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Surface Structures of Adsorbed Gases on Solid Surfaces. A Tabulation of Data Reported by Low-Energy Electron Diffraction Studies

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Contents

I. Introduction	233
II. The LEED Experiment	233
III. Conversion of the Diffraction Pattern to a Surface Structure	234
IV. Types of Substrates Used in LEED Studies	235
V. Surface Structures of Adsorbates	245
VI. Text References	249
VII. References for Tables II-VI	249

I. Introduction

Studies of ordered surface structures formed upon adsorption of gases on solid surfaces are carried out using low-energy electron diffraction (LEED). The technique of diffraction is sensitive to order, and low-energy electrons provide the needed surface sensitivity; therefore, LEED is well suited for determining the surface structures of monolayers of adsorbed gases. The number of investigations that report on ordered adsorbates has increased dramatically in the last four years. In 1974, a tabulation of over 300 surface structures observed in LEED experiments was published in a review article by Somorjai and Kesmodel.¹ Since that time over 500 surface structures have been reported in more than 300 papers. In this review we have updated and expanded the previous tabulation to include this large amount of new data.

Not only has the number of LEED studies increased, but the types of experiments now cover a wider range. In the past most of the reported surface structures were from experiments dealing with the adsorption of small inorganic molecules (H_2 , O_2 , CO , CO_2 , N_2 , etc.) on low Miller index surfaces. At that time only three studies on stepped or high Miller index surfaces were reported. Since 1974 the number of LEED experiments on stepped surfaces has greatly increased. As a result we have prepared a separate table for listing the surface structures formed on stepped surfaces. There is also a large number of LEED investigations of organic molecule adsorption on surfaces, and we have listed these surface structures in a separate table. Ethylene and acetylene are the two most widely studied organic molecules, but there have also been several adsorption studies of large organic molecules both in the monolayer and multilayer regimes. We have excluded the LEED studies of ordered structures formed by condensed metallic monolayers from our tables and discussion.

The surface unit cells formed during the adsorption of mole-

cules and atoms on various substrates yield information on the size, shape, and orientation of the surface unit mesh. While they do not give the precise location or identification of the adsorbed surface species, this is possible by the analysis of the diffraction beam intensities. In surface crystallography the intensity profiles of the diffraction spots obtained as a function of the incident electron beam energy (I - V curves) are analyzed to determine the positions of atoms in the surface unit mesh. Out of the 300 LEED articles in the past four years, over 30 contained experimental I - V curves and/or the analysis of these curves.

The results of the surface crystallography analysis have been reviewed recently.² This analysis involves multiple scattering calculations and requires the availability of accurate I - V data on a large number of diffraction beams. Most LEED studies report only the size and shape of the two-dimensional surface unit mesh and do not provide enough information to permit surface structure analysis.

II. The LEED Experiment

A typical LEED apparatus is shown in Figure 1. A monoenergetic beam of electrons (10 to 300 eV) is directed at the surface of a single crystal which backscatters a portion of the incoming electrons. A set of hemispherical grids is used to remove the inelastically backscattered electrons while the elastically backscattered electrons are post-accelerated onto a phosphorus screen for viewing of the diffraction pattern. The crystal and the detection system are enclosed in an ultrahigh vacuum (UHV) chamber in order to attain and maintain a clean surface. As seen in Figure 1 there is a window present in the UHV chamber directly opposite the phosphorus screen which allows the diffraction pattern to be viewed and photographed from outside the UHV chamber. A polaroid camera is commonly used for photographing the diffraction pattern and the published LEED patterns are from such photographs. LEED is commonly combined with other techniques such as Auger electron spectroscopy (AES), thermal desorption spectroscopy (TDS), ultraviolet photoelectron spectroscopy (UPS), and electron loss spectroscopy (ELS). This allows correlation of the surface structure information with surface composition, binding energies, electronic properties, and vibrational modes for an adsorbate.

A well-ordered crystal surface will yield a diffraction pattern consisting of bright, well-defined spots with very low background intensity. The sharpness and overall intensity of the spots depend on the degree of order on the surface. Although the surface may

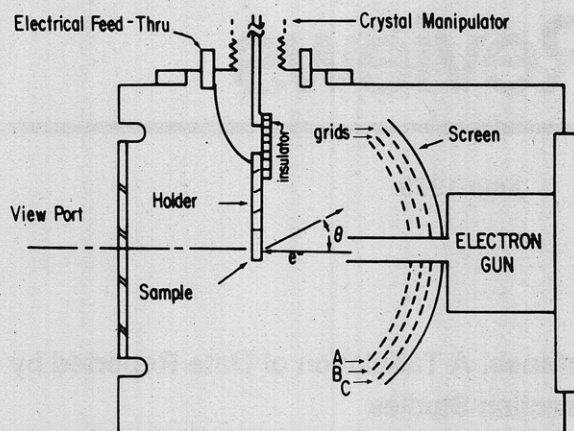


Figure 1. Schematic diagram of a typical LEED apparatus.

