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A SEARCH FOR EXPERIMENTS TO EXPLOIT THE SPACE SHUTTLE ENVIRONMENT

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A SEARCH FOR EXPERIMENTS TO EXPLOIT THE SPACE SHUTTLE ENVIRONMENT

by

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First of Two Volumes

Abstract

This study extends an earlier search for worthwhile experiments in pure and applied physics and chemistry which might take advantage of conditions achievable aboard the Space Shuttle. Of particular interest were the very large pumping speeds at high or ultra high vacuum, the highly non-equilibrium composition of the ambient atmosphere, and the relative absence of gravitational effects. Ideas and suggestions were solicited in the course of visits to 31 research establishments in Western Europe, India and Japan, conversations with over 90 scientists, and presentations at three international meetings. Intriguing possibilities emerged in five arenas: (1) Spectroscopy of the transition state in chemical reactions; (2) Flame structure and analysis; (3) Solid propellant combustion; (4) Analysis of atmospheric composition; (5) Turbulence Effects on Aerosol Coagulation.

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Summary

This report comprises a geographic and substantive extension of an earlier attempt in 1976 to identify worthwhile experiments which might advantageously be carried out aboard a Space Shuttle in orbit. The earlier investigation focussed on experiments with free jets which would take advantage of the very high pumping speed available in space. It was based on communication with scientists in America and Western Europe. The present author, who had participated in the earlier study, last year spent two months in India, three months in Japan and one month in Europe visiting laboratories and talking with research scientists and engineers. In addition, during the period since the first report was completed, he had made presentations at three international meetings in an attempt to stimulate interest in and suggestions for such experiments and others not involving free jets. This document reports on the results of these further attempts to identify worthwhile experiments. The harvest was rather lean but five interesting avenues of investigation were identified:

1. Natural Lasers and Transition State Spectroscopy. In the upper atmosphere the species OH is vibrationally very hot and rotationally very cold and thus invites attempts to obtain stimulated emission over very long path lengths. It might be rewarding to look very carefully at the infrared emission in the wings of excited OH. Because OH is formed by highly exothermic reaction of ozone and H atoms, any observed broadening could be interpreted in terms of the radiation occurring while the OH was still closely associated with the OOOH transition state complex.

2. Very Low Pressure Flames. It turns out that the volumetric flow rate of premixed fuel and oxidant required to maintain a stable flame is inversely proportional to the pressure. The lowest pressures which have been reached on earth are of order one torr where the mean free path is only a micron. To reach much lower pressures one

must have very high pumping speeds, such as might be achieved on the Space Shuttle. One inviting prospect is that flame front structure could be resolved in much more detail than is now possible. Another is that collisional quenching times could be increased to the same order as radiation life times, thus giving rise to possibly interesting radiation effects.

3. Solid Propellant Combustion. For reasons similar to those involved in gaseous flames, achieving stable combustion of solid propellants at very low pressure also requires very high pumping speeds. There are a number of interesting and unanswered questions about low pressure deflagration of such propellants which might be answered by experiments at high pumping speeds.

4. Composition of Upper Atmosphere. In spite of many measurement attempts there are large uncertainties in the composition of the upper atmosphere which stem from difficulties in avoiding perturbations of the composition by the measuring instrument. Possibilities for overcoming these problems include velocity discrimination in sampling and laser sensing techniques.

5. Turbulence Effects on Aerosol Coagulation. Agglomeration or coagulation of colloidal particles due to Brownian motion is reasonably well understood. Agglomeration of larger particles in gaseous systems may be strongly affected by velocity fluctuations due to turbulence. Such effects may have had a profound influence on the composition of planets and other bodies formed by condensation from primordial gas. Interesting agglomeration experiments may be possible on the Space Shuttle in the absence of gravitational settling in gaseous suspensions of large particles.

A SEARCH FOR EXPERIMENTS TO EXPLOIT THE SPACE SHUTTLE ENVIRONMENT

I. Introduction

In 1976 Relay Development Corporation (RDC) undertook a study program for NASA-JPL aimed at identifying and evaluating worthwhile experiments which might be advantageously carried out in an environment to which the Space Shuttle promises to provide access. In particular, RDC's assignment was to consider experiments in which supersonic free jets would play a vital role. Such free jets have been rewarding objects of study because they comprise a rich source of phenomena which occur under conditions readily achieved in such jets but which are not otherwise obtainable. The attraction of the Space Shuttle Environment (SSE) consists in its ability to provide virtually unlimited pumping speed at relatively low background pressures. Such large pumping speed would make possible much higher source Reynolds numbers at lower background pressures than would be economically feasible at the bottom of the ocean comprising Earth's atmosphere. Large Reynolds numbers would permit experiments at relatively large scale and/or at large pressure ratios for the expansion.

The RDC Study culminated in a report which summarized the results of an extensive literature search, conversations with nearly 100 scientists and analysis of a number of gedanken experiments.[1] The essential conclusions were:

(1) No experiments emerged which in the sense of their scientific implications could be considered sufficiently critical to justify ab initio the investment of resources which would be required to carry them out aloft.

(2) There were some interesting and worthwhile experiments which, though not "critical", the SSE could expedite or enhance but there could be no assurance that clever earthbound investigators might not find ways to achieve equivalent results at lower cost and in less time.

(3) The prospectively most interesting experiments were spectroscopic in the sense that they all involved the interaction of molecules with photons. The principal basis for their appeal stems from the ability of the SSE to provide long optical paths in nearly collisionless gas. These long paths mean that there can be relatively large numbers of molecules in the field of view of a detector for relatively long times. The absence of collisions means that the states of the molecules do not change. Thus, initially non-equilibrium conditions can be maintained.

Since the appearance of that RDC report there has been renewed consideration of the so-called Molecular Wake Shield or MWS. This concept involves the disposition of an impermeable surface of relatively large frontal area on the Shuttle itself or on some outboard vehicle. The idea is that this shield would sweep the molecules of ambient atmosphere out of its path so that in its immediate wake the effective background pressure or density would be substantially lower than that of the ambient atmosphere through which the Shuttle is flying. Subject to some unknowns, e.g., the contribution to be expected from outgassing of shield and vehicle surfaces, it has been estimated that the effective background pressure for a typical orbit altitude and velocity would be reduced from about 10^{-6} torr in the free stream to the vicinity of 10^{-12} torr[2,3] in the wake of the shield. This ultra-high vacuum environment may make inviting some experiments which might not be feasible or interesting at the much higher background pressure presumed in the original study. Moreover, a corollary consequence of such a shield is the possibility of generating a collimated beam of molecules of ambient gas by means of a suitably shaped inlet aperture in the shield which would play the role of a skimmer in conventional nozzle beam systems. Oxygen atoms are the dominant atmospheric species at probable oribiting altitudes. For example, they are present at concentrations of nearly $10^{10}/cm^3$ at an altitude of 200 kilometers. An orbiting velocity of 8 km/s would thus give rise to a beam of oxygen atoms with an intensity near $8 \times 10^{15}/cm^2$-s. Such a beam, which would have a translational energy of about 5 eV, cannot now be readily generated in earthbound laboratories and would make feasible many interesting scattering experiments.

In sum, the SSE in conjunction with the MWS opens up possibilities not contemplated in RDC's original study.

Another limitation of the original RDC study concerned the scientists polled for ideas, suggestions and comments. Though their number was appreciable, they represented a community which was restricted geographically to North America and Western Europe and scientifically to those who had some research experience with molecular beams and/or rarefied gas dynamics. Moreover, good ideas frequently have fairly long gestation periods and many of the scientists who were approached had no previous occasion to consider the possibility of doing experiments in space. Consequently, it seemed appropriate to undertake an extension of the original survey. One objective would be to include a broader segment of the scientific community. Another would be to renew encounters with some of those who have been accosted earlier to see whether some seeds sown the first time around might have since germinated.

