1+DF2)/2.0

C     THE ETALON FORMULA

      DX =(3.0E+10/((2.0*1.0*11.7859*
     1 *2.54)*(AVG)))/1.0E+06


      FE(1)=FE0-(DX*(IP1X-1))
      DO 28 I=2, 1024
      FE(I)= (FE(I-1)+DX)
 28   CONTINUE

C     TO CALCULATE THE EXPERIMENTAL
C     VOIGT LINEWIDTH

      PY2= P1Y/ 2.0
      DF1 = 1.0E+10
      DO 30 I= 201, 500
      DIFF = (PY2-ANS(I))
      DF2 = SQRT(DIFF**2)
      IF(DF2.GE.DF1) GOTO 30
      DF1 = DF2
      ID1 = I
 30   CONTINUE
 31   DF3 = 1.0E+10
      IPP=ID1+10
      DO 32 I= IPP, 1024
      DIFF = (ANS(I)-PY2)
      DF4 = ABS(DIFF)
      IF(DF4.GE.DF3) GOTO 32
      DF3 = DF4
      ID2 = I
 32   CONTINUE


      HW = DX*(ID2 - ID1)


      WRITE(12,73)FE0
      WRITE(12,71)DDL
      WRITE(12,72)HW
 71   FORMAT(/,'DOPPLER WIDTH    =',F15.6,1X,'MHz'/)
```

```
72    FORMAT(/,'EXPT LINE-WIDTH =',F15.6,1X,'MHz'/)
73    FORMAT(/,'LINE CENTER     =',E15.6,1X,'MHz'/)


      DO 50 I=1, 1024

      ANS(I)=ANS(I)/TAD
      FE(I)=(FE(I)-FE0)/DDW

50    CONTINUE

C     CALCULATION OF ABSORPTION COEFFICIENT
C     AT LINE CENTER

      XH = FE(ID1)
      X0 = FE(IP1X)
      CK = ANS(ID1)


      XL = X0
      YL = 1.0
      LK = 11

      CALL VOIGT(XL, YL, LK, VT, MET)
      CVT = VT
      LK = 9

C     INITIAL FITTING


      Y1 = 0.0
      Y2 = 10.0
      NN = 0
85    Y3 = (Y1+Y2)/2.0
      NN = NN +1
      XL = X0
      YL = Y3
      CALL VOIGT(XL, YL, LK, VT, MET)
      CVT= VT
      XL = XH
      CALL VOIGT(XL, YL, LK, VT, MET)
      CD = CK - (VT/CVT)
      CDD = SQRT(CD*CD)
      IF(CD.EQ.0.0) GOTO 88
      IF(CDD.LE.0.0001) GOTO 88
      IF(CD.GT.0.0) GOTO 86
      Y2 = Y3
      GOTO 85
86    Y1 = Y3
      GOTO 85
88    YL = Y3
      XL = X0
      CALL VOIGT(XL, YL, LK, VT, MET)
```

```
      CVT = VT

      XL = XH
      CALL VOIGT(XL, YL, LK, VT, MET)
      CD = VT/CVT

      YL = YL - 0.6
      CIN= 0.1

      ISQ = 2

  102 DO 91 M = 1, 10
      YL = YL + CIN
      YA(M) = YL

C     SUM OF SQUARED ERROR
C     FITTING

      SER = 0.0
      SEQR= 0.0

      XL = X0
      CALL VOIGT(XL, YL, LK, VT, MET)
      CVT = VT

      DO 95 I=200,750
      XL = FE(I)

      CALL VOIGT(XL, YL, LK, VT, MET)
      DVT(M,I)=VT/CVT
      SER = SER + (DVT(M,I)-ANS(I))
      SEQR =SEQR + (DVT(M,I)-ANS(I))**2
   95 CONTINUE

