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THE AUTOMATIC CONTROL, INFORMATION PROCESSING AND ANALYSIS OF CONDENSATION PUMPING EXPERIMENTS

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C O N T E N T S

A B S T R A C T

During the past two and a half years we have been studying the practical potentialities and limitations of condensation pumping hydrogen and deuterium in the ultra-high vacuum regime on surfaces cooled by liquid helium to around $3^{o}K$. These studies have required analysis of the variations of the sticking coefficients and desorption rates with such condensation parameters as gas incidence rate, surface coverage, surface temperature, gas temperature and thermal radiation load. Separation of the influence of each of these parameters upon the pumping performance requires cross correlation of detailed results from a fairly large number of experiments under different condensation conditions. To recover the maximum amount of information from each experimental run, and hence to economise in both experimental time and the use of liquid helium, a punched paper tape data logging system has been used to scan and record all relevant experimental parameters during the course of the experiment. A sequence timing unit has been used to control the switching of the gas inflow, as required for analysis of sticking coefficients and desorption rates, and for initiating the scanning of the data logger. The punched paper tape records have been analysed on the English Electric KDF9 computer at Culham and the results presented directly in both printed and graphical forms.

The main advantage we have found in the use of automatic recording and analysis techniques is the ease of accurate processing of large amounts of information. This helps to ensure that all experimental observations are actually analysed - even though from seemingly less successful experiments. Earlier observations may also be easily reprocessed, and the results presented in alternative ways for comparison with more recent experiments.

The present paper describes the basic design features of the control and information recording and processing techniques, and illustrates their practical application with results from our condensation pumping studies.

1. Introduction

During the past three years we have been studying the condensation pumping of hydrogen and deuterium onto liquid helium cooled surfaces in the ultra-high vacuum region. These studies have enabled us to assess the potentialities and limitations of this pumping technique, and have also revealed some interesting features of the growth and behaviour of condensed gas films (Chubb, Gowland and Pollard (1968)).

To predict the overall pumping effect of an extensive surface, for example by Monte Carlo calculations (Chubb (1965)), it is necessary to know the pumping characteristics of individual surface elements and how these depend upon gas condensation conditions and the history of the surface. The particular features which characterise the pumping capability of a surface are the sticking coefficient and the rate of desorption from the surface. In our studies of condensation pumping we have been examining how these features vary with gas incidence rate, surface coverage, surface temperature, gas temperature and thermal radiation loading. The angular incidence distribution and gas purity may also be relevant parameters, but so far we have not examined these.

Sticking coefficients and desorption rates may be measured during condensation pumping experiments (Chubb (1966); Chubb, Gowland and Pollard (1968)) using the signals observed by ion gauges and mass spectrometers in the presence of, and in the absence of, additional gas inflow to the study chamber. With a switchable gas flow system (Chubb, Gowland, 1967) and short time-constant amplifiers, detailed pictures can be obtained of the changes in the sticking coefficient and desorption rate as the layer of condensed gas grows under steady condensation conditions. To handle the large quantities of information which this switchable gas flow system makes available we have used a punched paper tape data logging system to record experimental observations directly throughout the course of experiments. Computer analysis and automatic graph plotting have been used for the calculation and display of results from these paper tape records.

The aim of the present paper is to describe the main features of the data recording and processing techniques we have used, and to illustrate their application with results from some of our condensation pumping experiments.

2. Control of Experiment and Recording of Observations

2.1 Introduction

In analysis of individual experiments we wanted to correlate the calculated values of sticking coefficients and desorption rates with the condensation conditions and history of the condensed layer. This meant that it was necessary to record not only signals relating to ion gauge and mass spectrometer observations but also information on the total time the experiment had been running, the total quantity of gas introduced, the temperature of the gas incident on the surface, the temperature of the condensing surface, etc. We decided that the most convenient arrangement would be to have a data sampling system which would examine and record (at any instant required) the overall state of the experiment. The computer program subsequently handling this data would then select the information required to calculate sticking coefficients, desorption rates and the relevant condensation conditions and history of the layer. This approach allows considerable flexibility in both the recording and analysis of information. For example, provision may be made to handle data samples recorded before introduction of gas, data samples taken during zeroing of gauges and mass spectrometers, of multiple samples taken during and after gas injection, and of corrupted and absent data sequences.