As it happened, one of the authors of the original RDC report, Professor John B. Fenn, was to be on leave from Yale University during the spring term of 1979. He had been invited to spend two months at the Indian Institute of Science in Bangalore and at the Institute of Space and Aeronautical Sciences of the University of Tokyo. In addition, he planned to travel a month in Europe visiting laboratories and attending the International Symposium on Molecular Beams beginning on 28 May at Riva del Garda in Italy. This itinerary appeared to provide an excellent opportunity for him to extend the scope of the original survey by seeking ideas from a broader segment of the scientific community than had been included in the earlier report. Moreover, he would have an opportunity for second encounters with some of the people who had been previously exposed to the idea of experiments in the Space Shuttle Environment. Perhaps some seeds sown then might have fallen on fertile ground. Professor Fenn was willing to pursue these goals during his travels and was commissioned to do so. This

report summarizes his experiences and findings. Volume I includes a description of the possible experiments which emerged during the survey, a catalog of the scientists who were interviewed, and an account of the meetings at which formal presentations were made about the possibilities for Space Shuttle experiments. Volume II is essentially a travelogue describing the places which were visited. In the interests of informality and economy of words the writer will resort to the use of the vertical pronoun.

II. The Results

The word about possibilities for experiments on board the Space Shuttle was spread substantially farther and wider in this survey than during RDC's initial study. Even so, the harvest of ideas was in some sense still disappointing. As in our earlier census, most responses fell into one of the following categories; usually expressed in more euphemistic terms than I will employ.

1. This is all so new and different that I will have to think about it.
2. It is too far from my regular research beat and I can't see any connection which would make it worth my while to give it much attention.
3. Clearly a boondoggle. I could make better use of the money in my lab on the ground.
4. You Americans have enough money to contemplate such experiments. We have to devote our resources and attention to more immediate problems.
5. What a great idea! You could do this, and this, and this,..., all the "thises" being fairly thoughtless and naive.
6. Sounds like a great opportunity but I can't think of any way to take advantage of it.

Amidst all this chaff, there were a few grains of wheat, some proposed experiments which seemed interesting enough to report. They are set forth in the following paragraphs of this section.

1. Lasers Au Naturel and Transition State Spectroscopy. After nearly twenty-five years of molecular beam reactive scattering experiments and maybe a decade of spectroscopy and photochemistry by lasers, today's chemists know more about the microscopic details of chemical reactions than Arrhenius and Bodenstein could have dreamt of. In particular, these modern techniques have led to so-called "state-to-state" chemistry which contemplates complete experimental specification of velocities, internal energy levels and even the orientation of reactant and product species immediately before and after a reactive encounter. What still eludes the most intrepid investigators is any direct observation of that construct, the "transition state"--a configuration of species which marks at once the end of their identity as reactants and the beginning of their identity as products. Of extremely short lifetime and perhaps in some cases not even identifiable or definable, this ephemeral species has existed thus far mainly in the minds of investigators. Whatever characteristics have been ascribable to its reality are largely based on deductions as to plausible bridges between reactant states and product states. Before the beam and laser era, most experimental data related to the initial state of reactants and the final state of products. We now have increasingly direct information on the final state of reactants and the initial state of products so the bridges to be built are much shorter and therefore less speculative in their design.

The direct experimental identification and description of the transition state has been called by John Polanyi the "last frontier" of chemical kinetics. Of late there have been a number of suggestions by theorists that extremely high powered lasers might be able to probe the transition state structure, and indeed, take advantage of its asymmetric nature by bringing about laser promoted reactions between reactants which in their symmetric initial configurations are not capable of absorbing photons.(4,5) The calculated power requirements are

so large that many people are pessimistic about the outcome. Among the optimists is John Polanyi of the University of Toronto, and he sees the Space Shuttle, literally and figuratively, as a possible vehicle for experiments which might achieve the goal of direct observation of the transition state. After some discussion with me at the Riva meeting he wrote a letter summarizing his ideas. I know of no better way to present them than to reproduce his own words. What follows are essentially literal excerpts from his letter.

"The proposals for the skylab could be made to hinge on the observation of $OH^{\dagger}$ (vibrationally excited hydroxyl in its ground electronic state) and also Na* and Na** (electronically excited Na in the 3p and 4s states respectively). Since $OH^{\dagger}$ is emitting strongly from approximately 90 km and is hard to observe at ground level, I shall concentrate on that in setting forth the following two objectives:

(I) Look (for the first time) for evidence of what I termed in 1960 and 1961 publications, prior to the first laser, a "natural iraser" comprised of the upper atmosphere. The point was that vibrational temperature $T_{vib} \approx 10{,}000$ K and rotational temperature $T_{rot} \approx 230$ K. Hence hundreds of transitions in the P-branch of the fundamental ($\Delta v = 1$ at approximately 3 microns in the near infrared) have the potential for producing stimulated emission in view of the long path length.

The existence of "an inverse Frauenhofer effect" was postulated, i.e., the continuum emission from the sun should show narrow intervals of enhanced intensity when viewed through a long path-length of the upper atmosphere. (This, by the way, was the first time that $T_{vib} >> T_{rot} > 0$ had been noted to be a sufficient criterion for what was termed "partial population inversion"--a concept that underlies the CO_2 and CO vibrational lasers).

(II) A far more venturesome proposal which, however, requires a similar line of experimentation, is to look for infrared emission in the wings of the $OH^{\dagger}$ ($v \rightarrow v - 1$) fundamental, or the $OH^{\dagger}$ ($v \rightarrow v - 2$, $v \rightarrow v - 3$,...) overtones, extending into the photographic region. This would constitute observations of a type of collision-induced broadening due to strong (high energy) collisions that could only be due to the fact that $OH^{\dagger}$ is produced chemically through $H + O_3 \rightarrow [HOOO]^{\dagger} \rightarrow HO^{\dagger} + O_2$ (as is highly likely to be the case) and that one is observing the OH radical before it has moved out of range of the other product, O_2; i.e., one would have (for the first time) spectroscopic data bearing on the forces operating in $[HOOO]^{\dagger}$ -- <u>spectroscopy of the transition state in a chemical reaction</u>.

Such an observation has the best chance of success if one can observe a very long column of reacting $H + O_3$, as is the case in the upper atmosphere. The low pressure ensures that there is no local depletion of H through rapid reaction with O_3, i.e., it solves the difficult problem of reagent mixing for fast reaction. Observation from space eliminates water absorption of radiation.

A similar experiment is possible for that part of Na* and Na** that is formed chemically in the upper atmosphere, naturally through reaction of $O + NaO^{\dagger} \rightarrow O_2 + Na^*$ (or Na**) or from the reaction of naturally-occurring atomic species with Na_2 injected into the surroundings from a supersonic orifice, thus $O + Na_2 \rightarrow NaO + Na^*$.

The ratio of concentrations of transition state to product species is $10^{-10} - 10^{-11}$ for $OH^{\dagger}$, and $10^{-4} - 10^{-5}$ for Na*. This renders the experiment very difficult, but not impossible in view of the fact that photons can be counted against a dark background. In the case that Na_2 is injected, interposition of a chopper blade in the Na_2 flow will permit subtraction of any background from signal.

We very much want to try feasibility studies on Objective II in our laboratory and are ready to do so as soon as we get the signal to go ahead.

2. Flames At Very Low Pressures. Flames have fascinated man ever since he began to control and use fire, probably even before. Until Galileo introduced the controlled experiment and launched the era of modern science, fire as manifested by flame was regarded with awe as an embodiment of godly magic. The Greeks assigned it a fundamental role in the composition of the real world. Along with earth, air and water, it was considered one of the four elements from which all things were made. Flames are rather spectacular consequences of a complex interaction between physical and chemical processes. The combustion which gives rise to them is still the major source of the heat from which prime movers derive the work that powers industrial society. For these reasons, flames have been the objects of intense scientific study for nearly two centuries. Investigators have tried to understand their phenomenology in terms of their physics and chemistry. They have sought to relate their speeds, structure and stability to the thermodynamics and kinetics of chemical reactions and the physical transport of mass energy and momentum. In recent years there has been increasing interest in the role of reactants and products which are present in amounts too small to effect flame behavior but large enough to have major environmental consequences. Growing concern about the depletion of oil and gas resources has renewed interest in achieving even small increases in the efficiency of all kinds of combustion systems.

