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Energy partitioning in collisions of slow polyatomic ions with carbon surfaces

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Abstract

Energy transfer in collisions of slow polyatomic ions with carbon surfaces (Tore Supra carbon tile and highly oriented pyrolytic graphite) was investigated over the incident energy range 10–23 eV. Mass spectra and translational energy and angular distributions of product ions were used to determine the partitioning of the incident energy of the projectile ion into internal excitation of the projectile, product translational energy, and fraction absorbed by the surface. The ethanol molecular ion was used as a model polyatomic ion. For the incident angle of 60° (with respect to the surface normal) the peak values of the respective energy fractions were 6% for excitation of the projectile, 24%–28% for product ion translational energy, and 70%–66% absorbed by the surface. Similar values for energy transfer were found earlier for energy transfer at stainless steel surfaces covered by hydrocarbons and surfaces covered by a self-assembled monolayer (SAM) of C_{12} alkane chains. The occurrence of chemical reaction products (protonated ethanol and its fragment ions) formed by H-atom transfer from the surface material for all the above mentioned surfaces (the carbon surfaces, stainless steel with a hydrocarbon layer, alkane SAM) indicated that the carbon surfaces were covered with a layer of hydrocarbons, too, and thus the present results provide information of interest for energy transfer on carbon tiles covered with hydrocarbon films used in fusion research. (Int J Mass Spectrom 213 (2002) 145–156) © 2002 Elsevier Science B.V.

Keywords: Ion-surface collisions; Polyatomic ions; Energy partitioning; Carbon surfaces

1. Introduction

Collisions of hyperthermal ions with surfaces are of interest because of a wide range of applications in both science and technology [1]. Surface-induced dissociations (SID) of ions have been used to characterize structural properties of polyatomic ions [2]. Moreover, surface-induced chemical reactions are of growing interest not only as a class of chemical reactions of ions, but also as a tool for characterizing the chemical nature of surfaces [1–3]. Besides being of fundamental importance, polyatomic ion–surface interactions are also relevant to technological applications in a variety of fields like surface analysis, surface modifications for preparation of new materials (including plasma processing), and—quite significantly—plasma-wall interactions in discharges and fusion devices [4].

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Energy transfer in the course of ion–surface collisions is of prime importance. The questions of what fraction of collisional energy of the incident ion is transformed into its internal energy (and may lead to its further dissociation), what fraction is retained as translational energy of the scattered collision products, and what absorbed by the surface is of fundamental importance. Considerable attention has been paid in the past years to the estimation of the fraction of collision energy transferred in the surface collision into internal energy of the projectile ion. Several approaches have been used [5,6], e.g. the extent of fragmentation of "thermometer molecular ions" [7] or model calculations [8].

In our recent articles, we have used the ion–surface scattering method [9,10] to determine the energy partitioning in polyatomic ion–surface collisions. Not only were the average energies transferred in surface collisions measured, but information on distributions of energies transformed in surface collisions into internal energy of the projectile, absorbed by the surface, and retained as translational energy of the scattered ion products was obtained. The scattering experiments can be carried out for projectile ions impinging on the surface under different incident angles and provide the following data: (1) mass spectra of the ion products of surface collisions: the extent of fragmentation of a well-characterized projectile is then used to estimate the distribution function of energy transformed into internal energy of the projectile ion; (2) measurements of translational energy distributions of product ions from surface collisions: this enables a direct determination of the fraction of collision energy which appears as translational energy of the product ions; and (3) angular distributions of product ions resulting from surface collisions: this provides additional information which helps to understand the scattering process.

In this way one obtains information on the terms in the general energy transfer relation

$$E_{\mathrm{tot}} = E_{\mathrm{tr}} + E_{\mathrm{int}} = E'_{\mathrm{int}} + E'_{\mathrm{tr}} + E'_{\mathrm{surf}} \tag{1}$$

The entrance channel is the translational energy of the incident projectile ion, E_{tr}, possibly complemented by the initial internal energy content of the ion, E_{int}. This energy is distributed (product energies primed) into the internal energy excitation of the product(s) (E'_{int}), translational energy of the product(s) (E'_{tr}), and energy absorbed by the surface (E'_{surf}). The various energy fractions are characterized by the respective distribution functions, $P(E'_{\mathrm{int}})$, $P(E'_{\mathrm{tr}})$, and $P(E'_{\mathrm{surf}})$.

In this article we describe results of experiments on energy partitioning in collisions of a model polyatomic ion with specific carbon surfaces. The aim of this set of experiments was to determine energy transfer for surfaces relevant to fusion research. Therefore, the carbon surface used was the surface of a TORE SUPRA carbon tile. The results are compared with data obtained with a standard highly oriented pyrolytic graphite (HOPG) carbon surface. Both surfaces were kept at ambient temperatures (about 300 K) during the experiments. The model polyatomic ion used was the ethanol molecular ion $C_2H_5OH^+$. It should be emphasized that the exact nature of the projectile ion is of secondary importance in these studies. The ethanol molecular ion represents here only a suitable polyatomic moiety of about ten chemically bound atoms with well-characterized properties, in particular including: (1) its break-down pattern (the relative abundance of the molecular and various fragment ions on the excitation energy) follows unimolecular decomposition kinetics and is well known from both experimental [11] gas-phase studies and theoretical calculations [12]; (2) the internal energy content of the primary projectile ion can be estimated [9] as being rather low; and (3) the decomposition pattern of the corresponding protonated ion (formed in a surface chemical reaction by H-atom transfer) is very simple and can be subtracted from the mass spectrum of the ion products.