Our data sampling system is a commercial data logging equipment made by MB Metals Ltd using punched paper tape as the data storage medium. We have added some digital counting units, logical gating circuits and a parity generator of our own design. On command, this logger scans through and punches out each of the digital numbers and up to twenty input voltages describing the state of the experiment. The total time for scanning and punching is about 3½ seconds. The paper tape from this logger, containing perhaps 20,000 number from a single experimental run, is then read by our main computer at Culham, an English Electric KDF 9, and the results presented in printed and graphical form. This off-line arrangement for analysis of the experimental observations allows all the facilities of a large computer to be used with fairly inexpensive equipment associated directly with the experiment. It also gives simple permanent storage of the raw experimental observations, and permits easy re-analysis of this raw data whenever required.

2.2 Sequence Timing

To give a regular predetermined pattern to the gas injection and pause periods as well as provide trigger pulses at appropriate instants on the gas injection cycle to initiate data scanning, we developed a simple sequence timing system. This consisted of a number of identical basic timer units interconnected to give the required overall logical time sequence.

The basic timer units consist of a model TCeF4PEV Sodeco counter and two relays. Each timing unit receives a continuous train of 1 second clock pulses and on receipt of a start pulse (earthing the 'start' connection) the counter starts counting down from its pre-set initial value towards zero. From receipt of the start pulse until counter zero is reached, two sets of contacts are held in the changed-over position and can be used to control external circuits. When zero is reached the transfer connection is earthed while the counter is re-set. The transfer connection can thus be used to initiate counting of one or more subsequent timer units. The control of external circuits for periods exceeding the counting time of single units can easily be provided with auxiliary latch and de-latch relay units triggered in parallel with the appropriate 'start' and 'transfer' connections.

The overall timing sequence required during operation of the experiment is illustrated in Fig.1 in relation to the type of signal variation observed on a mass spectrometer detector. Provision has been made to zero the mass spectrometer amplifier during the gas flow off-period because experience has shown that amplifier zero drift can be a serious problem when looking at signals in the range 10^{-15} to 10^{-14} amp. The method of zeroing is to use a high voltage relay to switch off the accelerating volts in the mass spectrometer control unit. If any modulated Bayard Alpert gauges are used on the experiment it is convenient to modulate these to check their residual currents whilst the mass spectrometer is being zeroed.

The above sequence timing system has proved very reliable and flexible. The timing arrangement illustrated in Fig.1 allows easy adjustment of the gas injection and pause periods without changing the relative timing of the data samples with respect to the instant of switching off the gas inflow. Although sticking coefficients and desorption rates may be calculated both for switching on and for switching off the gas inflow, we have confined our calculations to the latter instance. This restriction was made because we felt that even with careful balancing of our switchable gas flow system there might be some small additional signal variations at the beginning of a new gas injection period, associated with setting-up the gas inflow, which would affect the results.

2.3 Data Recording

The state of the experiment at any instant is specified to the data logger in the following way. There are five digital counter assemblies using a total of 24 Sodeco 5TD single digit registers, each having its decimal read-out converted to B.C.D. The first three counters display the number of seconds the experiment has been running, the number of seconds for which gas has been injected and the number of the gas injection cycle. The other two counters provide information which enables a small adjustment to be made to the mean gas inflow rate to give the instantaneous flow rate at the time of a data sample. The period of the saw-tooth modulation of the gas inflow is displayed on one counter and on the other counter is displayed the time elapsed since the preceding 'step-up' in the waveform. The logger is presented with the output signals and range of each ion current amplifier, the electron emission of each ion gauge and mass spectrometer, a thermo-couple voltage to give the temperature of the gas incident on the condensing surface, a voltage related to the temperature of the surface, the voltage of the modulator electrode of a modulated Bayard Alpert gauge to indicate if this is modulated, and a voltage to indicate if the gas flow is switched on.