One important and powerful variable in the experimental study of flames is pressure. In early experiments pressures were almost always atmospheric or higher, partly because such pressures were easy to achieve in the laboratory and partly because practical systems operated in this range. With the advent of high altitude flight internal combustion engines were required to perform at subatmospheric pressures. In the laboratory experimenters began to appreciate and exploit the fact that reaction zones in flames could be greatly extended and magnified by lowering the pressure and therefore the density of the reacting

gases. In flames of premixed gases at one atmosphere much of the action occurs in a region somewhat less than a few tenths of a millimeter in thickness. At 25 torr this flame zone expands to a centimeter or more, depending upon the composition of the entering gas. This increase in thickness greatly improves the resolution of structure which can be achieved by various kinds of probes.

On a very elementary plane of flame phenomenology the question was often asked whether there was a limiting pressure below which a flame front could not propagate into unburned gas. In an attempt to answer this question and at the same time to increase the resolution of their spectroscopic probing of flame front structure, Gaydon and Wolfhard in 1950 carried out a then heroic effort to produce flames at very low pressures.[6,7] They found that there was in effect a characteristic Reynolds number below which stable flames could not propagate. In terms of more directly measurable quantities Reynolds number at a particular flame speed is proportional to the product of pressure and burner diameter. Thus, what Gaydon and Wolfhard found was that as long as this product was maintained at a characteristic value for a particular composition, they could lower the pressure as much as they wanted to as long as they increased the burner diameter correspondingly. They also found that for many fuel-oxidant combinations the burning velocity did not change appreciably with pressure. Thus, as the pressure was lowered the volumetric flow increased and they reached the limit of their available pumping speed at pressures of about one torr with a burner diameter of 10 cm. The pumping speed which they had available was not specified. They simply noted that they were using the largest available industrial vacuum pumps. With these low pressure flames and spectroscopic techniques, Gaydon and Wolfhard probed the species distribution in various flames. More recently, Wolfhard in collaboration with Vanpee, Hinck and Seamans examined the nature of OH radiation in flames at pressures down to about 10 torr

on a burner 10 cm in diameter.[8] Their system was exhausted by a Roots pump with a speed of 300 liters/sec. Even more recently Vanpee has made observations on flames down to about one torr in a system whose pumping speed is about 2400 liters/sec.[9] None of these investigators apparently made any particular attempt to cool the burned gases before they arrived at the pump. Appropriate cooling together with judicious use of cryopumping when the exhaust gases are readily condensible could have greatly enhanced their effective pumping speeds. Even so, if one wanted to burn flames at pressures substantially lower than one torr it seems clear that it would be difficult and expensive to provide sufficient pumping speed because the required speed goes up with the inverse square of the pressure. To remove the gases from a flame at a pressure of one millitorr would require 10^6 times as much pumping speed as would be required at one torr!

Is there any good reason to go to such low pressures? The answer to this natural question is not entirely obvious. A number of reasons can be cited. How good they are is a matter of conjecture. We can give such conjecture a starting point by noting that an age old question in combustion circles has been whether there is really a low pressure limit to flame propagation. To the extent that simple extrapolation of past experience can be relied upon, the answer seems to be that one can maintain flames at as low a pressure as one wants provided only that one makes the diameter of the burner sufficiently large. Testing of this empirical rule to pressures well below one torr would be perhaps interesting but certainly not of overwhelming importance per se. However, upon more careful reflection some intriguing possibilities emerge. In the first place, it is to be recalled that some of the elementary exothermic reactions in many flames almost certainly involve atom and radical recombination which are thought to require three body encounters. At one torr these events are relatively scarce compared to

binary collisions but still possibly numerous enough to allow ordinary flame reactions to proceed. Indeed, Wolfhard noted that in flames of carbon monoxide or hydrogen with oxygen there was a decrease in burning velocity with decreasing pressure which did not occur with hydrocarbons as fuels. He tentatively attributes this decrease in speed to the decrease in three body collisions but observed that another effect having to do with radiation could be involved.[10]

Flames clearly have fairly large populations of radiating species. Indeed, those that radiate in the visible portion of the spectrum are what make flames visible and attractive both esthetically and scientifically. The radiation lifetime of many of these species, especially those radiating in the infrared is much longer than the time between collisions at pressures as low as one torr. For example, radiation lifetimes for the various modes in CO_2 are all greater than three milliseconds. At one torr the time between collisions at flame temperatures is of the order of a microsecond. Thus, at that pressure the average CO_2 molecule undergoes several thousand collisions during its radiation lifetime, probably enough to insure thermalization of its internal energy. At substantially lower pressures, however, the possibility of radiation before thermalization becomes enhanced giving rise to a couple of provocative questions. Does the shift in mode of de-excitation for internally excited species make a difference in the structure and propagation characteristics of the flame? Is it possible that going to low pressures will greatly suppress collisional de-excitation so that population inversions capable of lasing might be achieved? It is to be remembered that in many exothermic reactions there is growing evidence that product molecules are formed in vibrationally or electronically excited states. It is this phenomenon which makes so-called chemical lasers possible. A possible advantage of flame systems for such lasers is that the reactants can be premixed because the relatively high activation

energy of the initial flame reactions prevents the premixed reactants from reacting until they enter the flame front which is a region of very rapid rise in temperature and/or the concentration of free radicals and chain carriers which cause the reaction to occur very quickly. The other requirement for achieving and maintaining the inversion necessary for lasing is that collisional deactivation of the excited species must not occur too rapidly. It is this latter requirement that low pressures could make possible in flame systems.

Of course, even if effective high power chemical lasers could be developed around flame systems by using the high pumping speed available in space, it might represent something of a pyrrhic victory because there might not be much use for them up there. Nevertheless, exploration of the possibility by spectroscopic studies of very low pressure flames would seem to offer the prospects of some interesting science.

3. A Variation on the Low Pressure Flame Theme. Flames generated by the combustion of solid propellants as used in rocket motors also offer opportunities for study at pressures low enough to require very large pumping speeds. These propellants are of two general classes. So-called colloidal or double base propellants are based on dispersions of nitrocellulose in nitroglycerine, i.e., very similar to the smokeless powder or cordite used in guns. More popular in rocket motors are the so-called composite propellants which comprise a granular oxidizer, usually ammonium perchlorate, embedded in a matrix of resin boinder which also is the fuel. These formulations are molded into large monolithic "grains," usually cylinders with an axial cavity whose size and shape are determined by the burning characteristics of the propellant and the ballistic requirements of the motor. In designing the grain for a particular motor and mission it is extremely important to know and if possible to control the burning rate of the propellant and its dependence upon pressure. Moreover,

there are a number of concomitant phenomena such as combustion instabilities with which are associated violent pressure oscillations which must be taken into account in the design of a motor. For these reasons there has been a great deal of experimental and theoretical study of solid propellant combustion. Even so, the theory of solid propellant burning is in a much more primitive state than the theory of flames in premixed gaseous systems. The difficulties are due in part to the much greater chemical complexity of solid propellant systems and in part to the complications stemming from the phase change as the solid reactants become gaseous products. Much of the experimental study of solid propellant combustion aimed at developing a theoretical understanding of the process is done with relatively small samples of the propellant, usually in the form of rectangular or cylindrical prisms called "strands". These strands are placed in a bomb in which the ambient pressure can be controlled independently of the combustion behavior. All strand surfaces but the uppermost one are coated with an inhibitor. The exposed surface is ignited and the deflagration rate, i.e., the linear regression rate of the burning surface into the substrate propellant, is monitored. Of primary interest is the dependence of this rate on the ambient gas pressure and the temperature and composition of the strand. It is well known that for any particular strand composition and size, i.e., cross sectional area of the burning surface, there is a critical pressure below which a flame cannot be sustained. This so-called Low Pressure Deflagration Limit or LPDL is of some practical interest because of problems associated with extinguishing and re-igniting a solid propellant rocket motor at high altitudes. Of more fundamental interest is its use as a test of models for the combustion process. Any self respecting model should be able to predict and characterize the LPDL phenomenon.