      SR(M) = SER
      SQR(M)= SEQR

   91 CONTINUE

      ISQ = ISQ - 1
      IF(ISQ.LE.0) GOTO 105

      DO 101 I=2, 10
      IF(SQR(I).GT.SQR(I-1)) GOTO 103
  101 CONTINUE
      GOTO 997
  103 CIN = (YA(I)-YA(I-2))/10.0
```

```
      YL = YA(I-2)-CIN
      GOTO 102

  105 DO 106 I=2, 10
      IF(SQR(I).GT.SQR(I-1)) GOTO 106
      YS=YA(I)
      M = I
  106 CONTINUE

      DO 108 I= 1, 1024
      IF(DVT(M,I).GT.0.5) GOTO 110
  108 CONTINUE

C     TO CALCULATE
C     THE FITTED
C     VOIGT LINEWIDTH

  110 DDI  = DVT(M,I)-DVT(M,I-1)
      DXI  = 0.5 - DVT(M,I-1)
      DDX  = FE(I) - FE(I-1)
      THW  = FE(I-1)+(DXI*DDX/DDI)
      THW  = SQRT((2.0*THW*DDW)**2)
      PBR  = YA(M)*DDW


      WRITE(12,44)THW
      WRITE(12,62)PBR
      WRITE(12,63)PRS
   44 FORMAT(/,'THEO LINE-WIDT[illegible]15.6,1X,'MH[illegible]
   62 FORMAT(/,'PRES BROD WID[illegible]15.6,1X,'MHz',/)
   63 FORMAT('[illegible]8.3,1X,'TORR',/)

  997 STOP
      END


C     ****** SUBROUTINE * 1 **

C     LEAST SQUARES PARABOLA
C     FIT TO COMPUTE THE
C     COORDINATES OF THE PEAK

      SUBROUTINE CORPEK(X, Y, N, PX, PY)
      DOUBLE PRECISION X(N), Y(N)
      AK1 = 0.0
      AK2 = 0.0
      AK3 = 0.0

      X4 = 0.0
      X3 = 0.0
      X2 = 0.0
      X1 = 0.0
```

```
      A(7)  = 0.0362157301623914
      A(8)  =-0.0208497654398036
      A(9)  = 0.0111960116346270
      A(10)=-0.0056231896167109
      A(11)= 0.0026487634172265
      A(12)=-0.0011732670757704
      A(13)= 0.0004899519978088
      A(14)=-0.0001933630801528
      A(15)= 0.0000722877446788
      A(16)=-0.0000256555124979
      A(17)= 0.0000086620736841
      A(18)=-0.0000027876379719
      A(19)= 0.0000008566873627
      A(20)=-0.0000002518433784
      A(21)= 0.0000000709360221
      A(22)=-0.0000000191732257
      A(23)= 0.0000000049801256
      A(24)=-0.0000000012447734
      A(25)= 0.0000000002997777
      A(26)=-0.0000000000696450
      A(27)= 0.0000000000156262
      A(28)=-0.0000000000033897
      A(29)= 0.0000000000007116
      A(30)=-0.0000000000001447
      A(31)= 0.0000000000000285
      A(32)=-0.0000000000000055
      A(33)= 0.0000000000000010
      A(34)=-0.0000000000000002

C     HERMITE CONSTANTS

      GA(1)= 0.5246476
      GA(2)= 1.6506801
      GA(3)= 0.7071068

      GB(1)= 0.2562121
      GB(2)= 0.02588268
      GB(3)= 0.2820948


C     DAWSONS FUNCTION FOR
C     25  POINTS FOR
C     X = 1 TO 5

      DO 900 I=1, 15
      DI(I)= -I/2.0
  900 CONTINUE

      DO 500 I=1, 25
      EX(I) = 0.201*(I-0.5)
      EXX(I)= EX(I)/5.0
```

```
      DO 13 I=1,100
      AK1 = AK1+(Y(I)*(X(I)**2))
      AK2 = AK2+(Y(I)*X(I))
      AK3 = AK3+Y(I)
      X4  = X4+(X(I)**4)
      X3  = X3+(X(I)**3)
      X2  = X2+(X(I)**2)
      X1  = X1+X(I)
   13 CONTINUE

      E   = (N*AK1)-(AK3*X2)
      F   = (N*AK2)-(AK3*X1)
      XX1= (N*X4) -(X2*X2)
      XX2= (N*X3) -(X1*X2)
      XX3=  XX2
      XX4= (N*X2) -(X1*X1)