This article describes results of projectile ion–surface collisions on the two carbon surfaces at incident energies of 12 and 23 eV. The incident angle was 60° (measured from the surface normal, i.e. 30° with respect to the surface). Mass spectra of the product ions, product ion angular and translational energy distributions were measured and from these results, the partitioning of energy in the surface collision was derived.

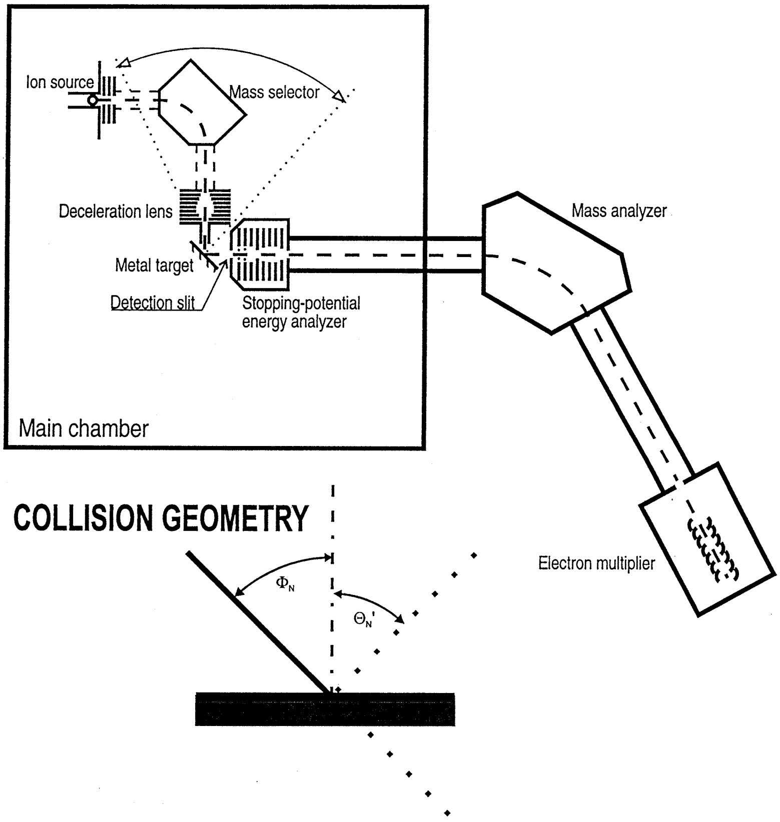

Fig. 1. Schematic of the experimental arrangement, inset shows the collision geometry.

2. Experimental

The experiments were carried out using the Prague beam scattering apparatus EVA II, built originally for studies of gas-phase ion–molecule collision dynamics, and modified for ion-surface collision studies [9] (Fig. 1). The modification consisted in replacing the crossed beam arrangement with a carbon surface target from which projectile ions were scattered and detected. In the present experiments, projectile ions were formed by bombardment of ethanol molecules in a low-pressure ion source by 120 eV electrons. The resulting ions were extracted, accelerated to about 140 eV, mass analyzed by a 90° permanent magnet, and decelerated to a required energy in a multielement deceleration lens. The resulting beam had an energy spread of 0.2 eV, full-width-at-half-maximum (FWHM), an angular spread of 1°, FWHM, and geometrical dimensions of 0.4 × 1.0 mm. The beam was directed towards the surface under a pre-adjusted incident angle Φ_N. Ions scattered from the surface passed through a detection slit (0.5 × 1 mm), located 25 mm away from the target, into a stopping potential energy analyzer; they were then accelerated to 1000 eV into a detection mass spectrometer (a magnetic sector instrument) and detected with a Galileo channel multiplier. The primary beam exit slit, the target, and the detection slit were all kept at the same potential during the experiments and this equipotential region was carefully shielded by μ-metal sheets. The primary beam-target section could be rotated about the scattering center with respect to the detection slit to obtain angular distributions.

The energy of the projectile ions was measured by applying to the target a potential exceeding the nominal ion energy by about 10 eV. The target area then served as a crude ion deflector directing the projectile ions into the detection slit. The energy of the deflected ions could be determined with accuracy better than about 0.2 eV. The impact angle of the projectile ions was adjusted before an experimental series by a laser beam reflection with a precision better than about 1°. Incident (Φ_N) and scattering (Θ'_N) angles were measured with respect to the surface normal (see inset in Fig. 1).

The carbon surface target was (1) a 5×5 mm carbon plate about 1 mm thick cut from a TORE SUPRA carbon tile and polished by diamond powder; the sample was cleaned in an ultrasonic cleaner successively in an acetone, methanol, and water bath before being placed into vacuum; 2) a 5×5 mm sample of highly oriented pyrolytic carbon (HOPG) sample from which the surface layer was peeled-off immediately before placing it into vacuum; Both samples were mounted into a stainless steel holder located 10 mm in front of the exit slit of projectile ion deceleration system. The incident angle of the projectile ion beam Φ_N was set with an accuracy of $\pm 1°$. Most of the experiments were carried out with target surfaces kept at ambient temperature. The scattering chamber of the apparatus was pumped by a 2000 L/s diffusion pump (Convalex polyphenyl ether pump fluid), and the detector by a 160 L/s turbomolecular pump; both pumps were backed by rotary vacuum pumps. The background pressure in the apparatus was about 5×10^{-7} Torr; during the experiments the pressure was about 3×10^{-6} Torr due to the leakage of the source ethanol vapor into the scattering chamber.