Some years ago Roy Cookson and I carried out some experiments on LPDL in which we measured the pressure at which the flame was extinguished for a range

of strand sizes, i.e., areas of burning surface.[11] We found that the LPDL varied directly with the hydraulic radius of the strand, i.e., the ratio of perimeter to cross sectional area. Consequently, we were able to make a straight line extrapolation to a zero value of this hydraulic radius which would correspond to an infinite burning area. Somewhat surprisingly we found that at this limit the LPDL was finite. That is to say, the flame would go out at a finite pressure even for a burning surface of infinite area. Most theories indicate that the LPDL is due simply to a heat loss by radiation from the surface and the hot gases. Our results suggest that some other mechanism may be involved because at zero pressure and infinite area of burning surface the flame front would be infinitely thick. It is not entirely clear that radiative heat loss could be significant under these circumstances. It would seem likely that as the pressure decreases the accompanying decrease in the number of three body collisions and the increase in the ratio of radiation life time to time between collisions might well be expected to play an important role in solid propellant flames as well as in the premixed gaseous flames discussed in the previous section.

I hasten to point out that the pumping speed which was available was only about 10 liters/sec and was just sufficient to cope with a strand about 2.5 cm in diameter for which the LPDL was 40 torr. It is a very long extrapolation from 2.5 cm to infinity! Because the deflagration rate is inversely proportional to pressure and the gas density decreases directly with pressure, the pumping speed required per unit area of burning surface is roughly constant. But the burning area increases with the square of strand diameter. Consequently, the required pumping speed also goes up with the square of diameter. Thus, to go from 2.5 cm to 100 cm would require a pumping speed of something like 16 thousand liters a second at a pressure somewhere between 5 and 25 torr. That would seem to require a very large and expensive rig in which to dump very dirty hot gas.

By going to much larger strand sizes than Cookson and I were able to accommodate in our rig, one could test our extrapolation out to much larger sizes. In addition, of course, lowering the pressure would spread out the flame zone and make possible much more effective probing by spectroscopy and sampling probes. Thus, the SSE might lend itself to some interesting studies of solid propellant combustion.

4. On the Composition of the Space Shuttle Environment. One of the items on which there was unanimous agreement of Professor James Mayer's ad hoc Committee on Experiments in Space was the need to characterize as completely as possible the composition of the gas through which the Space Shuttle would be flying. In addition, for many experiments, it would be important to know the composition of the gas actually "in" the laboratory or the immediate environs of the space craft. The obvious way to determine chemical composition of low density gas is with a mass spectrometer and it would seem to be almost a routine problem in the case of "in lab" atmosphere. For the free stream gas, however, there are substantial sampling problems. Contamination by outgassing from the vehicle is a serious problem. Moreover, because many of the free stream species are atomic and can undergo reaction upon collision with a surface, it becomes very difficult to be sure that the measured ion currents are truly characteristic of free stream gas and do not include contributions from species which have collided with a surface somewhere on the vehicle or even in the instrument. For these reasons there is substantial uncertainty as to the true composition of the outer atmosphere in spite of the many measurements which have been made with instruments on board sounding rockets and balloons. A further reason for pursuing the problem of composition measurement is that the composition is not uniform in time or space. Consequently, one would like a lot of data taken at various times and places in order to obtain information on the scale and intensity of the fluctuations in composition in order to learn more about the structure of the atmosphere.

In the course of my visits in Europe I learned about two projects relating to mass spectrometry measurements on board the shuttle. Although both of them are probably well known to JPL-NASA I will mention them briefly here for the sake of completeness in reporting my discussions. The German Space Group have access to some space on one of the early flights which one of its component companies (Dornier or Messerschmidt, I believe) committed itself to "rent" or "buy" when NASA accepted bids a few years ago. They have also obtained a spare of the gold plated mass spectrometer which von Zahn had designed for the Mars mission. They are now in the process of designing and building the auxilliary gear which will adapt this instrument for use in their "rented" space. For reasons which are not clear to me, this adaptation involves a major electronics development which is to cost several hundred thousand marks. Everyone seems to recognize that the sampling problems will not be solved in this experiment. They claim justification on the basis that they will get some hands on experience in carrying out an experiment in space. In particular, they hope to find out what kinds of problems they will have to solve before they can contemplate obtaining truly reliable mass spectrometric analyses of the free stream atmosphere.

A more advanced project has been proposed to NASA by Berndt Feuerbacher of the Space Science Department of the European Space Agency (ESTEC) at Noordwijk in the Netherlands. In a proposal responsive to NASA AO-OSS-2-78 he outlines a method for discriminating between free stream gas and any distortions due to outgassing or surface interactions in mass spectrometric analysis. This discrimination is achieved by forming a molecular beam using two skimmers aligned with the velocity vector of the shuttle and analyzing the beam with an integrated time-of-flight quadrupole mass spectrometer. Because the vehicle flight velocity is much higher than the thermal velocity of most species, contaminants from outgassing or reflection from surfaces will have markedly different velocities

(both speed and direction) from the free stream species. Thus, fairly crude time-of-flight velocity analysis obtained by chopping the incoming beam can readily distinguish between free stream and contaminant species.

In my view this approach seems sound and I hope that NASA decides to support the proposed program. It should be noted that the proposed apparatus will also lend itself to experiments in which the incoming beam species can be deliberately scattered from various kinds of surfaces in order to study gas surface interactions. It has often been pointed out that the Shuttle can generate a reasonably intense highly collimated beam of O atoms with an energy of about 5 eV and a speed ratio of about 9 or 10. Such beams cannot now be readily produced in earthbound laboratories and would permit many kinds of interesting gas-gas and gas-surface scattering experiments. In particular gas-gas scattering experiments with hydrocarbons and other fuel molecules might provide much needed information on the chemistry of the flame combustion reactions in which O atoms are presumed to play an important role. Because these possibilities have been much discussed, I will not spend time and space in this report ruminating over them anew. I mention them at all by way of indicating that the Feuerbacher proposal would not be an isolated experiment but could be an important starting point for an extended series of interesting and worthwhile experiments.

There is one drawback to the use of mass spectrometers. They cannot readily provide information about the internal energy states of the species in the sample. In the lower atmosphere essentially all species are in the ground state. Because of its low density and exposure to the full intensity of solar radiation, the upper atmospheric gas can have substantial concentrations of internally excited species. Whether one wishes to carry out experiments in the SSE or whether one is concerned primarily with atmospheric structure and processes, it would be most valuable to know about the internal states of upper atmospheric species as well as their relative abundance. The availability of tunable lasers promises to make

possible the acquisition of data on internal energy states. Two laser methods which have been fairly extensively investigated and which seem applicable to the SSE conditions are laser induced fluorescence and laser multiphoton ionization. These are both very sensitive but, of course, require lasers tunable in the absorption range of the species of interest. The former works better when the fluorescence is in the near visible or shorter wavelength range of the spectrum because the photons are higher energy and more readily detectable and because the radiation lifetimes are usually short so that emission will occur while the excited species are still in the field of view of the detector. The latter requires very high photon densities and consequently samples a very small volume of gas because the laser beam must be focused to a small area. If tunable lasers become available in the uv portion of the spectrum, single photons will become energetic enough to cause ionization and the requirement for photon beam intensity will be relaxed and the sampling volume will be correspondingly increased.

There is a third possibility for using tunable lasers to identify internal energy states which has recently been developed by Professor G. Scoles and his colleagues at the University of Waterloo and which seems worthy of note here. Scoles has been a long time devotee of the use of super conducting bolometers as molecular beam detectors. Bolometers respond to the total energy content of the incident molecular beam. Thus, he finds that he can cross a dc molecular beam with a laser beam which is chopped and obtain an ac signal from his detector at the frequency of the laser beam chopping. That is, when a beam molecule absorbs a photon, it deposits the photon energy on the detector along with any other internal or translational energy which it possesses at the time of the absorption. These other energies are dc so that by appropriate adjustments of chopping frequency and phase his detector output indicates only the absorbed photons. He tunes the laser over a frequency range and obtains signal corre-

sponding to absorption when the laser frequency matches the absorption frequency of the molecule. In this way he has been able to do absorption spectroscopy at the very low densities characteristic of molecular beams.[12,13] Of course, the flight time of the excited molecule between the laser beam and the bolometer must be short relative to the radiation lifetime. This situation is quite characteristic of the infrared region of the spectrum so that his method becomes an admirable supplement to detection based laser induced fluorescence where long radiation lifetimes are a great handicap. Scoles estimates that with a bolometer sensitivity of 10^{-13} watts/$hz^{1/2}$ he can detect fluxes of 3×10^{6} molecules/sec photon absorption in the near to middle infrared. If one could achieve an equivalent sensitivity for a detector surface area of one cm^2 and if the shuttle flight velocity is 8 km/s, then one could detect about 40 excited molecules/cc of sampled gas. Even if the photon absorption cross sections are very small, the effective sensitivity would be extremely high. Of course, this method like all laser methods depends upon the availability of tunable lasers over the spectral range of interest, but the tunable range is increasing steadily. Already, with color center lasers and other solid state devices there is a very wide range of infrared already within reach.