The data logger first scans sequentially each digit register of the digital counters and punches them out on the paper tape. A Solatron LM 1420 Digital Voltmeter is then used to scan the voltage inputs and each reading is punched in turn on the paper tape. The range of the digital voltmeter may be programmed by a simple plugboard unit to match the sensitivity required for each individual input channel. The reed relays used to switch the input to the digital voltmeter are only suitable for switching voltages in the region of 250 volts. It was, hence, not practical to present the mass spectrometer electron emission directly to the data logger as the emission signal when looking at hydrogen is 2 kV from earth. To overcome this problem a suitable input voltage was set manually. The same method was also used to give the input relating to the temperature of the condensing surface by making the voltage proportional to the helium vapour pressure over the liquid helium bath cooling the condensing surface.

We have used our own character code and word format on the paper tape as generally no agreed codes were available. For each character (i.e. a single row on the punched paper tape) we use three parity bits with four information bits (B.C.D.) in a Hamming code (Hamming 1950). This code enables both error detection and correction to be carried out by the computer and so a single error in punching or reading any character may be corrected.

Each digit register of the digital numbers is recorded as a separate character with punching of the eighth hole reserved to identify the start of each word. Each voltage signal is represented by six characters, the first to give the sign and range of the digital voltmeter and having the eighth hole punched, the second to give the multiplication factor of the voltmeter, and the following four are equivalent to the four windows of the digital voltmeter. In addition to identifying the start of each word by punching the eighth hole of its first character, we have arranged for the eighth hole of the second character of the second voltage input signal to be punched. By examining the pattern of eighth hole punching the computer program reading the paper tape can ensure that only valid data is accepted into the main program and that corrupted or absent sequences are ignored.

3. Computer Analysis

The computer program for analysing the experimental observations recorded on paper tape first reads in general information about the date of the experiment, the type of gas studied, the gas inflow rates and the gauge and mass spectrometer sensitivities. Tables of numbers are also read-in to give the variations of impact density at the ion gauges and mass spectrometers with sticking coefficients, the variation of voltage with temperature of the thermocouple junction indicating the gas inlet temperature, the variation of helium vapour pressure with temperature and the variation of the enthalpy of hydrogen gas with temperature. The program then reads-in data samples from the paper tape records up to the first gas inflow period. The subroutines which read these records check and, if necessary, correct individual characters and also check the overall format of each data sample. The information returned to the main program by these routines consists of the five numbers from the digital counters and the value of each voltage presented to the input terminals of the digital voltmeter. The main program prints out this raw data and also calculates and prints out the gas densities observed by each gauge and mass spectrometer. Provision is made for updating the zero offset of each ion current amplifier and the electron emission signal whenever the electron emission level falls below specified values. Provision is also made for updating the calculated residual current level in modulated gauges if data samples in the modulated and unmodulated state are taken within ten seconds of each other. Throughout the program, background gas densities are calculated using the latest values of zero offset and residual current.

At the first data sample for which the gas inflow is switched on, control passes to the second section of the main program which is concerned with selecting appropriate data samples for calculation of sticking coefficients and desorption rates. This selection involves finding successive data samples of which one is the last sample taken before switching off the gas inflow of a particular gas inflow period, and the other is the first sample taken after switching off the gas inflow period. The changes in gas density represented by the difference between these data samples are used to calculate the values of sticking coefficient seen by each detection instrument. The calculation makes use of interpolation routines and the read-in relationships between the sticking coefficient at the condensing surface and the impact density at the entrance orifice of each detection instrument. The instantaneous gas flow rate for these sticking coefficient calculations is obtained by modifying the read-in value of mean gas flow rate at this time by a fraction of the saw-tooth modulation of the gas inflow rate. This fraction is given by the proportion of the saw-tooth waveform which has elapsed at the time of the data sample. The data sample taken directly after the end of the gas inflow period is used to calculate the background gas density seen by each detection instrument. These values are then combined with their respective sticking coefficients to give the desorption rate for each instrument (Chubb, Gowland, Pollard (1968)).