In an additional set of experiments, the carbon samples were resistively heated in the scattering chamber for 20 min to about 1000 K (measured by a pyrometer). Heating of the samples was carried out to check, if the surface material of the samples prepared on air had the same properties as the surface material of the samples cleaned by heating in vacuum. Mass spectra of ion–surface collision products were measured with the surface heated, during cooling of the samples to the room temperature (about 1 hr), and for several hours afterwards.

3. Results

3.1. Mass spectra of the product ions

Fig. 2 shows mass spectra of product ions obtained in collisions of ethanol molecular ions of incident energies of 12.3 (12.4) and 22.7 (22.6) eV on the two carbon samples, TORE SUPRA tile and HOPG, respectively. The incident angle was $\Phi_N = 60°$ (measured from the surface normal, i.e. 30° with respect to the surface) and the scattering angle was set to the maximum of the angular distribution at $\Phi'_N = 75°$ (15° from the surface).

The spectra show three types of ions [9,10]. (1) Inelastically scattered product ions from dissociations of the projectile ions upon interaction with the surface (nondissociated molecular ion, *m/z* 46, and fragment ions *m/z* 45, 31, 28, minute amounts of *m/z* 43, 30)

$$C_2H_5OH^+ + S \rightarrow (C_2H_5OH^+)^* \rightarrow \text{fragments} \qquad (2a)$$

(2) Inelastically scattered product ions from surface-protonated molecular ions, formed in a H-atom transfer chemical reaction with the hydrogen-containing substances on the surface, see later) and its dissociation products (*m/z* 47, 29, 27, 19; hatched peaks in Fig. 2)

$$C_2H_5OH^+ + H - S \rightarrow (C_2H_5OH_2{}^+) \rightarrow \text{fragments} \qquad (2b)$$

(3) Quasielastically scattered projectile ions (*m/z* 46) of approximately the incident ion energy; because of their substantially higher kinetic energy than the inelastically scattered ions sub (a) and (b), they appear in the mass scale of the magnetic detection spectrometer at a slightly higher apparent mass than *m/z* 46; the shift increases with the increasing difference between the incident energy and the peak energy of the inelastically scattered ions [dark shaded peaks at *m/z* 46.2 in Figs. 2(a) and (c) and *m/z* 46.4 in Figs. 2(b) and (d)]. The quasielastically scattered projectile ions

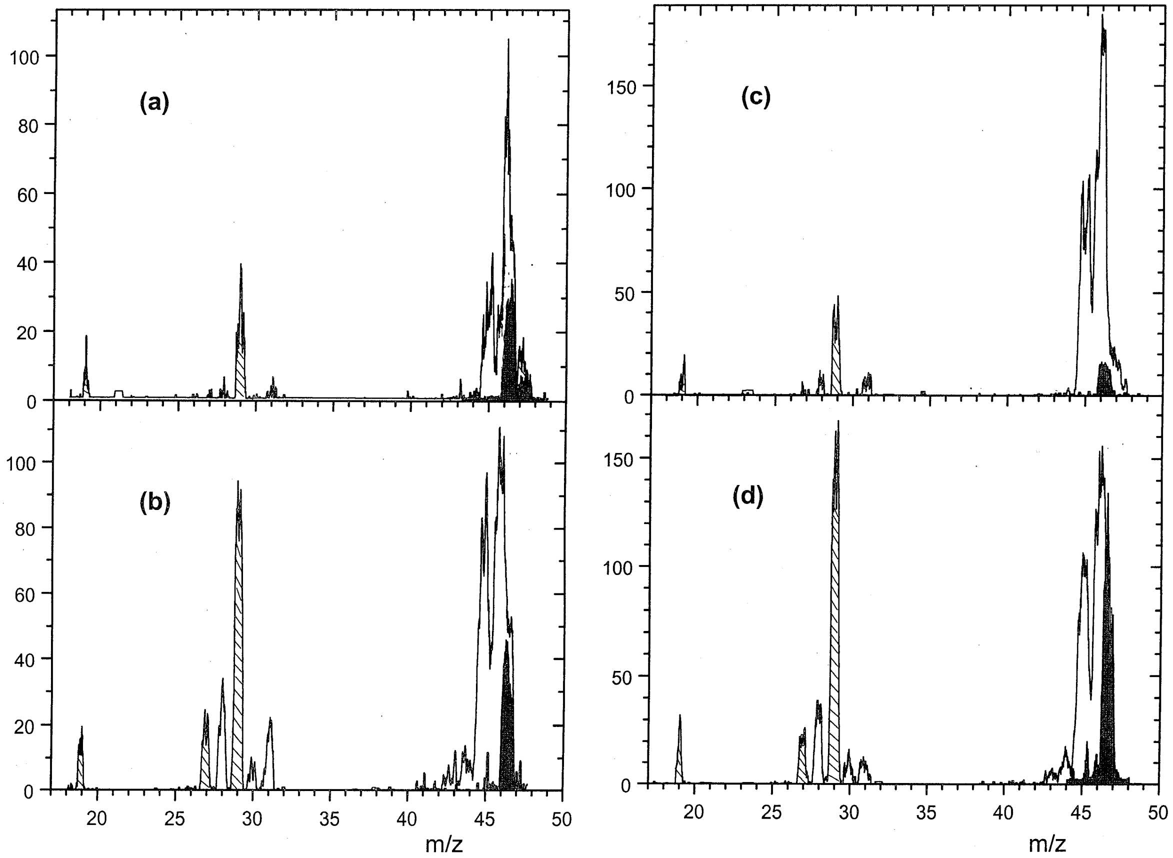

Fig. 2. Mass spectra of products ions from interaction of projectile ions $C_2H_5OH^+$ with carbon surfaces at two incident energies, E_{tr} (a) TORE SUPRA sample, E_{tr}: = 12.3 eV, (b) TORE SUPRA sample, E_{tr}: = 22.7 eV, (c) HOPG sample, E_{tr} = 12.4 eV, (d) HOPG sample, E_{tr} = 22.6 eV. Incident angle $\Phi_N = 60°$ (with respect to the surface normal), spectra measured at the product ion angular maximum, $\Theta'_N = 75°$. Dark shaded peak represent quasielastically scattered projectile ions, hatching indicates products formed as a result of surface chemical reactions of H-atom transfer.