      A = (E*XX4 - F*XX2)/(XX1*XX4 - XX3*XX2)
      B = (F- A*XX3)/XX4
      C = (AK3-(A*X2)-(B*X1))/N

      PX = -B/(2*A)
      PY = A*(PX**2)+(B*PX)+C
      RETURN
      END

C     ****** SUBROUTINE * 2 **

C     TO CALCULATE THE ABSORPTION
C     COEFF FOR A VOIGT PROFILE

      SUBROUTINE VOIGT(XL, YL, LK, VT, MET)

      DOUBLE PRECISION A(50), D0(25), D1(25),
     1 D3(25), D4(25), EX(25), GA(3), GB(3),
     1 T(80), COF(25), DI(25), EXX(25), D2(25)


      X = SQRT(XL*XL)
      Y = YL
      IF(LK.LE.10) GOTO 99

C     CHEBYSHEV COEFFICIENTS

      A(1) = 0.1999999999972224
      A(2) =-0.1840000000029998
      A(3) = 0.1558399999965024
      A(4) =-0.1216640000043988
      A(5) = 0.0877081599940391
      A(6) =-0.0585141248086907
```

```
C      COMPUTATION USING CHEBYCHEV POLYNOMIALS

       T(1)=1.0
       T(2)=EXX(I)

       DO 201 J=3, 70
       T(J)=(2.0*EXX(I)*T(J-1))-T(J-2)
  201  CONTINUE


       FX = A(1)*T(2)

       DO 251 J=1, 33
       FX = FX+(A(J+1)*T(2*J+2))
  251  CONTINUE


       D0(I)=FX
       D1(I)=1.0 - 2.0*EX(I)*D0(I)
       D2(I)=(EX(I)*D1(I)+D0(I))/DI(2)
       D3(I)=(EX(I)*D2(I)+D1(I))/DI(3)
       D4(I)=(EX(I)*D2(I)+D2(I))/DI(4)

  500  CONTINUE


       DO 551 I=1, 19
       COF(I)= (20-I)/2
  551  CONTINUE


   99  X = SQRT(XL*XL)
       Y = YL

       IF(X-5.0) 100, 200, 200
  100  IF(Y-1.0) 150, 150, 110
  110  C1 = 1.85*(3.6-Y)
       IF(X.GT.C1) GOTO 200

C      CONTINUED FRACTION METHOD

       X = SQRT(XL*XL)
       Y = YL
       MET = 2
       GG = Y
       RR = X



       DO 120 I=1, 19
       R = COF(I)/(RR**2 + GG**2)
       GG = Y + R*GG
       RR = X - R*RR
```

```
 120  CONTINUE
      VT =(GG/(RR**2 + GG**2))/1.772454

      RETURN


 150  C3=X+Y
      IF(C3.GE.5.0) GOTO 300

      MET = 1

      N = X/0.207
      DX = X - EX(N+1)
      R =(((D4(N+1)*DX+D3(N+1))*DX+D2(N+1))*DX+
     1D1(N+1))*DX+D0(N+1)

      G = 1.0 - 2.0*X*R
      RR = (EXP(Y*Y-X*X)*COS(2.0*X*Y)/1.128379)
     1 - Y*G
      GG = -Y

      DO 155 I=2, 6, 2
      R = (X*G+R)/DI(I)
      G = (X*R+G)/DI(I+1)
      GG= -GG*Y*Y
      RR= RR+G*GG
 155  CONTINUE

      VT = 1.128379*RR
      RETURN

C     TWO-POINT METHOD

  200 X = SQRT(XL*XL)
      Y = YL
      C2 = 11.0 - (0.6875*X)
      IF(Y.LT.C2) GOTO 300

      GG= X - GA(3)
      RR= X + GA(3)

      VT = Y*((GB(3)/(Y**2+GG**2))
     1 +(GB(3)/(Y**2+RR**2)))
      MET = 3
      RETURN

C     FOUR POINT METHOD
```

```
300 X = SQRT(XL*XL)
    Y = YL

    G = X - GA(1)
    R = X + GA(1)
    GG= X - GA(2)
    RR= X + GA(2)