If a new value of residual current is calculated for a modulated gauge within ten seconds of a data sample after the end of a gas inflow period, with the gas inflow still switched off, then this new residual current is used to recalculate the values of background gas density and desorption rate for this gas inflow period.

The temperature of the inflowing gas, the temperature of the condensing surface and the heat released by condensation of the inflowing gas are calculated from the data sample and the initial information with the help of interpolation routines. The coverage of the condensing surface is calculated by adding to the previous coverage the product of the present gas incidence rate at the surface and the number of seconds of gas inflow since the preceding calculation was made.

As the paper tape is being read the various steps of the above calculations may be printed out if required for detailed checking. The computer stores from each pair of samples the total time elapsed since the start of the first gas injection period, the gas incidence rate to the surface, the surface coverage, the gas temperature, the heat energy released on condensation, the background gas densities, and the desorption rates. These values are then used in subsequent print out and graphical presentation of results. The reading in of information from the paper tape is terminated when a sample is found with a time from the start of the experiment of zero seconds. This sample is readily generated at the end of an experimental run after resetting all the digital counters to zero.

Graphical output may be obtained from our KDF 9 at Culham through the Benson-Lehner Model 120 Film Plotter using the special graphical output language (Larkin (1967)). At present we plot five basic graphs for each experimental run - the variation of background gas density with surface coverage, the variation of desorption rate with surface coverage, the variation of sticking coefficient with surface coverage, and the variation of background gas density with surface temperature. Examples of such graphs are shown in Figs.2, 3, 4, 5 and 6. To facilitate comparison between graphs from different experiments, and to make each graph generally more readable, we have provided general headings on each graph and a summary of the condensation conditions at the start of the experiment. This form of presentation makes the graphs produced automatically by the computer directly suitable for inclusion in reports and for showing as slides.

4. Conclusions

The main advantage which arises from the use of automatic data recording and analysis techniques is the ability to analyse large quantities of information quickly and accurately. In conjunction with automatic graphical display these techniques allow direct presentation of detailed results in readily comprehensible forms. Our condensation pumping experiments usually involve 200-300 gas injection periods, and hence yield 200-300 values of sticking coefficient, desorption rate, etc. for each observation instrument. The time for computer analysis of such a run is around 15 minutes. Although the application of these analysis techniques has dramatically reduced the time needed for analysis of experiments it has involved a fair amount of time in program development - mainly in order to handle information from non-ideal experiments in which, for example, a thermocouple lead was not connected or an amplifier range indicator was not working.

Our present feelings are that the application of these automatic processing techniques has made a useful contribution to the understanding of our condensation pumping studies. It is, however, necessary to look at these results in conjunction with the continuous U.V. records which are made of signal variations during an experiment to keep a good physical insight into the general course and meaning of experiments.

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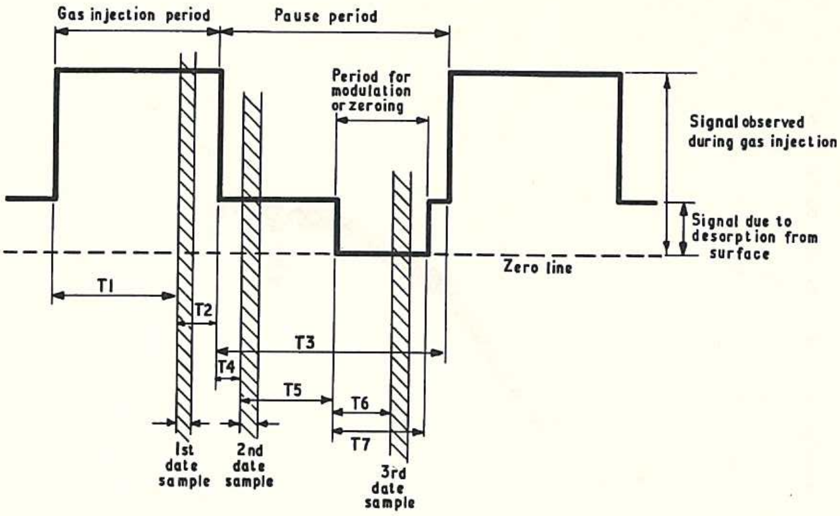