were measured by applying to the energy analyzer a stopping potential by 3 eV lower than the incident ion energy.

The extent of fragmentation of the projectile ion, the relative abundance of the product ions *m/z* 46, 45, 31, and 28 were used to obtain the distribution of energy transformed into internal energy of the projectile as a result of the interaction with the surface, $P(E'_{int})$. Similarly as in our previous articles [9,10] the breakdown pattern of the ethanol molecular ion (Fig. 3) was used to fit the relative abundances of the ion species in the mass spectra by a computed distribution function, using the expression

$$I_i = \int P\ (E'_{int})\ A_i\ (E'_{int})\ dE'_{int} \tag{3}$$

where $A_i(E'_{int})$ is the abundance of the ion species *i* in the breakdown pattern at E'_{int} An iterative computer program was used to obtain the best fit with the abundance of the ions in mass spectra in Fig. 2. Fig. 3 shows the $P(E'_{int})$ distributions obtained in this way for the incident energy of the projectile ion of about 22.5 eV for both carbon targets. In addition, the $P(E'_{int})$ obtained from the results on collision of the ethanol molecular ion projectile with a stainless steel target, covered by a multilayer of hydrocarbons [9] is

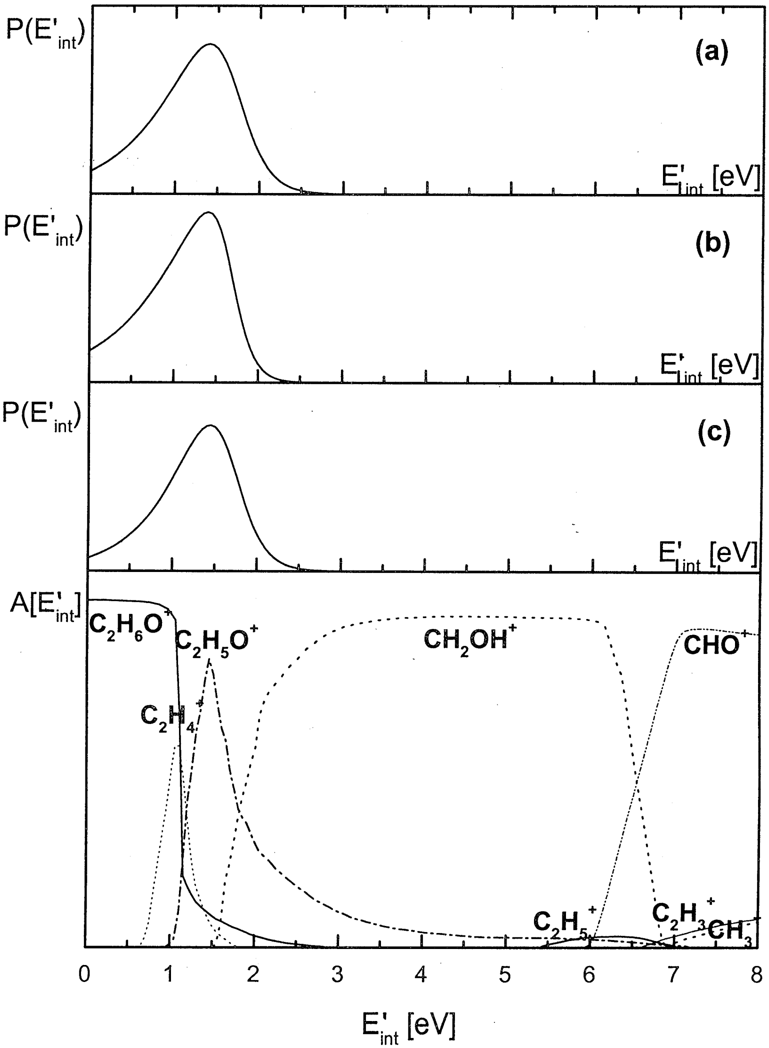

Fig. 3. Distribution of energy transformed into internal energy of projectile ions $C_2H_5OH^+$ during interaction with the surface, $P(E'_{\mathrm{int}})$: (a) TORE SUPRA sample, $E_{\mathrm{tr}} = 22.7$ eV, (b) HOPG sample, $E_{\mathrm{tr}} = 22.6$ eV, (c) stainless steel, $E_{\mathrm{tr}} = 22.3$ eV [9]. Incident angle $\Phi_N = 60°$. Lower part shows the breakdown pattern of the ethanol molecular ion used in the evaluation [9,12].

given in Fig. 3, also. It can be seen that the three $P(E'_{\mathrm{int}})$ curves are very similar, with a peak value at 1.4 eV (6.2% of E_{tr}) and a total width of about 2.5 eV (FWHM 1.1 eV).