    AKA = GB(1)/(Y**2+G**2)
    AKB = GB(1)/(Y**2+R**2)
    AKC = GB(2)/(Y**2+GG**2)
    AKD = GB(2)/(Y**2+RR**2)

    VT = Y*(AKA+ AKB+ AKC+ AKD)
    MET = 4

    RETURN
    END
```

ASSEMBLEY LANGUAGE PROGRAM LISTING FOR
DATA ACQUISITION INTERFACE

```
TLR      EQU $7000   8291 address in the memory space
CLR      EQU $7800   8292 address in the memory space

***************************************************
*              Registers in 8291                  *
***************************************************

DINR     EQU TLR     data in reg
DOUT     EQU TLR     data out reg
INST1    EQU TLR+$1  int status      read only
INTEN    EQU TLR+$1  int enable      write only
INST2    EQU TLR+$2  int status 2    read only
INTEN2   EQU TLR+$2  int enable 2    write only

SPLST    EQU TLR+$3  serial poll status    r
SPMD     EQU TLR+$3  serial poll mode      w
ADDST    EQU TLR+$4  address status        r
ADDMD    EQU TLR+$4  address mode          w
CMNDPT   EQU TLR+$5  command pass thro     r
AUXMD    EQU TLR+$5  aux mode              w

ADD0     EQU TLR+$6  add 0                 r
ADD01    EQU TLR+$6  address 0/1           w

ADD1     EQU TLR+$7  address1
EOS      EQU TLR+$7  end of sequence character   w

***************************************************
*               8292 REGISTERS                    *
*          These registers belong to              *
*               Controller                        *
***************************************************

CINST    EQU CLR+$1  interrupt status   read only
CMDFG    EQU CLR+$1  command flag register
CINMSK   EQU CLR     int mask   this reg is for write only
*                    but issuing  RINM  will transfer
*                    its contents to RDBUS

ERRMSK   EQU CLR     error mask  this reg is for write only
*                    but  RERM  will transfer its contents
*                    to RDBUS

RDBUS    EQU CLR
WRBUS    EQU CLR

***************************************************
*           COMMAND ALLOCATION FOR 8291           *
```

```
*****************************************************

*           FOR ADDRESS MODE REGISTER

TONLY    EQU $80
LONLY    EQU $40

*           FOR AUX MODE REGISTER

IXPON    EQU $00     imm ex pon
CRST     EQU $02     chip reset
FHS      EQU $03     finish hand-shake
SEOI     EQU $06     send EOI with next byte
PON      EQU $08     power on
CLOCK    EQU $22     sets 8291 clock as 2Mhz
AUXA     EQU $83     this has to be written in aux-A register
*                    via aux mode register
*
AUXB     EQU $A8     similar to aux-A, but for aux-B
AUXP     EQU $70     similar to aux-A,B, but for aux-P

*****************************************************
*          OPERATION AND UTILITY COMMANDS FOR THE   *
*                    CONTROLLER                     *
*****************************************************

*           OPERATION COMMANDS

SPCNI    EQU $F0     stop counter int                   TCI
GIDL     EQU $F1     go to idle                         TCI
RST      EQU $F2     reset                              TCI
RSTI     EQU $F3     reset int                          TCI
GSEC     EQU $F4     goto stand by, but enable count    TCI
EXPP     EQU $F5     ex parallel poll                   TCI
GTSB     EQU $F6     go to stand by                     TCI
SLOC     EQU $F7     set loc mode                       TCI
SREM     EQU $F8     set rem control                    TCI
ABORT    EQU $F9

TCNTR    EQU $FA     take control                       TCI
TCASY    EQU $FC     take control asynchronously        TCI
TCSY     EQU $FD     take control synchronously         TCI
STCNI    EQU $FE     start counter int                  TCI

*           UTILITY COMMANDS

WTOUT    EQU $E1     wr time out reg
WEVC     EQU $E2     wr event counter
REVC     EQU $E3     rd evc reg
RERF     EQU $E4     rd err flag
RINM     EQU $E5     rd int mask
```

