Concept for the HI-LITE Neutral Atom Imaging Instrument

Peter Wurz[1], Peter Bochsler[1], Arthur G. Ghielmetti[2], Edward G. Shelley[2], Federico Herrero[3] and Mark F. Smith[3]

[1]) Physikalisches Institut, Universität Bern, Sidlerstraße 5, 3012 Bern, Switzerland
[2]) Lockheed Palo Alto Research Laboratory, Dept. 91-20, 3251 Hanover Street, Palo Alto, CA 94304, U.S.A.
[3]) Laboratory for Extraterrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.

The scope of the neutral atom imaging instrument on the proposed HI-LITE mission is to study the instantaneous global distribution of the low energy ion outflow from the high latitude auroral region, and its large scale temporal evolution with solar and geomagnetic activity by detecting neutral atoms that are produced through charge exchange between the outflow ions and the neutral atmosphere.

The proposed instrument will record spatially resolved maps of energy and mass of this region. Because of limited particle fluxes, high ionization efficiency for the two species of principal interest, H and O, in the energy range of 10 eV to 300 eV is necessary. To achieve this, a low work function converter surface will be employed, where a considerable fraction of the reflected primary atoms will be negatively ionized. Under optimal conditions, the instrument has a detection efficiency of 11% to 25% for hydrogen in the energy range from 10 to 100 eV.

1. Introduction

One of the major objectives of space physics is to understand the Earth's magnetosphere and its interaction with the ionosphere and the solar wind. This interaction is readily apparent in the high-latitude regions of the Earth's magnetosphere. Input from the solar wind produces significant effects on the Earth's ionosphere including auroral displays and upwelling of ionospheric ions that ultimately become part of the magnetospheric population, and interact back on the ionospheric plasma. If the amount of solar wind mass, energy, and momentum added to the magnetosphere is high, the system becomes highly disturbed and the imparted energy is dissipated explosively through the substorm process. Geomagnetic activity also plays an important role for the ion outflow in these regions[1,2]. The demands on new missions to enhance the understanding of these highly variable processes are both global observation of the entire source region, and a time resolution commensurate with the time scale of these processes.

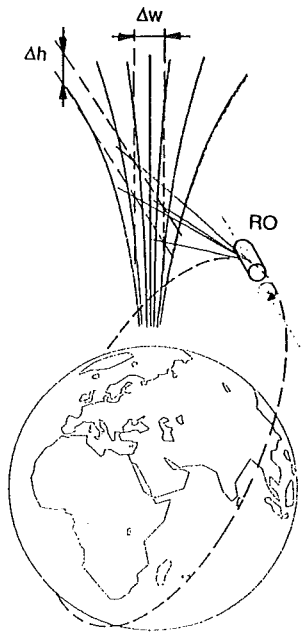

Figure 1: Schematic of HI-LITE mission. The satellite, RO, will be placed in an elliptical 250 km by 4500 km orbit at an inclination of 65°. 10 sectors will be used for angular mapping, the rotation of the satellite will be used for lateral mapping.

The proposed High-Latitude Ion Transport and Energetics (HI-LITE) Explorer[3] will collect data from the global ion outflow from the high-latitude ionosphere to investigate the relationship to auroral processes and the consequences of this outflow on magnetospheric processes. The HI-LITE Explorer will be placed in an elliptical 250 km by 4500 km orbit at an inclination of 65° (see Fig. 1 for mission schematics). There will be three imaging instruments on this mission: i) an 834 Å O^+ imaging instrument to map the ion outflow[4], ii) a UV spectrometer to determine ion and electron precipitation[5], and iii) a low energy neutral atom imager to remotely sense the charge exchanged H^+ and O^+ distributions in the 10 eV to 300 eV energy range. This instrument, coined ILENA, is described in the present paper. In addition to the imaging instruments, a plasma ion mass spectrometer will measure the in situ composition, energy and angular distribution of up flowing ions.