3.2. Translational energy distributions of the product ions

Translational energy distributions were measured for all major product ions (*m/z* 46, 45, 31, 29) at the maximum of their angular distributions. The measured distributions were then converted to velocity distributions. An example of such a plot is given in Fig. 4 for product ions scattered from the HOPG surface at $\Phi'_N = 75°$ (projectile ion energy 22.6 eV, incident angle $\Phi_N = 60°$). The projectile ion incident velocity under these conditions was $v_{\mathrm{inc}} = 9.72$ km/s. All product ions have considerably smaller velocities, peaking at about 5 km/s, i.e. at about 0.5 v_{inc}, with maximum velocities smaller than about 8 km/s. This

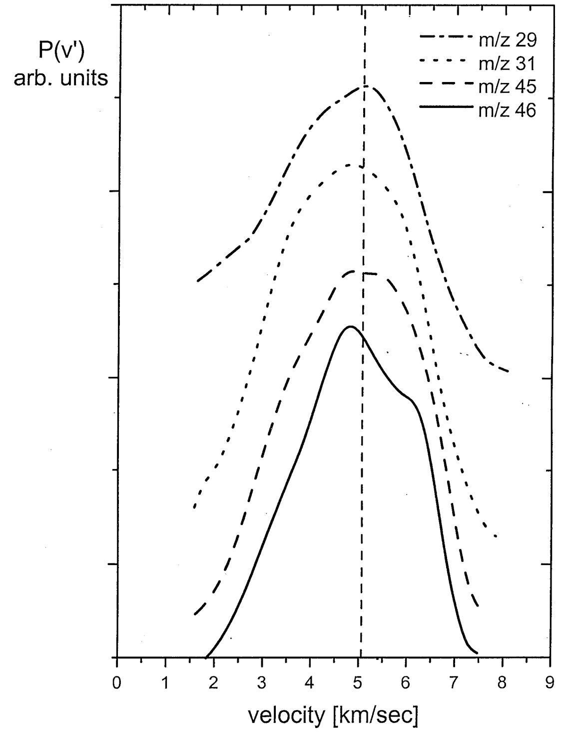

Fig. 4. Velocity distributions, $P(v')$, of product ions formed in interaction of projectile ions $C_2H_5OH^+$ with the HOPG surface: *m/z* 46: $C_2H_5OH^+$, *m/z* 45: $C_2H_5O^+$, *m/z* 29: $C_2H_5{}^+$, *m/z* 19: H_3O^+. Incident energy E_{tr} = 22.6 eV, incident angle $\Phi_N = 60°$. The profiles were determined at the product ion angular maximum, $\Theta'_N = 75°$.

indicates a large inelasticity of the dissociative and reactive collisions with the surface. Moreover, the inelastically scattered undissociated molecular ions and all product ions resulting from dissociative processes have very similar velocity distributions (we regard the high-velocity hump in the *m/z* 46 curve in Fig. 4 as an experimental artifact rather than a real structure, as it did not show in any curves of the inelastically scattered undissociated molecular ion at other incident energies). This implies that the fragmentation of the projectile, excited in the surface collision, occurred after the interaction with the surface in a unimolecular way [9,10].

The averaged distributions of translational energies of the product molecular ion, which may be thus taken as representative of the energy distributions of the surface-excited projectile ions, dissociating further to

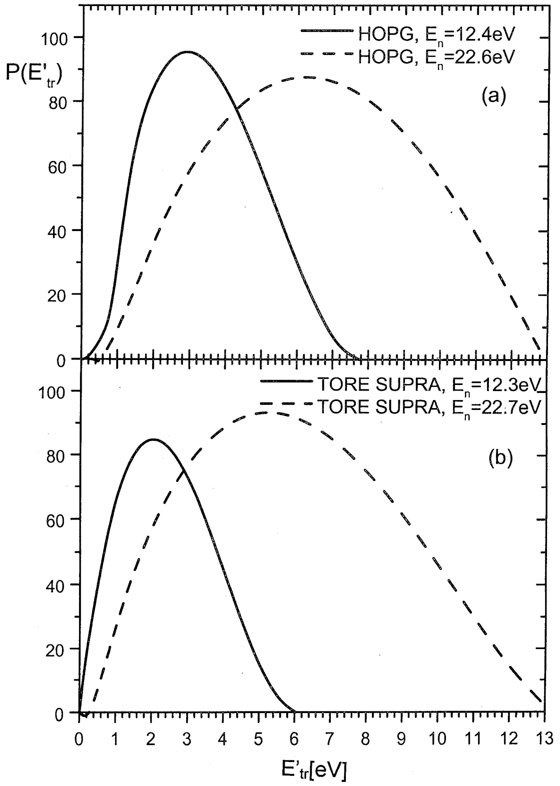

Fig. 5. Translational energy distribution, $P(E'_{tr})$ of product ions formed in interaction of projectile ions $C_2H_5OH^+$ with carbon surfaces: (a) HOPG sample, E_{tr} = 12.4 eV (solid line), E_{tr} = 22.6 eV (dashed line). (b) TORE SUPRA sample, E_{tr} = 12.3 eV (solid line), E_{tr} = 22.7 eV (dashed line); incident angle of projectile ions, $\Phi_N = 60°$.

various fragment ions, are given in Fig. 5 for both collision energies and for both carbon surfaces. The translational energy distributions $P(E'_{tr})$ of the ions after interaction with the surface show a slight difference for the two carbon samples: the $P(E'_{tr})$ for the HOPG sample tend to peak at energies of about 23% and 28% of the incident energy (2.8 and 6.2 eV for collision energies of 12.4 and 22.6 eV, respectively), somewhat higher that those for the TORE SUPRA carbon tile surface (2.0 and 5 eV for the two collision energies, i.e. 16% and 22% of the incident energy).