```
RCST     EQU $E6     rd controller status
RBST     EQU $E7     rd bus status
RTOUT    EQU $E9     rd time out reg
RERM     EQU $EA     rd err mask reg
IACK     EQU $FF     int ack

MTA      EQU $5E     my talk address/ for signal averager
MLA      EQU $3E     my listen address/ sig ave'r
UNL      EQU $3F     unlisten

BIM      EQU $01     byte input mask
BOM      EQU $02     byte outpt mask

TLOC     EQU $6800   test location write to display LED
RAM      EQU $0800   begining of RAM
STACK    EQU $0B8F   stack pointer

*****************************************************
*            ACIA REGISTERS                         *
*****************************************************

CONRG    EQU $01     control register     w  OUT
STARG    EQU $01     status  register     r  IN
TXRG     EQU $03     transmitt  reg       w  OUT
RECRG    EQU $03     receive reg          r  IN

*****************************************************
*            INITIALIZE ACIA                        *
*****************************************************

         ORG $0000
OGN      NOP
         NOP
         LXI SP,STACK           stack pointer

         MVI A,$03
         OUT CONRG              7 bit, even parity
         MVI A,$01              2 stop bits
         OUT CONRG
         IN RECRG

         CALL SYS               display system on
         CALL ACI               display acia initialized
```

```
        MVI A,$51
        STA TLOC

****************************************************
*           INITIALIZING 8291,8292                  *
****************************************************

INTI    MVI A,RST
        STA CMDFG               reset 8292



        MVI A,ABORT
        STA CMDFG               abort ieee-bus activity

        MVI A,$A0
        STA CINMSK              enable TCI int

        MVI A,$AC
        STA TLOC
        MVI A,CRST
        STA AUXMD               reset 8291


        MVI A,TONLY
        STA ADDMD               set 8291 to talk only

        MVI A,CLOCK
        STA AUXMD               set 8291 clock to 2Mhz

        MVI A,AUXA
        STA AUXMD               set contineous hand shake
        MVI A,AUXB
        STA AUXMD
        MVI A,AUXP
        STA AUXMD               ignore parallel poll


        MVI A,$FF
        STA TLOC
        MVI A,IXPON
        STA AUXMD

****************************************************
*       now the 8291 should be initialized          *
*       and should be ready for data transmission   *
****************************************************

        CALL IEI                display ieee488 initialized

        MVI A,$AD
        STA TLOC
```

```
        MVI A,MLA               address of the averager
        STA DOUT
        CALL CBOUT              call subroutine to check
*                               byte o/p
*

        MVI A,$EF
        STA TLOC
        MVI A,SREM              set remote enable
        STA CMDFG
        CALL TCI                call task complete int
        CALL DELA
*****************************************************
*          set controller standby                   *
*****************************************************

        MVI A,$BB
        STA TLOC
        MVI A,GTSB              go to stby
        STA CMDFG
        CALL TCI


        MVI A,$52
        STA TLOC
        CALL DELA

        CALL CSBY

*****************************************************
*          clear the memory of the                  *
*                averager                           *
*****************************************************

        MVI A,'C'
        STA DOUT
        OUT TXRG
        CALL OUT
        CALL CBOUT
        MVI A,'M'
        STA DOUT
        OUT TXRG
        CALL OUT
        CALL CBOUT
        MVI A,$0D
        STA DOUT
        OUT TXRG
        CALL OUT
        CALL CBOUT
        MVI A,$0A
        STA DOUT
        OUT TXRG
        CALL OUT
        CALL CBOUT
```

```
        CALL DELA

        CALL CMST

        MVI A,$53
        STA TLOC
        CALL DELA            press switch to continue

        MVI A,FHS
        STA AUXMD
        MVI A,TCSY
        STA CMDFG
        CALL TCI             take control

        CALL TCTR

        MVI A,UNL
        STA DOUT
        CALL CBOUT

        MVI A,MTA
        STA DOUT
        CALL CBOUT           set avg'r to talk

        CALL AGTK

CON3    MVI A,PON
        STA AUXMD
        MVI A,LONLY
        STA ADDMD
        MVI A,$80
        STA AUXMD
        MVI A,IXPON
        STA AUXMD            set 8291 to listen only
        CALL DELA