For remote sensing of an ion population, one takes advantage of the naturally occurring charge exchange between the ions and the neutral gas with which they coexist. In our

case, the singly-charged ions are neutralized by charge exchange with atmospheric H and O at a certain probability and become low energy neutral atoms. Freed from the confinement by the magnetic field of the Earth, they travel ballistic trajectories to the remote observer, RO in Fig. 1. By imaging the region in two dimensions, maps of the original ion population are obtained. One obtains an estimate for the expected particle flux by integrating the H and O ion densities over the volume of an imaged pixel ($\Delta h \times \Delta w$) and taking into account the charge exchange cross sections. Per pixel, we anticipate a flux of approximately 100 and 30 atoms/second for hydrogen and oxygen, respectively. For these low particle fluxes a high detection efficiency is needed to achieve the desired time resolution. To make these atoms available to analysis they have to be ionized in the instrument. The efficiency of electron impact ionization is of the order of 10^{-5} to 10^{-6} in the projected energy range. Furthermore, these energies are too low to utilize the well-known carbon-foil method for ionization[6]. Therefore, we chose negative surface ionization, that is, formation of negative ions after reflection from an appropriate (low work function) converter surface[7].

2. Surface Ionization

Since the ionization of the neutral particles is the most crucial part of this instrument it will be covered in more detail. Particles are reflected from a surface as negative ions if they have a positive electron affinity and the work function of the surface is sufficiently low[7]. For hydrogen and oxygen the electron affinities are 0.75 eV and 1.46 eV. The surface with the lowest work function is W(110) with an overlayer of half a monolayer of Cs[8]. For such a system, the fraction of negative ions in the reflected particle flux of up to 67% has been reported[9]. For our application we are interested in the overall detection efficiency. Thus, the probability for reflection from the surface has to be taken into account. The reflection probability was calculated with the TRIM code[10]. Two configurations were investigated: a polycrystalline tungsten substrate (200 Å) covered either with half a monolayer or a full monolayer of cesium (5 Å). The fraction of reflected atoms from a 10 and 100 eV hydrogen beam for impact angles from 0° to 85° was calculated. This result was convoluted with the yield of particles reflected as negative ions[11] as depicted in Fig. 2. As can be seen from Fig. 2, for half a monolayer Cs coverage the detection efficiency is about a factor of 5 higher than for full Cs coverage. Therefore, in the instrument we will use similar conditions as were used before to obtain the highest negative ion fraction[9], that is half a monolayer Cs on a W(110) surface. At an impact angle of 65° the detection efficiency will be 11% and 25% for 10 and 100 eV

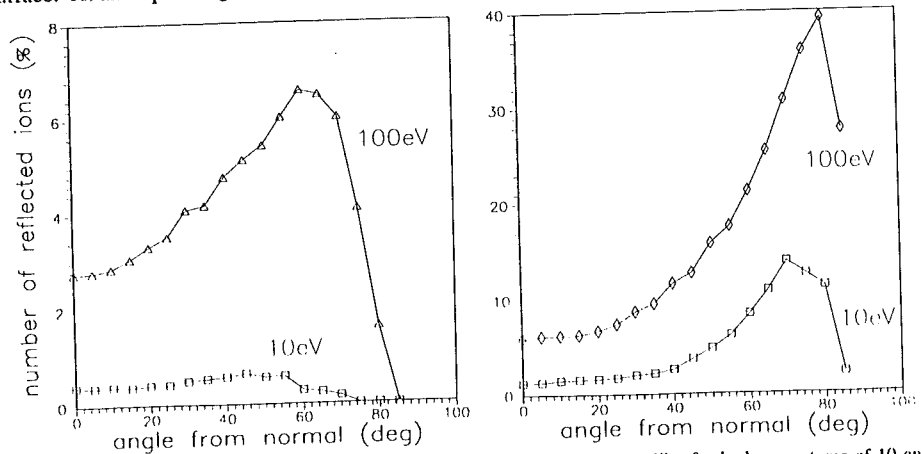

Figure 2: Convolution of the ionization probability with the reflection probability for hydrogen atoms of 10 and 100 eV impinging on a tungsten surface covered with 1 and 0.5 monolayer of cesium, (left panel and right panel).

hydrogen. Making the impact shallower would increase the detection efficiency somewhat, but also increase the surface area that has to be maintained in proper condition. Moreover, the ion optical system would be more difficult, which ultimately will increase weight. Of course, the feasibility of this choice of surface for a space application has to be studied in detail first. The calculations for oxygen are currently under way. Since the electron affinity of oxygen is higher than for hydrogen a higher detection efficiency is anticipated. Other promising candidates for the conversion surface are Ba[11] or diamond[12], which are more resistant against contamination of the surface.