3.3. Angular distributions of the product ions

Angular distributions of inelastically scattered product ions, represented here by the angular distri-

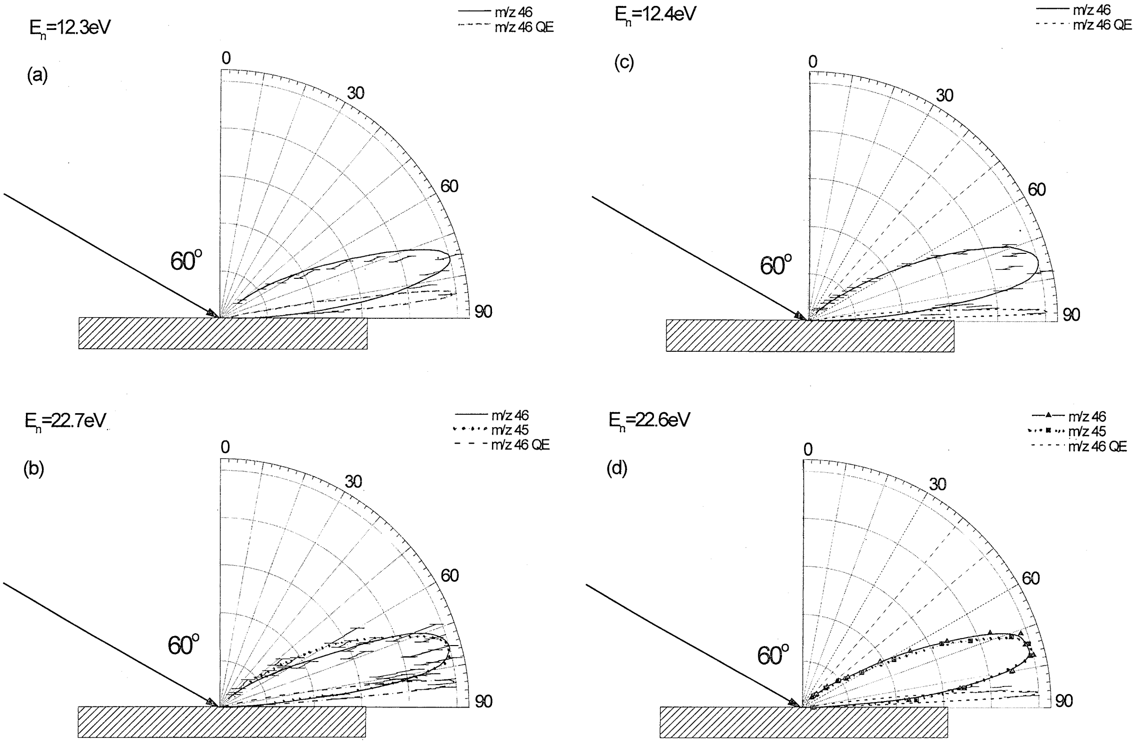

Fig. 6. Angular distributions of product ions (*m/z* 46: $C_2H_5OH^+$) formed in interaction of projectile ions $C_2H_5OH^+$ with carbon surfaces: (a) TORE SUPRA sample, $E_{tr} = 12.3$ eV, (b) TORE SUPRA sample, $E_{tr} = 22.7$ eV, (c) HOPG sample, $E_{tr} = 12.4$ eV, (d) HOPG sample, $E_{tr} = 22.6$ eV; incident angle $\Phi_N = 60°$. Dashed lines show angular distributions of quasielastically scattered projectile ions $C_2H_5OH^+$ (*m/z* 46QE).

bution of the molecular ion product of *m/z* 46 and the fragment ion of *m/z* 45 are shown in Fig. 6(a)–(d) as polar plots for both incident energies and for both carbon surfaces. Other product ions (*m/z* 31, 29) showed similar angular distributions and were omitted from these figures. In addition, dashed curves show angular distributions of the quasielastically scattered projectile ions of final translational energy practically the same as the incident energy.

Angular distributions of all the inelastically scattered ions at both energies and for both surfaces are very similar, peaking at $\Phi'_N = 75°$, i.e. at about half of the incident angle (with respect to the surface). This is different than in the scattering experiments on the hydrocarbon-covered stainless steel surface [9], where for this incident angle the maximum of the angular scattering was at $\Phi'_N = 60°$ (i.e. the incident and the scattering angle were about the same). The quasielastically scattered projectile ions show a much narrower angular distribution with a peak very close to the surface (Φ'_N at 84°–88°).

3.4. Incident energy partitioning

From the experimental data one can derive the distributions for energy partitioning in ion-surface interactions on the two carbon surfaces, the TORE SUPRA carbon tile surface and the HOPG surface. As in our earlier treatments [9,10], one starts from Eq. (1) and introduces the respective distributions. For $P(E_{tr})$ the translational energy distribution of the incident projectile molecular ion was used and to it the initial internal energy distribution of the ethanol molecular ion, $P(E_{int})$, was added; this term was estimated in the same way as earlier [9,10] from the range of stability of the non-dissociated molecular ion as given by the breakdown pattern and the probability of populating internal energy states in this region of excitation