Quite clearly, the advantages of the Scoles detection method lends itself to many of the kinds of spectroscopic experiments which were discussed in the original RDC report. It further enhances the prospects of many kinds of scattering experiments which might be done with beams extranced from the flux of atmospheric gas by the spacecraft. For these reasons I sincerely hope that Scoles will receive the support necessary to develop further this most ingenious application of bolometer detectors.

5. Microgravity and Coagulation in Turbulent Aerosols. The opportunities for experiments to take advantage of the microgravity condition in the SSE have been recognized from the beginning, especially in the field of fluid mechanics. Indeed in the European plans for space lab there is a whole module devoted to fluid mechanics experiments. One area of interest is in the effects due to surface tension which can become very important when gravitational forces become negligible. There are prospective practical implications of these effects because they can be very influential in the process of drawing single crystals from melts, for example. The surface tension of such melts is very high and in the presence of temperature gradients it can cause strong convection currents, i.e., the so-called Marangoni effect. At the DFVLR-AVA Institute at Goettingen I ran across some very interesting research on this problem. Dr. Ch.-H. Chun has developed a technique for studying surface tension effects in an earth bound system. He minimizes distortions due to gravity by going to very small masses (i.e., volumes) of liquid so that the surface tension forces are large relative to the gravitational forces. He suspends a drop of liquid between the ends of two vertical copper rods 3 mm in diameter. Each rod can be rotated in either direction over a range of speeds and the temperature of each rod can be independently controlled. He induces Marangoni convection by providing a downward temperature gradient through the liquid, i.e., making the top rod slightly warmer than the bottom rod. Dispersed in the fluid is particulate material which is illuminated by a vertical sheet of light passed through the vertical axis of the drop so that only the particles in the plane of the sheet are illuminated. With an enlarging lens and a TV camera he projects the illuminated plane on a screen which very clearly displays the flow streamlines. He finds he can markedly affect the flow patterns if he rotates one rod with respect to the other. In a counter rotating mode at an appropriate differential velocity the Marangoni flow cell is completely inhibited. These experiments

are being done in anticipation of studies to be performed in the Fluid Dynamics Module. Thus, they are already tuned in to the Shuttle Program and need no further elaboration here. I report them simply because they were to me beautiful and interesting.

More appropriate to the purpose of this report are some experiments being carried out by Professor Hiroshi Sato at the Institute of Space and Aeronautical Studies at the University of Tokyo. He is addressing himself to the problem of how turbulence may affect the growth of droplets in a gas undergoing condensation. He mixes a stream of moist air with a stream of colder air and produces a stream of air with small droplets in it, i.e., a stream of fog. He then passes this stream vertically through grids of various sizes in order to induce varying degrees of turbulence. At various distances above the grid he probes the foggy stream with a hot wire in an anemometer configuration. The wire cools and gives a signal via resistance change when it is struck by a droplet. The size of the signal pulse is proportional to the size of the droplet. The frequency of pulses indicates the number density of droplets. Thus he obtains a measure of growth rate as a function of time by knowing the velocity of flow and comparing probe signal patterns at various heights in the stream. The apparatus has not yet been perfected but meaningful results are beginning to accumulate.

Professor Sato is convinced that an understanding of droplet agglomeration and growth by turbulence has important and far reaching implications. He seems particularly intrigued by the effects this phenomena may have had upon the composition of the planets during the condensation and accretion from initial primordial gas. He even thinks that it may have something to do with the fact that all planets rotate in the same direction. Of course, the coagulation of solid colloidal particles in liquids and the effects of stirring on the coagulation process have been studied for a long time. Smoluchowski of kinetic theory fame even did some theoretical anal-

ysis of the process many years ago. There seems to have been very little if any work done on gaseous dispersions of liquids. The diminution of gravitational effects which could be achieved in the SSE is obvious. Experiments like those which Sato is trying can deal only with particles small enough so that drag forces will keep them suspended in the gas. It is not entirely clear just how such experiments might be designed and carried out on the shuttle but they certainly would seem to deserve some careful consideration. Professor Sato himself has a great interest in pursuing this kind of work and assured me that he would be happy to cooperate in any project which might be undertaken in anticipation of performing such experiments.

III. Conclusions and Recommendations

I talked to many people from many disciplines. The response was somewhat less than overwhelming but I did glean a few ideas which seem to merit further consideration and analysis. Moreover, I was able to identify some capable investigators who are not now associated with a space program but who are interested in pursuing possibilities for extending their studies to take advantage of the Space Shuttle Environment:

1. Professor John C. Polanyi of the Department of Chemistry at the University of Toronto is keenly interested in high resolution spectroscopy of species native to or introduced into the upper reaches of the atmosphere.

2. Professor Marcel Vanpee of the Department of Chemical Engineering at the University of Massachusetts would be very interested in a spectroscopic study of ephemeral but kinetically important species in low pressure flames and tube reactors taking advantage of the high speed pumping that SSE offers.

3. Professor Giacinto Scoles of the Department of Chemistry at the University of Waterloo in Waterloo, Ontario is eager to develop his laser-bolometer detector system for use in the analysis of atmospheric species and the determination of their internal energy levels.

4. Professor Hiroshi Sato of the Institute of Space and Aeronautical Sciences wants very much to cooperate in any project which might extend his study of aerosol coagulation by turbulence, possibly taking advantage of the low gravity forces in orbiting laboratories.

If NASA gets to the point where it can seriously entertain proposals for research projects toward any of these goals, it would do well to get in touch with these investigators.

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APPENDICES

"Spreading the Word"

This section attempts to provide some dimension to the extent of my evangelistic activities. Section A comprises a list of all those with whom I have had direct conversations in the past year on possible SSE experiments. In addition to these "person-to-person" encounters, I also described the opportunity and the advantages of the spacecraft environment for experiments to audiences of various sizes in the course of lectures and seminars presented during my travels. On three occasions I made organized presentations on the subject to relatively large groups. At the 1978 Conference on Dynamics of Molecular Collisions at Asi lomar, California in June 1978 and at the Eleventh International Symposium on Rarefied Gas Dynamics at Cannes in July 1978, I made oral presentations with slides and transparencies. These meetings were prior to the term of the contract for which this document is the final report, but they were subsequent to the report on the original RDC study. Therefore, to indicate the extent of exposure to the idea of Space Shuttle experiments, Section B is an attendance list for the Asilomar Conference and Section C is a list of participants at the Cannes meeting.

The third occasion for a selected audience was the International Symposium on Molecular Beams which was at Riva del Garda, Italy in June 1979. At that meeting the message was presented in a Poster Session which remained on display throughout the week of the symposium. During scheduled Poster Sessions I was on hand for discussion. Unfortunately, I do not have an attendance list for that meeting but I am including a program in Section D. Because most scientists have to present papers if they are to qualify for travel support from their sponsors, this program provides a fairly representative census of those in attendance. Needless to say it also includes authors who stayed home, but maybe they got the word by hearsay from their colleagues.