3. Design of the Instrument

To utilize surface ionization on a space mission, one has to meet the stringent requirements posed on instruments for space crafts. These requirements are: limited weight, limited electrical power (about 8kg and 10W for the entire instrument), and maintenance free operation for a couple years. Furthermore, the instrument has to survive the launch (more than 8g vibrations). During operation there is a high background of visible and UV photons as well as charged particles in a wide energy range. Moreover, from the point of view of surface science one encounters high levels of background gas, mainly from sources inside the instrument due to the limiting pumping through the entrance aperture.

Most of the parts of the ILENA instrument are state-of-the-art in space science instrumentation. The only new technology is the surface ionization. The instrument consists of a collimator, a conversion unit, a pre-acceleration lens, an electrostatic analyzer, and a time-of-flight (TOF) mass analyzer with position sensitive detection. A cross section of the instrument schematics is shown in Fig. 3. The rotational symmetry of the instrument about the centerline of the figure gives a 90° field-of-view in the plane normal to the figure with imaging over the entire range of accepted angles. A more detailed description of the instrument can be found in[13].

The required high sensitivity is achieved with a large geometric factor and with simultaneous imaging in angle, energy, and mass parameter space, which by eliminating the scan in angle, mass,

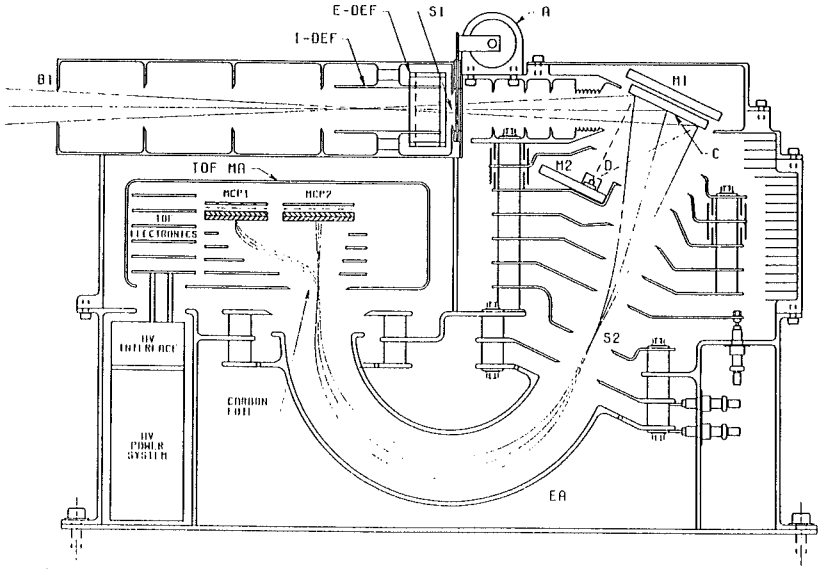

Figure 3: Schematic drawing of the ILENA instrument. B1 is the entrance collimator, I-DEF and E-DEF are the ion and electron deflectors, S1 is a shutter, C is the converter surface, M1 and M2 are the secondary electron suppression magnets, D is the cesium dispenser, S2 is the energy limiting slit, EA is the energy analyzer, and MA is the time-of-flight mass analyzer.

and energy increases the time resolution significantly. Double coincidence detection in the TOF analyzer coupled with high UV rejection insure the low background countrates needed.