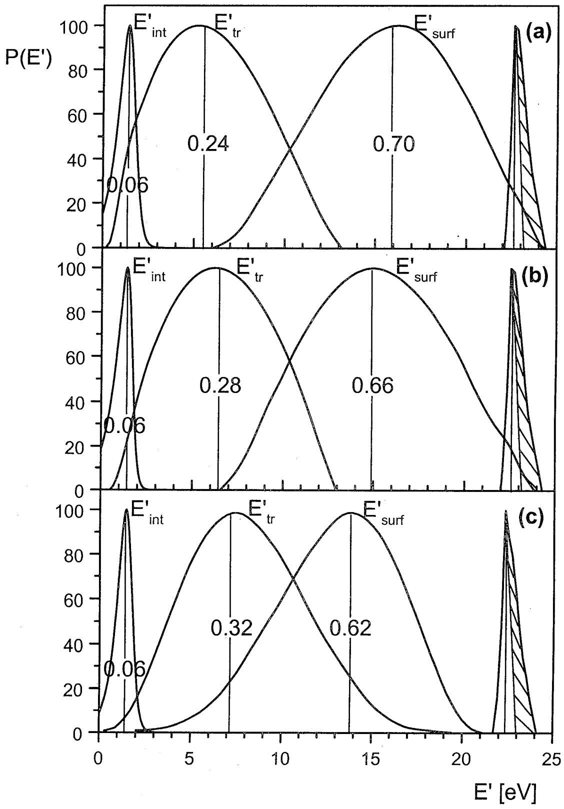

Fig. 7. Distribution functions for energy partitioning into E'_{int}, E'_{tr}, and E'_{surf} on interaction of projectile ions $C_2H_5OH^+$ with (a) TORE SUPRA sample, $E_{\mathrm{tr}} = 22.7$ eV, (b) HOPG sample, $E_{\mathrm{tr}} = 22.6$ eV, (c) stainless steel, $E_{\mathrm{tr}} = 22.3$ eV. Incident angle $\Phi_N = 60°$. The narrow peak in the right-hand side indicates the energy distribution of the incident projectile ions, its shaded area denotes their internal energy distribution.

energies, as obtained from photoelectron spectra of ethanol. The term $P(E'_{\mathrm{tr}})$ was taken from the direct measurements of the translational energy distributions of the product ions as given in Fig. 4, and $P(E'_{\mathrm{int}})$ was obtained from the fits of the fragmentation data (Fig. 3). The term for the distribution of the energy absorbed by the surface, $P(E'_{\mathrm{surf}})$, was taken as the difference of these terms.

The distributions for energy partitioning in surface collisions at the incident projectile ion energy of 22.7 (22.6) eV, are summarized in Fig. 7 for collisions (a) with the TORE SUPRA carbon tile surface and (b) with the HOPG surface. In addition and for comparison, our earlier data [9] obtained for analogous conditions (same incident energy and incident angle of the ethanol molecular ion projectile) on collisions with a stainless steel surface covered with a multilayer of hydrocarbons are given in Fig. 7(c).

3.5. Mass spectra of heated samples

Heating of the samples to about 1000 K led to substantial temporary changes in the mass spectra of the ion products from ethanol ion–hot surface interaction. Mass spectra, recorded during the heating and during the first minutes after the heating was terminated, showed that upon $C_2H_5OH^+$ impact the fraction of product ions originating from the chemical reaction of H-atom transfer with the surface material (protonated ethanol $C_2H_5OH_2^+$ and its decomposition products) considerably increased (2–3 times) in comparison with the fraction of product ions from dissociations of the projectile ions upon interaction with the surface. When $C_2D_5OD^+$ (deuterated ethanol molecular ion) was used as a projectile, the product of the chemical reaction at the surface was prevailingly deuteronated ethanol $C_2D_5OD_2^+$ (resulting from a D-atom transfer reaction at the surface) and its dissociation products.

Mass spectra recorded 4–5 h after terminating the heating were practically the same with the $C_2H_5OH^+$ projectiles as before the heating (see Fig. 2). When $C_2D_5OD^+$ was used as a projectile, the fraction of product ions resulting from the chemical reaction at the surface were protonated projectile ions $C_2D_5ODH^+$ (resulting from a H-atom transfer reaction with the surface material) and the respective decomposition products.

This indicates that heating the samples to about 1000 K removed the hydrocarbon surface layer and the chemical reaction at the heated surface occurred with background source vapor ethanol molecules (C_2H_5OH or C_2D_5OD) adsorbed on this cleaned carbon surface. After the end of heating period, however, the hydrocarbon layer gradually developed on the cooled surface again, and after 4–5 h the ion scattering products resulted from interaction of the projectile ions with this hydrocarbon layer, similarly as with the unheated samples. It appears that the background ethanol molecules do not stick to this hydrocarbon layer, as with the cooled samples the D-atom transfer reactions were not observed to any measurable extent.

The hydrocarbon multilayer developed in the vacuum of the apparatus on the carbon samples prepared on air thus appears to have the same properties as the hydrocarbon multilayer developed after several hours on the carbon samples cleaned by heating in the vacuum.

4. Discussion

The distribution functions for energy partitioning in collisions of ethanol molecular ions with the two carbon surfaces, TORE SUPRA carbon tile and HOPG, are very similar: they show that 6% (peak value) of the incident energy is transformed into the internal energy of the projectile ion and is available for its dissociation upon interaction with the surface. Also, the shape of the distribution function, $P(E'_{\mathrm{int}})$ is very similar for both surfaces: it is rather narrow and it stretches over the region of 0% to about 10% of the incident energy. The fraction of energy which remains as kinetic energy of the inelastically scattered product ions is also very similar for the three target surfaces, being only slightly (peak value 28%) higher for the HOPG surface than for the TORE SUPRA surface (peak value 24%). The shape of the distribution, $P(E'_{\mathrm{tr}})$, for both carbon samples is rather similar, too: it is quite broad covering the range from practically 0% to about 58% of the incident energy of the projectile ion. The fraction of energy absorbed by the surface, obtained as a difference, has its peak value of 70% for the TORE SUPRA sample and about 66% for the HOPG sample, for this incident angle, and it is rather broad, too.