Fig. 1 Timing sequence of data samples in relation to gas injection period
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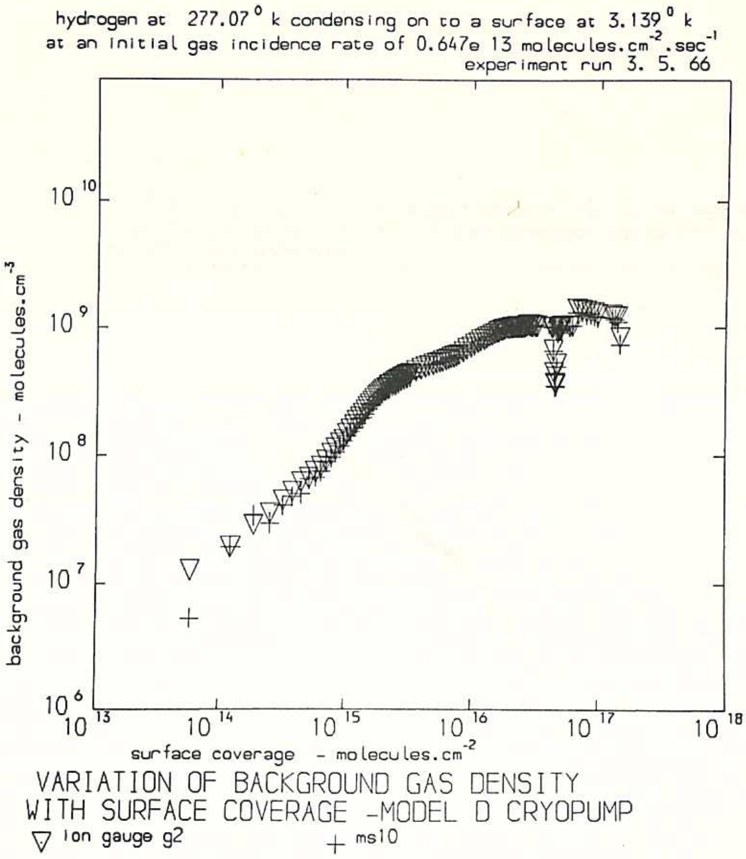