The collimator: Particles enter the instrument through the external aperture B1 of the collimator and pass through a system of baffles that prevent forward scattering of photons and particles. A pair of horizontal electrostatic deflection plates are used to sweep out charged particles with energies less than about 20 keV and keep them from striking the converter surface. A small broom magnet additionally deflects away electrons with energies < 200 keV. Internal surfaces of the entrance collimator are serrated and/or Cu-sulfide blackened to further reduce photon reflection and forward scattering of neutralized primary particles. The collimator is fan shaped to provide the desired 90° azimuth acceptance, while the elevation angle acceptance, defined by the B1 and S1 slits, is 6°.

Conversion unit: The primary flux of neutral particles impinges on a converter surface at 65° from the surface normal, and the reflected particles are negatively ionized with a certain probability (see Fig. 2). The conversion surface is segmented, with the facets aligned on a conical surface centered about the axis of rotational symmetry. The converter surface consists of a tungsten substrate covered with half a monolayer of cesium.

Pre-acceleration lens: The reflected negative ions are accelerated away from the converter surface by a focusing lens system (PAL). As shown in Fig. 3, the field produced by this lens focuses the ions on the S2-slit plane. The pre-acceleration voltage of approximately 7 kV applied to the PAL lens system represents a trade-off between the requirements for energy dispersion and azimuth angle resolution. At this voltage, the beam spreads in the azimuth (out of plane) direction, caused primarily by the angular scatter of the reflected atoms. Due to its energy dispersive properties this acceleration lens focuses the more energetic ions at larger radii (see Fig. 4). In addition, by applying the appropriate potential on the last electrode, this feature eliminates ions with low energy and will be used to suppress the cold exospheric background gases.

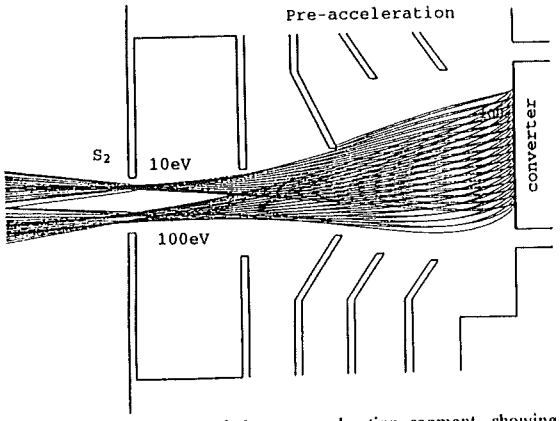

Figure 4: Ray-tracing of the pre-acceleration segment, showing 10 eV and 100 eV ions with position dispersion at slit S2. The slit will be placed so that only ions in the desired energy range can pass.

Energy analyzer: Following passage through the S2 slit, the ions enter a conventional spherical electrostatic energy analyzer, EA, that is focusing in elevation angle. The EA image plane is aligned with the carbon (C-) foil, where different energies are dispersed radially. The analyzer is designed to transmit all ions passed by the S2 slit with initial energies from 10 eV to 300 eV.

Time-of-flight mass analyzer: Following deflection in the EA, ions are post accelerated to 25 keV into the mass analyzer section. The mass analyzer consists of a conventional TOF system of the type used in the CODIF[14] spectrometer for the CLUSTER mission. The principal components are a C-foil, a time-of-flight path, and two micro channel plate (MCP) detectors. When the ions pass the C-foil, they are either neutralized or charged and secondary electrons are emitted[15]. The secondary electrons are extracted to MCP1 and produce the start pulse, while the ions and neutrals go straight to MCP2 and provide the stop pulse for the TOF. Both start and stop signals are obtained from a low (50 %) transmission grid placed behind the MCP's. A radially segmented

anode placed behind the grid of the start detector provides the radial position of the start signal from which crude energy resolution is derived. Azimuthal angle information is obtained from an azimuthally segmented MCP2-anode. The signal from each of the 5 radial and 9 azimuthal segments is processed by discrete pre-amplifiers. The entire position and TOF encoding electronics is contained in the HV bubble. The position and TOF encoded information is transmitted through a fiber optics cable to an interface for further transmission to the data processing unit.