APPENDIX A

People Engaged in Direct Conversation

(Numbers in parentheses refer to key for Fields of Interest at end of II-A)

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1. Fluid Mechanics
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3. Gas Dynamics
4. Rarefied Gas Dynamics
5. Chemical Kinetics

6. Molecular Dynamics
7. Thermodynamics
8. Statistical Mechanics
9. Kinetic Theory
10. Monte Carlo Methods

11. Molecular Beam Experiments
12. Molecular Energy Transfer
13. Relaxation Rates
14. Nucleation-Condensation
15. Vaporization Studies

16. Physical Organic Chemistry
17. Heterogeneous Catalysis
18. Molecule Surface Scattering
19. Surface Physics
20. Laser Spectroscopy

21. Laser Induced Chemistry
22. Physical Chemistry
23. Chemical Physics
24. Combustion
25. Liquid Rocket Propellants

26. Solid Rocket Propellants
27. Propulsion Dynamics
28. Turbulence
29. Astronautics
30. Orbital Mechanics

31. Satellite Trajectory Analysis
32. Heat Transfer
33. Molecular Structure
34. Surface Chemistry
35. Solid State Physics

36. Solid State Chemistry
37. Spectroscopy
38. Structural Chemistry
39. Amorphous Materials
40. Solution Chemistry

41. Chemical Engineering
42. Chemical Process Dynamics & Control
43. Chemical Reaction Engineering & Reactor Design
44. Gas Dynamic Lasers
45. Liquid Crystals

46. Theoretical Physics
47. Biochemistry
48. Biophysics
49. Meterology
50. Ionospherics

51. Radio Wave Propagation
52. Geomagnetics
53. Ultrasonic Acoustics
54. Plasma Physics
55. Power Transmission

56. High Field Phenomena
57. Dielectric Materials
58. Properties of Materials
59. Electrostatics
60. Astro Physics

61. UV Astronomy
62. X-Ray Astronomy
63. Electronics
64. Heat Pipes
65. Low Energy Electron Scattering

66. Photochemistry
67. Excited Atom Chemistry
68. Charge Exchange
69. Mass Spectrometry

70. Isotope Enrichment
71. Molecular Clusters
72. Synchroton Radiation Spectroscopy

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Dr. Bernard Zappoli
Societe Europ de Propulsion
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France

APPENDIX -D Program - 7th International Symposium on Molecular Beams
Riva del Garda (Trento, Italy) 5/28/79

MONDAY - INELASTIC SCATTERING

8.30 * K. Bergmann (Kaiserslautern)
LASER SPECTROSCOPY AND INELASTIC COLLISIONS

9.00 ** U. Buck (MPI - Göttingen)
MOLECULAR SCATTERING FROM NON-SPHERICAL POTENTIALS

10.00 * D. Beck, U. Ross, W.Schepper (Bielefeld)
ON THE BULGE EFFECT OF MOLECULAR SCATTERING

10.30 COFFEE BREAK

MINISYMPOSIUM ON ELASTIC SCATTERING

11.00 * J.J.H. v.d.Biesen, E.H.v.Veen, F.A.Stokvis, C.J.N.v.d. Meijdenberg (Leiden)
MEASUREMENT OF THE GLORY STRUCTURE IN THE TOTAL CROSS SECT. OF AR-KR, KR-KR, KR-XE AND XE-XE

11.30 U. Buck, G.Maneke, J.Schleusener (MPI - Göttingen), R.A. Aziz (Waterloo) G.Scoles (Waterloo - Trento) U.Valbusa (Waterloo)

ON THE QUESTION OF THE WELL DEPTH OF THE HeAr INTERATOMIC POTENTIAL

11.45 F. Torello, M.G. Dondi (Genova)
A NEW H-H_2 SPHERICAL POT. FROM HIGH RES. MOL.BEAM EXPERIMENTS

12.00 B. Brunetti, G. Liuti, E.Luzzatti, F.Pirani, F.Vecchiocattivi (Perugia)
ABSOLUTE TOTAL CROSS SECT. FOR O - O_2, O_2 - O_2, O - N_2, O_2 - N_2 COLLISIONS

12.15 R. Düren; H.O.Hoppe, H.Tischer (MPI - Göttingen)
OBSERVATIONS OF THE "ORBITING" PHENOMENON AS A BACKWARD PEAK IN THE DIFFERENTIAL CROSS SECTION

12.30 U. Schwalm, J.P. Toennies (MPI - Göttingen)
ORBITING RESONANCES IN THE SCATT. OF H ATOMS FROM MOLECULES

12.45 H.C.W. Beijerinck,P.M.A. v.d.Kam, N.F. Verster (Eindhoven)
THE SMALL ANGLE DIFF. CROSS-SECTION FOR AN INVERSE POWER POTENTIAL.

MINISYMPOSIUM ON NON SPHERICAL POTENTIALS

17.00 G. Rotzoll, A. Lübebrt (Hannover)
FITTING OF TOTAL DIFFERENTIAL ATOM-MOLECULE CROSS SECT. WITH ANISOTROPIC POTENTIALS

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* = Invited paper

17.15 H. Thuis (Nijmegen)
ANISOTROPY OF NO-INERT GAS SYSTEMS

17.30 W.P. Kraemer (MPI - München)
QUANTUMCHEMICAL SCF AND CI CALCULATIONS OF THE ENERGY HYPERSURFACE FOR THE SYSTEM He-CO

17.45 A.Kuppermann, M.Kiel, J.T.Slankas, G.A.Parker (Caltech)
ANISOTROPIC POTENTIALS FOR HELIUM BEAMS BY CROSSED MOLECULAR BEAMS OF N_2, O_2, NO, CO AND CO_2

18.00 V.N. Khromov, V.B. Leonas (Moscow)
ON THE USE OF SCATTERING DATA AS A TEST OF THE ACCURACY OF AB INITIO CALCULATIONS OF ANISOTROPIC POTENTIALS

18.15 W.R. Gentry, M.A. Hoffbauer, C.F.Giese (Minnesota)
PULSED MOL. BEAM STUDIES OF STATE-RESOLVED ROT. EXCITATION

18.30 J. Andres, U.Buck, F.Huisken, J.Schleusener, F.Torello (MPI - Göttingen)
STATE RESOLVED DIFFERENTIAL CROSS SECTIONS FOR $0 \rightarrow 2$ ROTATIONAL TRANSITIONS IN D_2 + Ne COLLISIONS

18.45 J. Schaefer (MPI - München)
RECENT RESULTS OF He - H_2 (HD) CROSS SECT. FOR EL. AND INELASTIC SCATTERING BELOW 1.5 eV CENTER OF MASS ENERGY

19.00 L. Monchick (Johns Hopkins), J.Schaefer (MPI - München)
AB INITIO CALCULATIONS OF THE TRANSPORT CROSS-SECTION OF H_2

19.15 CHAIRMAN'S REMARKS : G.P. TOENNIES (MPI - Göttingen)

- T U E S D A Y -

REACTIVE SCATTERING

8.30 * R. Grice (Manchester)
REACTIVE SCATTERING OF A SUPERSONIC OXYGEN AYOM BEAM

9.00 ** Y.T. Lee (Berkeley)
RECENT ADVANCES IN STATE TO STATE REACTIVE SCATTERING

9.45 ** J.C. Polanyi (Toronto)
CHEMICAL DYNAMICS; THEORY VS. EXPERIMENT

10.30 COFFEE BREAK

- T U E S D A Y -

MINISYMPOSIUM ON INELASTIC SCATTERING

11.00 S.B. Ryali (Connecticut), G.E.Kolb (Aerodyne Corp.), J.B. Fenn (Yale)
VIBRATIONAL EXCITATION OF CO_2 BY COLLISIONAL T-V EXCHANGE

11.15 F.A. Gianturco, U.T.Lamanna, D.Ignazzi (Bari)
VIB. EXCITATION OF SIMPLE MOLECULES BY COLLISION WITH PROTONS : A THEORETICAL STUDY ON CO TARGETS

11.30 J.A.D. Stockdale, R.J. Warmack (Oak Ridge)
COLLISIONAL IONIZATION OF Cs AND K BY O_2

11.45 M.J.P. Maneira, U.Weigmann, A.M.C. Moutinho, K.Lacmann (H. M.I. - Berlin)
DOUBLE DIFF. CROSS SECT. FOR K FORMATION IN K + $SnCl_4$ COLL.

12.00 J. Krenos (Rutgers)
CHEMICAL DYNAMICS OF ENERGY TRANSFER : FORMATION OF Ne^* IN COLLISIONS OF He (2^1S) WITH GROUND-STATE Ne.