        MVI A,$C3
        STA TLOC

        MVI A,GTSB
        STA CMDFG
        CALL TCI             set controller stby

        CALL CSBY

        CALL DELA
```

```
        LXI B,4
DIN     LDA INST1          look for din full
        ANI BIM
        JZ DIN
        LDA DINR
        ØUT TXRG            output to ACIA
        CALL OUT
        CALL DELA
        DCX B
        MOV A,C
        ANI $FF
        JNZ DIN


        MVI A,TCASY
        STA CMDFG
        CALL TCI


        CALL TCTR

        MVI A,TONLY
        STA ADDMD
        MVI A,AUXA
        STA AUXMD
        MVI A,IXPON
        STA AUXMD


        MVI A,MLA
        STA DOUT
        CALL CBOUT

        CALL AGLN

        MVI A,FHS
        STA AUXMD

        MVI A,GTSB
        STA CMDFG
        CALL TCI

        CALL DELA

*****************************************************
*           start sweep                             *
*****************************************************

        MVI A,'G'
        STA DOUT
        OUT TXRG
        CALL OUT
```

```
        CALL CBOUT
        MVI A,'O'
        STA DOUT
        OUT TXRG
        CALL OUT
        CALL CBOUT
        MVI A,$0D
        STA DOUT
        OUT TXRG
        CALL OUT
        CALL CBOUT
        MVI A,$0A
        STA DOUT
        OUT TXRG
        CALL OUT
        CALL CBOUT

        CALL CLF

        MVI A,FHS
        STA AUXMD

        MVI A,TCASY
        STA CMDFG
        CALL DELAY

        MVI A,UNL
        STA DOUT
        CALL CBOUT
        MVI A,MTA
        STA DOUT
        CALL CBOUT
        MVI A,LONLY
        STA ADDMD
        MVI A,$80
        STA AUXMD
        MVI A,IXPON
        STA AUXMD

        MVI A,$54
        STA RAM

        MVI A,GTSB
        STA CMDFG
        CALL TCI

        CALL DELA

        LXI B,5
DATA    LDA DINR
```

```
        OUT TXRG
        CALL OUT
DD      LDA INST1
        ANI BIM
        JZ DD
        DCX B
        MOV A,C
        ANI $FF
        JNZ DATA

        CALL CLF
        MVI A,'%'
        OUT TXRG
        CALL OUT



        MVI A,FHS
        STA AUXMD
        MVI A,TCSY
        STA CMDFG
        CALL TCI

        CALL FLASH

        LXI H,RAM+20
        LXI B,300
INPT    CALL INP
        IN RECRG
        MOV M,A
        INX H
        DCX B
        MOV A,B
        ANI $FF
        JNZ INPT
        MOV A,C
        ANI $FF
        JNZ INPT


ZZZ     LXI SP,STACK
        CALL FLASH


        LXI H,RAM+20
        CALL CLF

***********************************************
*          transfer temperature and           *
*            pressure data from               *
*               data logger                   *
***********************************************
```

```
ALFA    MOV A,M
        SUI '+'                look for + in the data stream
        JNZ BETA

KAPA    INX H
        MOV A,M
        SUI 'C'                look for C in the data
        JZ GMA

        MOV A,M
        SUI 'V'                look for V in the data
        JZ DLTA

        MOV A,M                transmit the valid data
        OUT TXRG
        CALL OUT
        JMP KAPA

GMA     CALL CLF
BETA    INX H
        JMP ALFA

DLTA    CALL CLF


        MVI A,TONLY
        STA ADDMD
        MVI A,AUXA
        STA AUXMD
        MVI A,IXPON
        STA AUXMD


        MVI A,UNL
        STA DOUT
        CALL CBOUT
        MVI A,MLA
        STA DOUT
        CALL CBOUT

        MVI A,GTSB
        STA CMDFG
        CALL TCI

        CALL DELA

        CALL DUMP

        MVI A,$FF
        STA TLOC
        MVI A,FHS
        STA AUXMD
```

```
        MVI A,TCSY
        STA CMDFG
        CALL TCI
        CALL DELA


        MVI A,UNL
        STA DOUT
        CALL CBOUT

        MVI A,MTA
        STA DOUT
        CALL CBOUT

        MVI A,LONLY
        STA ADDMD
        MVI A,$80              cor aux a register
        STA AUXMD
        MVI A,IXPON
        STA AUXMD
        CALL DELA
        MVI A,GTSB
        STA CMDFG
        CALL TCI
        CALL DELA