Background suppression: Besides the UV-photons, the two major potential sources of background in the instrument are photoelectrons from the converter surface and negative ions produced by attachment of photoelectrons to residual gas molecules. Due to the low work function of the converter surface, photoelectrons will be produced in large quantities, which would produce unacceptably high count rates in the TOF system, even though individually they could be discriminated against due to their short flight times. The weak magnetic field from the magnets M1/M2 will prevent the photoelectrons from reaching slit S2 and entering the TOF section. The ion production is minimized by accelerating the photoelectrons away from the surface. Those ions produced are discriminated against by their lower energy relative to the ions generated at the converter surface.

Converter surface regeneration: The conversion unit contains a subsystem for the conditioning of the converter surface. In case of contamination, the surface will be heated to 300°C to remove any adsorbates. Subsequently, the cesium on the surface will be replenished by a cesium dispenser. The conditioning of the surface can be checked directly by measuring the work function of the system. With the shutter closed, the surface is illuminated with light from three laser diodes at different wavelengths. The resulting photoelectron emission is a measure of the conversion efficiency of the surface. This is done for each segment of the surface independently. To maintain good conversion efficiency, the total gas load on the converter must be significantly less than a monolayer, which is 10^{15} atoms cm^{-2}. To minimize the contamination of the converter surface the shutter will be closed outside the actual data taking interval. This will prevent contamination of the converter unit with exospheric hydrogen and oxygen while the spacecraft passes through perigee. Their densities at apogee are of the order of 10^3 cm^{-3} and 1 cm^{-3}, respectively. The frequency of application of the regeneration depends on the rate of deterioration of the converter. At present we estimate an application of less than once per day.

4. Interstellar neutral gas

There are many areas in space science where the ability to detect low energy neutral atoms would be desired. One area, which is accessible during the proposed mission is the interstellar neutral gas. A sizeable fraction of the mass of galaxies is not condensed in stars but rather is distributed in interstellar space as atoms and molecules. This interstellar gas is of interest, because it is the remnant of extinguished stars and the building material of new ones. It is a mixture of neutral and ionized components, mainly hydrogen and helium, although the detailed composition is largely unknown. The solar wind and its intrinsic magnetic field form a bubble (the heliosphere), that cannot be penetrated by the interstellar ions, however this region is transparent to the interstellar neutral component. Although the flux of interstellar neutrals is significant at the Earth's orbit (>10^{14} cm^{-1} sec^{-1}), the detection of neutral particles was not accomplished satisfactorily until now for two reasons. First, a considerable fraction of the particles are lost due to photo-ionization by the sun. Second, ionization of the remaining neutrals with conventional techniques lacked the efficiency necessary for this kind of measurement.

The current knowledge of the interstellar neutral gas penetrating the heliosphere stems primarily from remote sensing optical resonance scattering observations[16,17]. The observation of interstellar ^{4}He and ^{1}H, ionized inside the Earth's orbit and picked up by the interplanetary magnetic field has been reported recently[18,19]. The first attempts to directly measure the interstellar gas composition were carried out on the LDEF mission using the foil exposure technique[20]. Recently,

Witte et al.[21] have observed interstellar species on ULYSSES. However, direct measurements have yet to be reported for the isotopic composition on interstellar H or He. The primeval D/H ratio in the early solar system can only be inferred from the solar wind He isotopic composition. The first direct determination of the deuterium abundance in the local interstellar gas will thus be an important cornerstone for the understanding of the early history and geochemical evolution of the solar system, and will also provide valuable astro-physical information for the isotopic evolution of the interstellar medium during the past 4.5 billion years.

The proposed instrument is also well suited for the measurement of interstellar H and O composition. Since the solar system moves through the interstellar medium, the interstellar neutral gas has a relative velocity of 20 to about 70 km/s (which translates to 2.1 to 26 eV for H and 33 to 406 eV for O), depending on the season of the year. These neutral atoms will be distinguished from any ambient exospheric neutrals by their direction of arrival and their substantially larger energies.

5. Acknowledgements

The help of Lukas Gubler during the preparation of the manuscript is gratefully acknowledged. Thanks to Robert Sheldon for suggesting diamond as a possible converter surface. This work is supported by the Swiss National Science Foundation.