Fig. 2 *(CLM - P 168)*

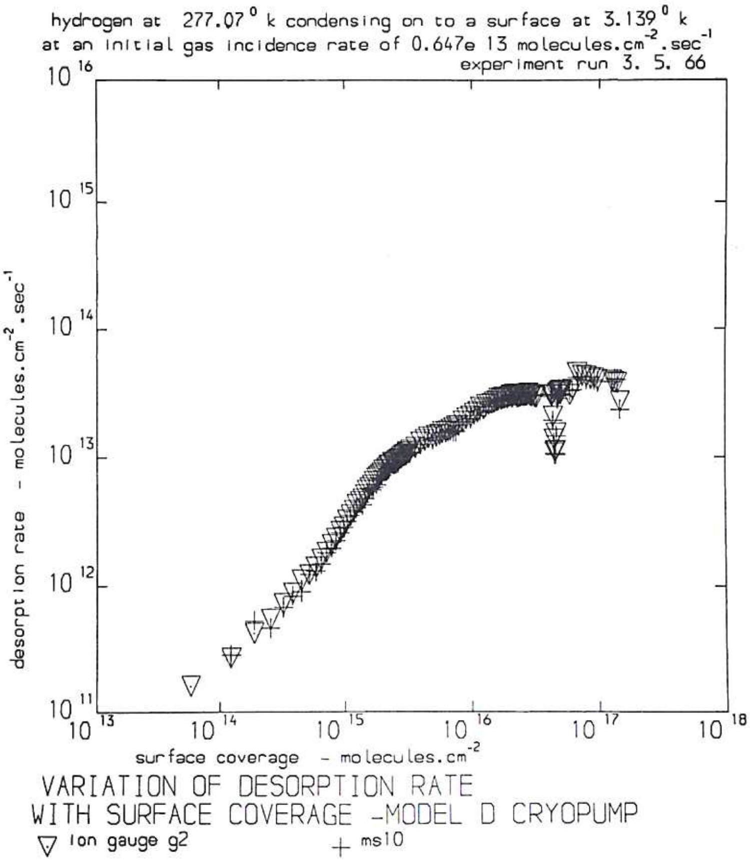
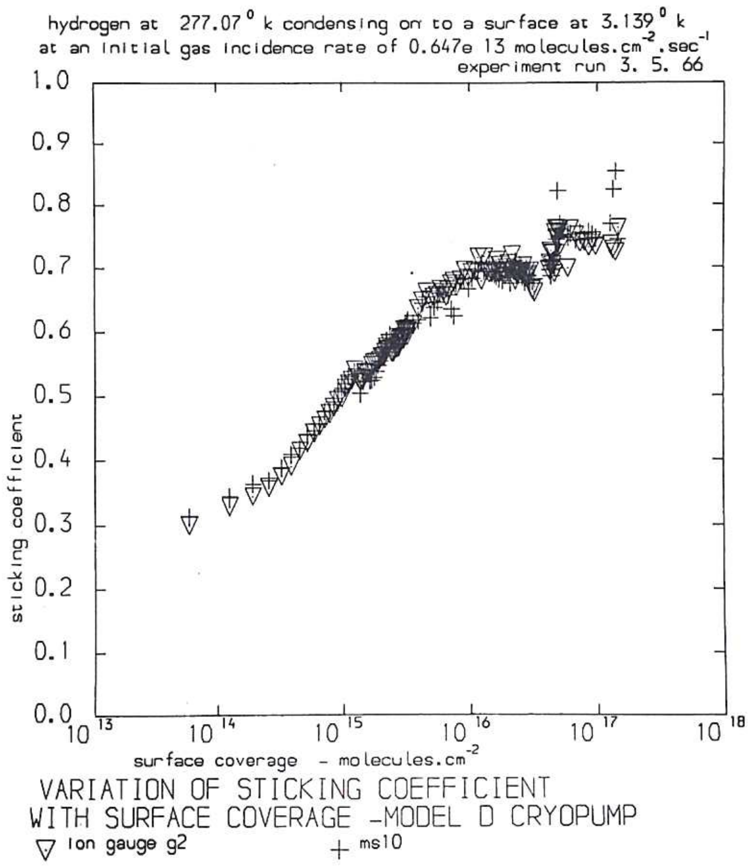