************************************************
*           dump memory data                   *
************************************************


        LXI B,1025             dumping 1024 locations
DIN1    CALL OUT
DI      LDA INST1
        ANI BIM
        JZ DI
        LDA DINR
        STA RAM+5


        ANI $F0
        JZ COUNT
        LDA RAM+5
        OUT TXRG

        CALL DELA
        JMP DIN1

COUNT   LDA RAM+5
        OUT TXRG
        CALL OUT
        CALL DELA
CTT     LDA INST1
```

```
ANI BIM
JZ CTT
LDA DINR
OUT TXRG
ANI $F0
JNZ DERR
DCX B
MOV A,C
ANI $FF
JNZ DIN1
MOV A,B
ANI $FF
JNZ DIN1

****************************************************
*        end of transmission character             *
****************************************************

CALL CLF
CALL CLF
MVI A,'9'
OUT TXRG
CALL OUT
MVI A,'9'
OUT TXRG
CALL OUT
MVI A,'9'
OUT TXRG
CALL OUT
CALL CLF


MVI A,FHS
STA AUXMD
MVI A,TCSY
STA CMDFG
CALL TCI
CALL FLASH
MVI A,AUXA
STA AUXMD
MVI A,TONLY
STA ADDMD
MVI A,IXPON
STA AUXMD
CALL DELA
MVI A,MLA
STA DOUT
CALL CBOUT
MVI A,GTSB
STA CMDFG
CALL TCI
CALL DELA
MVI A,FHS
```

```
        STA AUXMD
        MVI A,TCSY
        STA CMDFG
        CALL TCI
        CALL FLASH
        JMP OGN
        HLT

*****************************************************
*            SUBROUTINES                            *
*****************************************************

*            for data out check

CBOUT   LDA INST1           load accm with int status-1
        ANI BOM             and immd with byte out mask
        JZ  CBOUT
        RET

*            for data in check

CBIN    MVI C,$8
CB      DCR C
        MOV A,C
        ANI $FF
        JZ ERR1
        LDA INST1
        ANI BIM
        JZ CB
        RET

*            for flashing the data in "RAM"

FLASH   LXI D,$FFFF
        LDA RAM
        STA TLOC
CTR     DCX D
        MOV A,D
        ANI $FF
        JNZ CTR
        LXI D,$8FFF
        MVI A,$11
        STA TLOC
CTR1    DCX D
        LDA TLOC
        ANI $FF
```

```
        BIT 0,A
        JNZ CONT            jmp to cont if A0 is 1
        RET
CONT    MOV A,D
        ANI $FF
        JNZ CTR1
        JMP FLASH

*************************************************************
*             commanding  the averager to                   *
*             to dump the memory contents                   *
*************************************************************

DUMP    LXI H,DMP
        LXI B,16
ST      MOV A,M
        STA DOUT
        OUT TXRG
        CALL OUT
        CALL CBOUT
        CALL DELA
        INX H
        DCX B
        MOV A,C
        ANI $FF
        JNZ ST
        MOV A,B
        ANI $FF
        JNZ ST
        RET
DMP     FCC 'DP,0000,2046,A'
        FDB $0D0A

*             to check task complete

TCI     LDA TLOC
        ANI $FF
        BIT 7,A
        JZ TCI
        RET

*             to check data out in ACIA

OUT     IN STARG
        ANI $02
        JZ OUT
        RET

*             to check data in

INP     IN STARG
        ANI $01
```

```
        JZ INP
        RET

*****************************************************
*           MESSAGES                                *
*****************************************************