12.15 H. Haberland, P. Oesterlin (Freiburg)
THE PUMPING PROCESS OF THE HeNe-LASER, STUDIED IN DETAIL IN A CROSSED MOLECULAR BEAM EXPERIMENT

12.30 R. Düren; U. Krause, G. Moritz (MPI - Göttingen)
ELECTRONIC EXCIT. IN COLLISIONS OF Na, K and Rb WITH Hg

12.45 CHAIRMAN'S REMARKS : V. AQUILANTI (Perugia)

MINISYMPOSIUM ON REACTIVE SCATTERING

17.00 D. Brandt, J.C.Polanyi (Toronto)
MICROSCOPIC BRANCHING IN REACTIONS H+FY (Y=Cl, Br, I)→HF (v', J') + Y

17.15 J.R. Grover, D.E.Malloy, J.B.A. Mitchell (Brookhaven)
APPLICATIONS OF RADIOACTIVE MOL. BEAMS : (1) THE CHEMI - STRY OF ASTATINE; (2) THE MEAS. OF ABSOLUTE DIFF. CROSS. SECT.

17.30 K.K. Verma, W.C. Stwalley (Iowa)
THE PRODUCTION OF OH ($A\ ^2\Sigma^+$) FROM COLL. OF SUPERTHERMAL H ATOMS WITH H_2O AND O_2

17.45 A.C. Luntz, P. Andresen (IBM - San José)
DYNAMICS OF THE CHEMICAL REACTIONS OF O (^3P) WITH SATURATED HYDROCARBONS

18.00 S. Chapman (Columbia)
THEORETICAL STUDY OF Be + HF ⟶ BeF + H

18.15 E. Vietzke, M.Erdweg, J.Heuschkel, L.Matus, G. Stöcklin (Jülich)
CROSSED BEAM KINETICS : ABSTRACTION AND SUBSTITUTION IN THE REACTION OF Br WITH CH_3I AND $(CH_3I)_2$

18.30 R. Dirscherl, H.U. Lee (Stuttgart)
MOLECULAR BEAM KINETICS : REACTIVE SCATT. OF Sm WITH O_2 AND LASER FLUORESCENCE STUDY OF YbBr.

18.45 E.K. Parks, S. Wexler (Argonne)
COLLISION-INDUCED DISSOC. OF THE CESIUM HALIDES BY RARE GAS ATOMS AND SF_6 MOLECULES

19.00 W.L. Hase, R.J. Wolf (Wayne State)
CHEMICAL DYNAMICS OF C_2H_5 DECOMPOSITION

19.15 CHAIRMAN'S REMARKS : R.B. BERNSTEIN (Columbia)

- W E D N E S D A Y -

BEAMS OF CLUSTERS

8.30 * E. Schumacher, W.H.Gerber, A.Herrmann, M.Hoffmann, S.Leutwyler, L.Wöste (Bern)
SPECTROSCOPY OF METAL CLUSTERS IN MOLECULAR BEAMS

9.00 ** D. Herschbach (Harvard)
MOLECULAR CLUSTER BEAMS

10.00 * Dr. F.M.Devienne, M. Teisseire (Peymeinade)
METAL AGGREGATES FORM. BY HIGH ENERGY MOL. BEAMS BOMBARDMENT

10.30 COFFEE BREAK

MINISYMPOSIUM ON CLUSTERS

11.00 K. Sattler, J.Mühlbach, A.Reyes Flotte, E.Reckna - gel (Konstanz)
A SOURCE FOR METAL ATOM AGGLOMERATES OF UNIF. MASS

11.15 S. Romano, E. Clementi (Donegani)
MONTE CARLO SIMULATION OF SMALL ION-WATER CLUSTERS

11.30 G.L. Griffin, J.Kratsios, R.P.Andres (Princeton)
PRODUCTION AND SIZE ANALYSIS OF MOL. BEAMS OF METAL CLUSTERS

11.45 * R. Monot, E.R.Dietz,A.R. George,W.D.Knight (Berkeley)
BEAM OF POTASSIUM CLUSTERS : STERN-GERLACH EXPERIMENT.

- W E D N E S D A Y -

12.15 J. Caspann, H.Vollmar (Karlsruhe)
METASTABLE CLUSTERS

12.30 M. Cavallini, G. Grillo (Assoreni)
TWIN MOL. BEAM STUDY OF OXIDATION REACTIONS ON TRANS.METALS

12.45 L. Holmlid, J.O. Olsson (Göteborg)
SURFACE CATALYZED REACTIONS ON CARBON COVERED Pt(8%W)

MINISYMPOSIUM ON ION AND MUONIUM CHEMISTRY

11.00 * D.M. Garner, D.G. Fleming (Vancouver)
MUONIUM REACTION KINETICS : HYDROGEN ISOTOPE EFFECTS AND CHEMICAL DYNAMICS IN STUDIES OF Mu + X_2 AND Mu+ HX

11.30 J.N.L. Connor, A.Laganà (Manchester)
QUASICLASSICAL DYNAMICS OF LIGHT HEAVY-HEAVY ATOM REACTIONS - THE REACTIONS Mu + F_2 AND Mu + Cl_2

11.45 H. Schmidt, M. Konrad, F. Linder (Kaiserslautern)
CROSSED-BEAM MEASUREMENTS OF CHARGE TRANSFER REACTIONS FOR He^+ + N_2 AND He^+ + O_2 IN THE 1 eV COLLISION ENERGY RANGE.

12.00 I. Kusunoki, Ch. Ottinger (MPI - Göttingen)
CHEMILUMINESCENT ION-MOLECULE REACTIONS : ROT.-VIB. STATE DISTRIBUTIONS OF CH^+ (A) FROM C^+ + H_2 (D_2) COLLISIONS.

12.15 W. Lindinger, E. Alge, H.Villinger, H.Störi (Innsbruck); D.L. Albritton, F.C.Fehsenfeld (Boulder)
DEPENDENCE OF ION-MOLECULE REACT. ON THE ION VIB. ENERGY

12.30 * A. Ding, A.Redpath, U.Steinmetzger (H.M.I. Berlin)
INFRARED CHEMILUMINESCENCE FROM ION MOLECULE REACTIONS

- T H U R S D A Y -

SURFACE SCATTERING

8.30 * F. Tommasini (Genova), U.Valbusa (Waterloo)
ATOMIC HYDROGEN SCATTERING FROM CRYSTAL SURFACES

9.00 ** V. Celli (Virginia)
THE DYNAMICS OF GAS-SURFACE INTERACTIONS

9.45 ** L. Wharton (Chicago)
SURFACE REACTIONS AND MOLECULAR BEAMS

10.30 COFFEE BREAK

11.00 POSTER SESSION (in alph. order of 1st author)

D.H.H. Al-Amiedy,D.E.Dugdale,D.C.Lainé (Keele)
ELECTROSTATIC STATE SELECTION OF MOLECULES EMPLOYING A SINGLE WIRE HELIX.

E. Alge, H. Villinger, H.Helm, W.Lindinger (Innsbruck), D.L. Albritton, F.C. Fehsenfeld (Boulder)
DRIFT TUBE MEAS. : THE LINK BETWEEN THERMAL RATE CONST. AND CROSS SECT. OBTAINED IN BEAM EXPERIMENTS.

B. Andresen (Copenhagen),S.Hultberg, B.Jelencovic,L.Liljeby, S.Mannervick, E. Veje (Stokholm)
DISSOCIATION AND EXCITATION OF SMALL MOLECULES UPON PASSAGE THROUGH THIN FOILS

D. Bassi (Trento),M. Cavallini, G. Grillo (Assoreni)
THE CATALYTIC OXIDATION OF CO ON PALLADIUM SURFACES

D. Bassi, A. Boschetti, S.Marchetti, M.Zen(Trento)T.E.Gough, R.E. Miller (Waterloo), G. Scoles (Waterloo & Trento)
I.R. SPECTROSCOPY OF SUPERSONIC MOL. BEAMS WITH TUNABLE DIODE AND COLOR CENTRE LASERS

K.Bergmann, R.Engelhardt, U.Hefter, P.Hering (Kaiserslautern)
MOL. BEAM DIAGNOSTIC WITH INTERNAL STATE SELECTION : PERPENDICULAR VEL. DISTRIBUTION IN A NA/NA SUPERSONIC BEAM

G. Brusdeylins, R.B.Doak (M.P.I. Göttingen)
TOTAL INTEGRAL CROSS SECTIONS FOR He - CO

U.Buck, L.Mattera, D.Pust (M.P.I. Göttingen),D. Haaks(Wuppertal)
ULTRAVIOLET EMISSION IN Xe + Xe COLLISIONS NEAR THRESHOLD

J.M.Calo (Princeton)
CRYOGENIC DEPOSITION AND DESORPTION STUDIES OF STRATOSPHERICALLY RELEVANT SPECIES

G. Caracciolo,T.H.Ellis, G.O.Este, G.Knight, G.Scoles, U. Valbusa (Waterloo)
SCATTERING EXPERIMENTS WITH H ATOMS. NON-SPHERICAL SYSTEMS : $H + C_2H_6$, $H + C_3H_8$, $H + CO_2$, $H + CO$.