An important comparison provides the energy partitioning measured earlier for the stainless steel surface covered by a multilayer of hydrocarbons [Fig. 7(c)]. It shows distribution curves very similar to those for carbon surfaces in Fig. 7(a) and (b): for the fraction of energy transformed into internal energy, the peak value is the same and the distribution is very similar (see also Fig. 3). The fraction of energy in product translation peaks at a somewhat higher value (32%) than for the two carbon surfaces.

A very similar energy transfer for carbon and stainless steel surfaces suggests that the main factor determining its magnitude is similar in all cases. This appears to be the multilayer of hydrocarbons, which both in the case of the stainless steel sample and in the case of the two carbon samples covers the surface and at the room temperature of the samples determines their main properties. This conclusion is corroborated by the fact that the amount of products of chemical reactions at all three surfaces [formation of protonated ethanol and its decomposition products in a surface reaction between ethanol molecular ion and hydrogen-containing substance at the surface, reaction [Eq (3)] is about the same. In addition, scattering results using as target surfaces self-assembled monolayers of hydrocarbons [10] exhibit both energy transfer characteristics and chemical reactivity to form protonated ethanol very similar to the results discussed here. In particular, bombarding a target covered with a self-assembled monolayer (SAM) of C_{12} hydrocarbon chain (anchored by means of an S atom to a thin layer of gold on a silicon surface) by ethanol molecular ions of incident energy of 22.1 eV under an incident angle $\Phi_N = 60°$ led to the following energy partitioning [10]: 6% of incident energy into internal excitation of the projectile, 30% of incident energy into product ion translation, 68% of incident energy absorbed by the surface (the numbers refer to peak values analogous to those given in Fig. 7). Thus it appears that both the stainless steel surface and the two investigated carbon surfaces are covered by a layer of background hydrocarbons which behaves, as far as energy transfer and chemical reactivity is concerned, in a very similar way as a well-defined self-organized monolayer of C_{12} hydrocarbons anchored to a surface.

The exact composition of the hydrocarbon layer covering after some time the surface of the carbon samples is not known. However, it appears to be a rather general phenomenon in many mass spectrometers and special devices [2,3,9]. It has been generally assumed [2] that the hydrocarbon layer results from surface deposition of hydrocarbons backstreaming from rotary oil pumps and possibly cracked in the hot environment of diffusion pumps.

The conclusions concerning energy transfer in collisions of slow ions with hydrocarbon-covered carbon surfaces may be of interest for fusion research. A considerable effort has been directed recently to covering the walls of nuclear devices by hydrocarbon films to control the impurity level of the fusion plasmas caused by erosion of the first wall [13]. The growth of hydrocarbon C:H films by plasma chemical vapor deposition and the properties of these films has been given, therefore, considerable attention.

The presented results on energy transfer in collisions of slow polyatomic ions with carbon surfaces, covered by background hydrocarbons, thus may be regarded as a first step in obtaining information on energy partitioning in ion–surface collisions with materials important in fusion research. Further work, oriented towards surface collisions of simple ions (such as H_2^+, H_3^+, OH^+, O_2^+, CH_n^+, and other small C_2 and C_3 hydrocarbon ions), collisions with surfaces at elevated temperatures, and with surfaces covered by specially deposited films is in progress.

6. Summary

Measurements of mass spectra (fragmentation patterns), translational energy distributions, and angular distributions of product ions from interactions of a model polyatomic projectile ion (ethanol molecular ion) with carbon surfaces (TORE SUPRA carbon tile, HOPG surface) were used to determine the distribution functions for partitioning of incident energy of the projectile ion energy in slow polyatomic ion–surface collisions. The results were compared with results of analogous measurements using as a target surface stainless steel (covered by a multilayer of hydrocarbons) and self-assembled monolayer of C_{12} alkane chain on a metal surface.

The distribution of energy transformed into internal energy of the projectile ion, $P(E'_{\text{int}})$, was determined from the extent of its fragmentation with the help of the break-down pattern of the projectile molecular ion. The distribution of energy converted into product ion translational energy, $P(E'_{\text{tr}})$, was obtained from direct measurements. The distribution of energy absorbed by the surface, $P(E'_{\text{surf}}$, was obtained as a difference of the sums of the latter two terms and the incident energy of the projectile ion (with the estimated initial internal energy of the projectile ion included).

At the collision energy of about 22.5 eV and incident angle of 60° (with respect to the surface normal) the peak value of $P(E'_{\text{int}})$ was 6% of the incident projectile energy, the peak value of $P(E'_{\text{tr}})$ was 24%–28% for the carbon surfaces (to be compared with 32% of hydrocarbon-covered stainless steel surface), and the peaks value of $P(E'_{\text{surf}})$ was 70%– 66% (62% for the stainless steel surface).

The similarity of the energy transfer results and the chemical reactions observed at the surface (hydrogen atom transfer processes) for both carbon surfaces, for the stainless steel covered by a layer of hydrocarbons, and for the C_{12} alkane SAM surface suggests that the studied carbon surfaces were covered by a layer of hydrocarbons.

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