SYS     LXI H,MSG1
MG1     MOV A,M
        STA RAM+5
        CALL STOUT
        LDA RAM+5
        ANI $FF
        JNZ MG1
        RET
MSG1    FDB $0D0A
        FCC 'Z80- DATA ACQUISITION INTERFACE'
        FDB $0D0A
        FCC 'SYSTEM ON'
        FDB $0D0A
        FCC '>'
        FCB $00


*

ERR1    LXI H,MSG2
MG2     MOV A,M
        STA RAM+5
        CALL STOUT
        LDA RAM+5
        ANI $FF
        JNZ MG2
        HLT
MSG2    FCC 'INPUT BYTE NOT AVILABLE'
        FDB $0D0A
        FCC '>'
        FCB $00

*

ACI     LXI H,MSG3
MG3     MOV A,M
        STA RAM+5
        CALL STOUT
        LDA RAM+5
        ANI $FF
        JNZ MG3
        RET
MSG3    FCC 'RS232 SET'
        FDB $0D0A
        FCC '>'
        FCB $00
```

```
*

IEI      LXI H,MSG4
MG4      MOV A,M
         STA RAM+5
         CALL STOUT
         LDA RAM+5
         ANI $FF
         JNZ MG4
         RET
MSG4     FCC 'IEEE SET'
         FDB $0D0A
         FCC '>'
         FCB $00

*

DELAY    LXI H,$FF00
D1       DCX H
         MOV A,H
         ANI $FF
         JNZ D1
         MOV A,L
         ANI $FF
         JNZ D1
         RET
*

DELA     LXI D,50
D2       DCX D
         MOV A,E
         ANI $FF
         JNZ D2
         MOV A,D
         ANI $FF
         JNZ D2
         RET

*

DEM      FCC 'IMPROPER FORMAT FROM AVERAGER'
         FDB $0D0A
         FCB $00
DERR     LXI H,DEM
DEM1     MOV A,M
         STA RAM+5
         CALL STOUT
         LDA RAM+5
         ANI $FF
         JNZ DEM1
         HLT
*

CSMG     FDB $0D0A
```

```
        FCC 'CSBY'
        FDB $0D0A
        FCB $00
CSBY    LXI H,CSMG
CSB1    MOV A,M
        STA RAM+5
        CALL STOUT
        LDA RAM+5
        ANI $FF
        JNZ CSB1
        RET

*

CMSG    FDB $0D0A
        FCC 'CLEAR MEMORY'
        FDB $0D0A
        FCB $00
CMST    LXI H,CMSG
CMST1   MOV A,M
        STA RAM+5
        CALL STOUT
        LDA RAM+5
        ANI $FF
        JNZ CMST1
        RET

*

TCTG    FDB $0D0A
        FCC 'CONR ACTV'
        FDB $0D0A
        FCB $00
TCTR    LXI H,TCTG
TCT1    MOV A,M
        STA RAM+5
        CALL STOUT
        LDA RAM+5
        ANI $FF
        JNZ TCT1
        RET

*

AGT     FDB $0D0A
        FCC 'AVG TK'
        FDB $0D0A
        FCB $00
AGTK    LXI H,AGT
AG1     MOV A,M
        STA RAM+5
        CALL STOUT
        LDA RAM+5
        ANI $FF
```

```
        JNZ AG1
        RET

*

AGL     FDB $0D0A
        FCC 'AVG LN'
        FDB $0D0A
        FCB $00
AGLN    LXI H,AGL
AGL1    MOV A,M
        STA RAM+5
        CALL STOUT
        LDA RAM+5
        ANI $FF
        JNZ AGL1
        RET

*

LOOP    LXI D,$FFFF
        INX H
        DCX B
        MOV A,C
        ANI $FF
        JZ L1
        RET
L1      MOV A,B
        ANI $FF
        JZ L2
        RET
L2      LXI D,$0000
        RET

*

STOUT   INX H
        LDA RAM+5
        ANI $FF
        JZ STUT
        LDA RAM+5
        OUT TXRG
        CALL OUT
STUT    RET

*

CLF     MVI A,$0D           to transmit cr lf
        OUT TXRG
        CALL OUT
        MVI A,$0A
        OUT TXRG
        CALL OUT
        RET
```