6. References

[1]D.T. Young, H. Balsiger, J. Geiss, J. Geophys. Res., **87** (1982) 9077
[2]A.W. Yau, E.G. Shelley, W.K. Peterson, and L. Lenchyshyn, J. Geophys. Res., **90** (1985) 8417
[3]A detailed description is given in: M.F. Smith, M. Hesse, F. Herrero, A.G. Ghielmetti, E.G. Shelley, P. Wurz, P. Bochsler, D. Gallagher, T.E. Moore, T. Stephen, S. Chakrabarti, D. Cotton, R. Gladstone, S. Mende, C. Jamer, J. Gerard, and U. Liege, SPIE proceedings, (1993) submitted
[4]S. Chakrabarti, D. Cotton, and R. Gladstone, SPIE proceedings, (1993) submitted
[5]S. Mende, C. Jamer, J. Gerard, and U. Liege, SPIE proceedings, (1993) submitted
[6]G. Gloeckler, F.M. Ipavich, W. Studemann, B. Wilken, D.C. Hamilton, G. Kremser, D. Hovestadt, F. Gliem, R.A. Lundgren, W. Rieck, E.O. Tums, J.C. Cain, L.S. Masung, W. Weiss, and P. Winterhof, IEEE Trans. **GE-23** (1985) 234; E. Möbius, G. Gloeckler, D. Hovestadt, F.M. Ipavich, B. Klecker, M. Scholer, H. Arbinger, H. Höfner, E. Künneth, E. Laeverenz, A. Luhn, E.O. Tums, and H. Waldleben, IEEE Trans. **GE-23** (1985) 274
[7]J. Los, and J.J.C. Geerlings, Phys. Reports, **190** (1990) 133
[8]J.L. Desplat and C.A. Papageorgopoulos, Surf. Sci. **92** (1980) 97
[9]J.J.C. Geerlings, P.W. van Amersfoort, L.F.Tz. Kwakman, E.H.A. Granneman, J. Los, and J.P. Gauyacq, Surf. Sci. **157** (1985) 151
[10]J.F. Ziegler, TRIM-90.05, IBM-Research, Yorktown, NY, USA, (1990)
[11]C.F.A. van Os, and P.W. Amersfoort, J. Los, J. Appl. Phys. **64** (1988) 3863
[12]M.W. Geis, and J.C. Angus, Scientific American **October** (1992) 84
[13]A.G. Ghielmetti, E.G. Shelley, F. Herrero, M.F. Smith, P. Wurz, P. Bochsler, and T. Stephen, SPIE proceedings, (1993) submitted
[14]H. Rème, J.M. Bosqued, J.A. Sauvaud, A. Cros, J. Dandouras, C. D'Uston, E. Möbius, D. Hovestadt, D. Klecker, G. Paschmann, M. Scholer, C.W. Carlson, D. Curtis, R.P. Lin, J.P. McFadden, V. Formisano, E. Amata, M.B. Bavassano-Cattaneo, R. Bruno, M. Candidi, P. Cerrulli-Irreli, S. Orsini, E.G. Shelley, A.G. Ghielmetti, W. Lennartsson, A. Korth, H. Rosenbauer, P.W. Daly, V.M. Vasyliunas, R. Lundin, G.K. Parks, H. Balsiger, J.D. Scudder, I. Papamastorakis, R. Pellat, B.U.O. Sonnerup, B.A. Whalen, A.W. Yau, D.J. McEwen, ESA **SP-1103**, (1993) 65
[15]A. Bürgi, M. Oetliker, P. Bochsler, J. Geiss, M.A. Coplan, J. Appl. Phys. **68** (1990) 2547, M. Gonin, A. Bürgi, M. Oetliker, and P. Bochsler, ESA **SP-348** (1992) 381
[16]C.S. Weller, and R.R. Meyer, Astrophys. J., **246** (1981) 386
[17]E. Chassefiere, F. Dalaudier, and J.L. Bertaux, Astron. Astrophys., **201** (1988) 113
[18]E. Möbius, D. Hovestadt, B. Klecker, M. Scholer, G. Gloeckler, and F.M. Ipavich, Nature, **318** (1985) 426
[19]G. Gloeckler, J. Geiss, H. Balsiger, L.A. Fisk,A.B. Galvin, F.M. Ipavich, K.W. Oglivie, R. vonSteiger, and B. Wilken, Science, (1993) submitted
[20]D.L. Lind, J. Geiss, F. Bühler, and O. Eugster, NASA Conference Publication **3134**, part 1 (1991) 585
[21]M. Witte, H. Rosenbauer, E. Keppler, H. Fahr, P. Hemmerich, H. Lauche, A. Loidl, and R. Zwick, Astron. Astrophys. Suppl. Ser., **2** (1992) 333