Fig. 3 *(CLM - P 168)*



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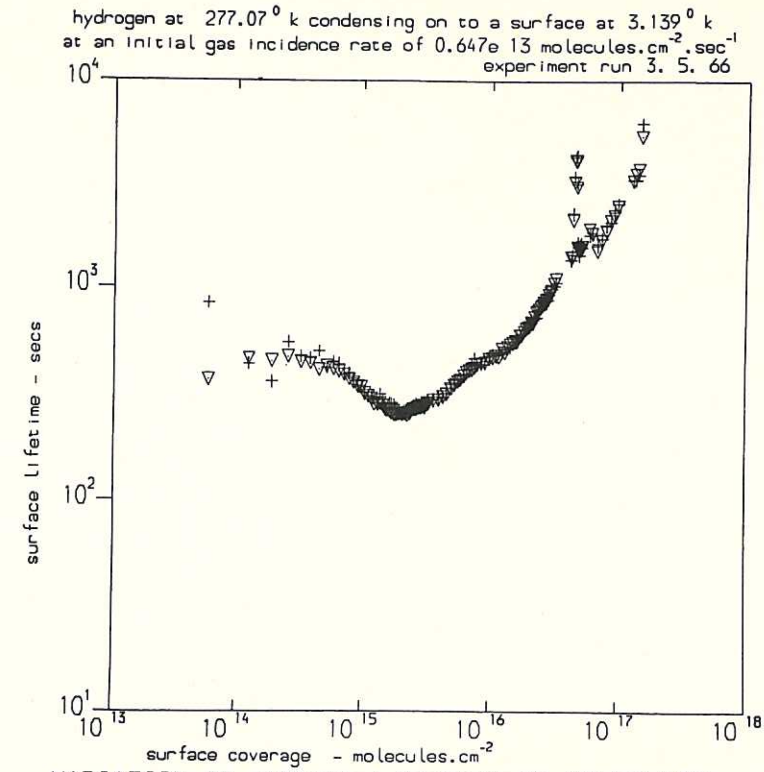
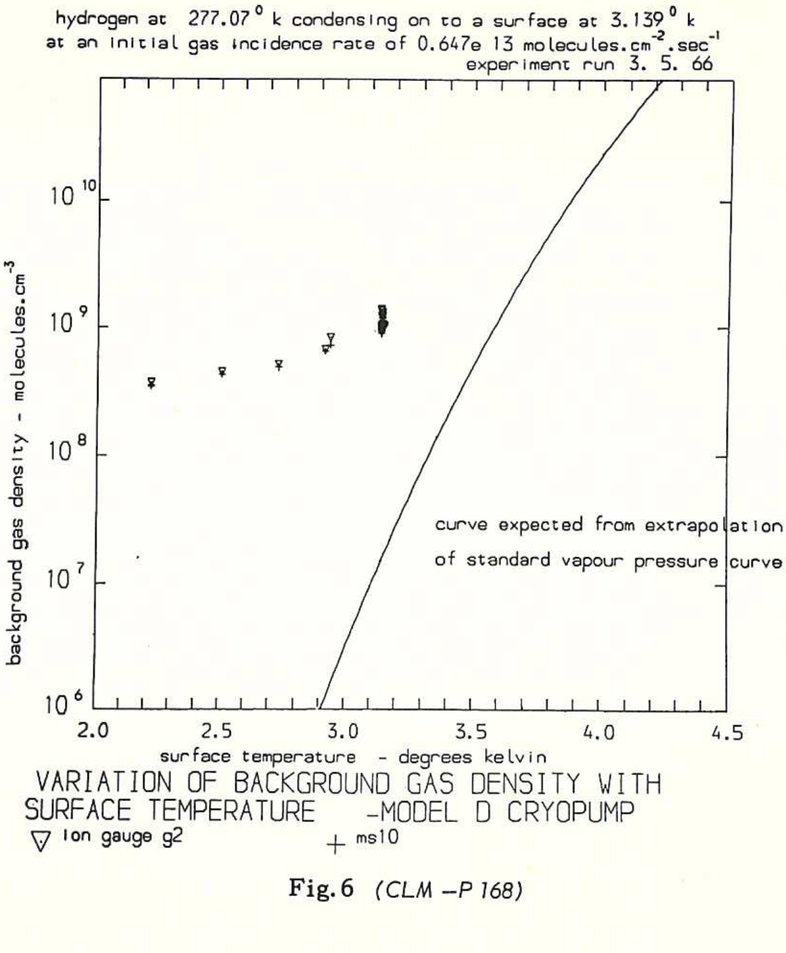


VARIATION OF SURFACE LIFETIME OF MOLECULES
WITH SURFACE COVERAGE -MODEL D CRYOPUMP

▽ ion gauge g2 + ms10

Fig. 5 *(CLM - P 168)*



VARIATION OF BACKGROUND GAS DENSITY WITH
SURFACE TEMPERATURE -MODEL D CRYOPUMP

▽ ion gauge g2 + ms10

Fig. 6 *(CLM - P 168)*