M.A.A.Clyne,SJ.Davis, M.C.Heaven, I.S. McDermid (Queen Mary Coll.)
QUANTUM-RESOLVED DYNAMICS IN DIATOMIC HALOGENS AND INTERHALOGENS, USING DOPPLER-LIMITED LASER EXCITATION.

C.Dankert, H.Legge (Göttingen)
INVESTIGATION OF A BEAM SKIMMED AT SMALL KNUDSEN NUMBERS

A.Ding (H.M.I. Berlin)
A SEMICLASSICAL INVERSION PROCEDURE FOR STUECKELBERG OSCILLATIONS

E.N.Evlanov, Y.V. Lebedev,V.B. Leonas (Moscow)
"COLD" BEAM OF HYDROGEN ATOMS

J.D. Ganière, R.Monot, R.Rechsteiner (Lausanne)
BEAMS OF NA CLUSTERS : TIME OF FLIGHT MASS SPECTROMETRY

F.A. Gianturco, U.T.Lamanna, A.Attimonelli
A SCATTERING-ORIENTED POTENTIAL ENERGY SURF. STUDY FOR VIB-ROT EXCITATIONS OF DIATOMICS BY H^+.

H. Helm, K.Stephan, T.D.Märk (Innsbruck)
MASS SPECTROMETRIC INVESTIGATION OR RARE GAS DIMER BEAMS

M.Hofmann, S.Leutwyler, E.Schumacher (Bern)W.Schulze (Berlin)
MATRIX SPECTROSCOPY OF NA AND K CLUSTERS FORMED IN A SUPERSONIC MOLECULAR BEAM

A.P. Kalinin, V.N. Khromov, V.B.Leonas (Moscow), R.W. Wijnaendts van Resandt, J.Los (Amsterdam)
DIFFERENTIAL SCATTERING OF Li^+ IONS ON N_2 MOLECULES

P.M.A. van der Kam, H.C.W. Beijerinck,N.F. Verster (Eindhoven)
MONTE CARLO CALCULATION OF ANGULAR RESOLUTION FUNCTIONS

M.E.Koch, W.C.Stwalley (Iowa)
MULTIPHOTON IONIZATION OF Li_2

M.J.P. Maneira,A.J.F. Praxedes, A.M.C.Moutinho (Lisboa)
DIFF. CROSS. SECT. FOR ION PAIR FORM. IN $K+CCl_4$ COLLISIONS

D.Menzel, V.Ramakrishan (Garching)
THERMAL ACCOMODATION OF HELIUM AND NEON ADSORBATE-COVERED TUNGSTEN SURFACES.

R.A.R. Porter, A.E.Grosser (McGill)
CH_2 MOLECULAR BEAM SOURCE

W.C.Stwalley, R.W.H. Webeler, R.F.Ferrante, Yea-Hwang Uang (Iowa)
A PROPOSED BEAM METHOD FOR PRODUCTION OF SPIN-ALIGNED HYDROGEN

P.G.A. Theuws, C.E.E.Pernot, H.C.W.Beijerinck, N.F.Verster (Eindhoven)
EXCITATION AS A DETECTION MECHANISM FOR GROUND STATE PARTICLES

P.G.A.Theuws, C.E.E.Pernot, H.C.W. Beijerinck, D.C.Schram, N.F. Verster (Eindhoven)
PRODUCTION OF METASTABLES IN A HOLLOW CATHODE ARC DISCHARGE

J. Verberne (Nijmegen)
SPECTROSCOPY ON $(H_2)_2$ DIMERS

A.E.Zarvin, R.G. Sharafutdinov (Novosibirsk)
DIRECT EXP. VERIFICATION OF SUPERSONIC MOL. BEAM FORMATION MODEL

MINISYMPOSIUM ON GAS-SURFACE INTERACTIONS

17.00 * M.J.Cardillo (Bell Labs.)
THE DIFFRACTION OF He ATOMS FROM Si SINGLE CRYSTALS

17.30 H.Conrad, G.Ertl, J.Küppers, S.W.Wang (München), K.Gérard, H. Haberland (Freiburg)
PENNING IONIZATION ELECTRON SPECTROSCOPY OF CLEAN AND CO-COVERED METAL SURFACES

17.45 E. Ficocelli-Varracchio (Bari)
FIELD-THEORETIC APPROACH TO SCATTERING OFF SOLID SURFACES

18.00 A.C. Levi (Genova and Trento)
DEBYE-WALLER FACTOR AND INELASTIC ATOM-SURFACE SCATTERING

18.15 A.Armand, J.Lapujoulade, Y.Lejai, N. Papanicolau (Saclay)
THERMAL DEPENDENCE OF THE SPECULAR PEAK OF HELIUM SCATTERED FROM (100) COPPER

18.30 E. Semerad, E.M. Hörl (Seibersdorf)
DEBYE-WALLER FACTOR IN Ne-BEAM SCATT. BY A LiF SURFACE

18.45 G. Boato, P. Cantini, C.Guidi, R.Colella (Genova)
CHARGE DENSITY WAVES OBSERVED BY MOL. BEAM DIFFRACTION

19.00 L. Greiner, H.Hoinkes, H. Wilsch (Erlangen)
CORRELATION OF SPEC. AND DIFF. INTENSITY AT SELECTIVE ADSORPTION EXP. INVESTIGATIONS WITH D ON LiF (001)

19.15 CHAIRMAN'S REMARKS : G. BOATO (Genova)

BEAM-PHOTON INTERACTIONS

8.30 * W.R. Gentry, M.A. Hoffbauer, C. Giese (Minneapolis)
PHOTODISSOCIATION OF v.d. WAALS DIMERS IN PULSED MOL.BEAMS

9.00 ** V.S. Letokhov (Moscow)
MULTISTEP PHOTOIONIZATION OF MOL. BEAMS BY LASER LIGHT

9.45 ** J. Durup (Orsay)
PHOTODISSOCIATION

10.30 COFFEE BREAK

MINISYMPOSIUM ON PHOTOIONIZATION AND PHOTODISSOCIATION

11.00 * N.J.A. van Veen, M.S. de Vries, A.E. de Vries (F.O.M. Amsterdam)
PHOTOFRAGMENTATION OF DIATOMIC HALOGEN COMPOUNDS

11.30 R.B. Bernstein (Columbia)
LASER MULTIPHOTON IONIZ. AND FRAGMENT. OF MOL. BEAMS

11.48 R.K. Sparks, L.R. Carlson, K.Shobatake, M.L. Kowalczyk, Y.T. Lee (Berkeley)
DYNAMICS OF PHOTODISSOCIATION OF O_3

12.06 S. Leutwyler, M. Hoffmann, E. Schumacher (Bern)
SEQUENTIAL TWO-PHOTON-IONIZATION OF NaK AND K_2 IN SUPERSONIC MOLECULAR BEAMS

12.24 I.M. Beterov, Yu.V.Brzhazovskii, V.P.Chebotaev, A.K.Rebrov, B.E. Semvachkin, A.A. Vostrikov
INFLUENCE OF CO_2 LASER RADIATION ON SF_6 CONDENSATION AND MOLECULAR BEAM INTENSITY.

12.42 J.R. Grover, J.B.A. Mitchell (Brookhaven)
A VERSATILE USER-ORIENTED ATOMIC AND MOL. BEAM APPARATUS FOR USE WITH THE NAT. SYNC. LIGHT SOURCE.