Charge exchange and dissociation processes of hydrogen molecules at Pd and Pd/K surfaces.

T. Schlathölter, K. Schmidt, A. Närmann and W. Heiland.
Universität Osnabrück, D-4500 Osnabrück.

The hydrogen-Palladium system has raised considerable interest as the news of "cold fusion" spread through the news media [1]. Even though the "cold fusion" is very likely a terrible knot of artefacts, the Pd + H and Pd/K + H system is of real interest in basic research for heterogeneous catalysis. Especially K is known as a "promoter" in heterogeneous catalysis [2]. In a typical UHV-chemisorption experiment it is found that K adsorption on Pd(100) lowers the dissociative sticking probability of H_2 considerably [3]. We found in fast beam scattering a sizeable decrease of the dissociation probability of H_2 on Pd(110) + K compared to the case of the clean Pd(110) surface [4]. In this paper we give account of some other details of the experimental results. The original experimental arrangement consisting of a pulsed ion beam source and means for time-of-flight (TOF) detection of scattered particles was enriched by a K-dispenser and a Kelvin probe [5] and more recently by gas cell affording neutral, pulsed beams [4]. Other details of the experiment are given in these proceedings [6].

Fig. 1 shows TOF spectra of H_2^+ and H_2° scattering from Pd + K. The K coverage is about 1 m.l. causing a work function change of $\Delta\phi$ = 3.0 eV. The spectra from clean Pd are comparable to those

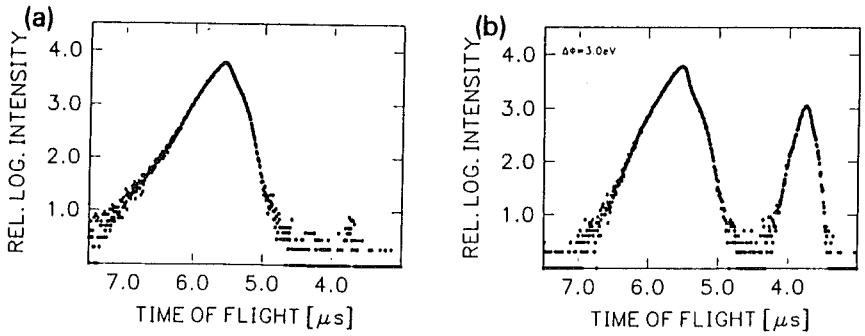

Fig 1: TOF-spectra of H_2^+ (left) and H_2° (right) scattered from Pd + K at grazing incidence. The primary energy is E_0 = 568 eV, the glancing angle of incidence is ψ = 5°, the scattering angle is ϑ = 10°. The primary energy corresponds to t_0 = 5.32 μs. The negative ions are separated from the neutrals by a postacceleration voltage NB = 1430 V.

from Ni (110) [6] and not shown here. In the H_2° case a very distinct narrow "hat" is found riding at about 5.5 μs on a broad distribution. The hat is identified as surviving H_2°, the broad distribution is dissociated H. The H^- peak at 3.6 μs is separated from the neutral peak by postacceleration. Obviously the survival probability for H_2 is very high on K when H_2° is the incident

3S'93

SYMPOSIUM ON SURFACE SCIENCE

CONTRIBUTIONS

Editors: **G. Betz**
P. Varga

Kaprun / Austria
May 9 -15, 1993