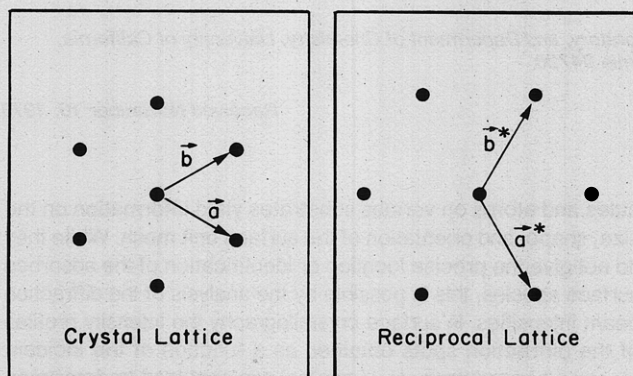


Figure 2. Real space vectors \vec{a} and \vec{b} and reciprocal space vectors \vec{a}^* and \vec{b}^* of a two-dimensional hexagonal lattice.

be irregular on a microscopic and submicroscopic scale (e.g., consisting of atomic terraces and ledges), the presence of sharp diffraction features indicates that the surface is ordered on an atomic scale; that is, most of the surface atoms are located in a two-dimensional lattice structure. The size of these ordered domains determines the quality of the diffraction pattern. Because of the experimental limitations on the coherence width of the electron beam, the quality of the diffraction pattern does not improve when the ordered domains become larger than 500 Å in diameter. However, if the ordered domains are significantly smaller than 500 Å, the diffractions spots become broader and less intense.

III. Conversion of the Diffraction Pattern to a Surface Structure

LEED diffraction patterns represent the reciprocal lattice of the surface and the diffraction pattern must be converted to real space in order to obtain the surface structure. In this section we will show how this conversion is performed. First, the relationship between the reciprocal and real lattices of the substrate will be shown; then determination of adsorbate surface structures from the LEED patterns will be discussed.

The diffraction pattern or reciprocal lattice has translational periodicity which is given by the vector \vec{T}^* which has the form

$$\vec{T}^* = h\vec{a}^* + k\vec{b}^* \quad (1)$$

where h and k are integers and \vec{a}^* and \vec{b}^* are the vectors of the primitive surface reciprocal mesh. The translational periodicity of the surface in real space is given by the vector \vec{T} which has the form

$$\vec{T} = n\vec{a} + m\vec{b} \quad (2)$$

where n and m are integers and \vec{a} and \vec{b} are the vectors of the

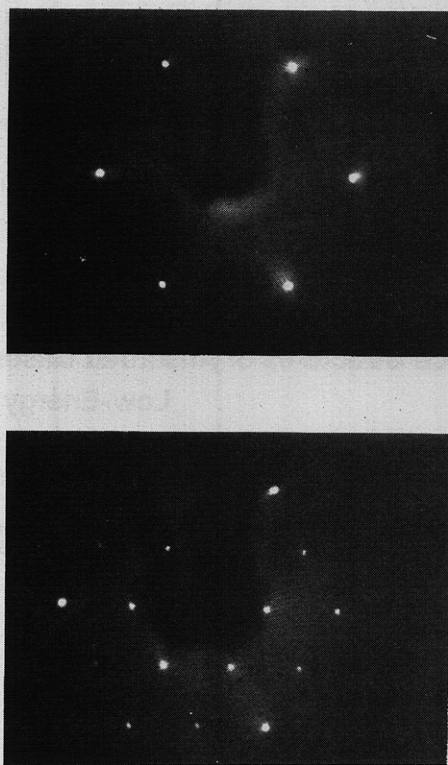


Figure 3. LEED patterns of a clean Pt(111) surface and the same surface after exposure to C_2H_2 . In both diffraction patterns the incident electron beam energy is 68 eV.

primitive surface mesh. The reciprocal unit cell vectors \vec{a}^* and \vec{b}^* are related to the real space unit cell vectors \vec{a} and \vec{b} by the following equations:

$$\vec{a}^* = (\vec{b} \times \vec{z}) / (\vec{a} \cdot \vec{b} \times \vec{z}) \quad (3a)$$

$$\vec{b}^* = (\vec{z} \times \vec{a}) / (\vec{a} \cdot \vec{b} \times \vec{z}) \quad (3b)$$

where \vec{z} is the surface normal. The relationship between the reciprocal and real space vectors is illustrated for a two-dimensional hexagonal lattice in Figure 2.

Adsorbing a gas on a surface usually results in a change in the diffraction pattern, corresponding to the appearance of a new surface mesh. This is illustrated in Figure 3 which shows a diffraction pattern of a clean Pt(111) surface and the diffraction pattern formed after the adsorption of acetylene. Figure 4 shows the unit mesh responsible for the diffraction patterns in Figure 3 superimposed on a model of the Pt(111) surface. No information concerning the location of the acetylene molecule within this unit mesh is indicated since this information can only be obtained from analysis of the diffraction spot intensities.

In order to make the transition from the diffraction pattern in Figure 3 to the surface structure in Figure 4, the adsorbate surface reciprocal mesh is referenced to the substrate reciprocal mesh. This is done by visual inspection of the diffraction pattern where the differences in spot intensities are neglected and only the positions of the diffraction beams are considered.

For the general case the relationship of adsorbate reciprocal mesh to the substrate reciprocal is given by the equations

$$\vec{a}^{*'} = m_{11}^* \vec{a}^* + m_{12}^* \vec{b}^* \quad (4a)$$

$$\vec{b}^{*'} = m_{21}^* \vec{a}^* + m_{22}^* \vec{b}^* \quad (4b)$$

where $\vec{a}^{*'}$ and $\vec{b}^{*'}$ are the vectors of the primitive adsorbate reciprocal mesh and the coefficients m_{11}^* , m_{12}^* , m_{21}^* , and m_{22}^* define the matrix

$$M^* = \begin{pmatrix} m_{11}^* & m_{12}^* \\ m_{21}^* & m_{22}^* \end{pmatrix}$$

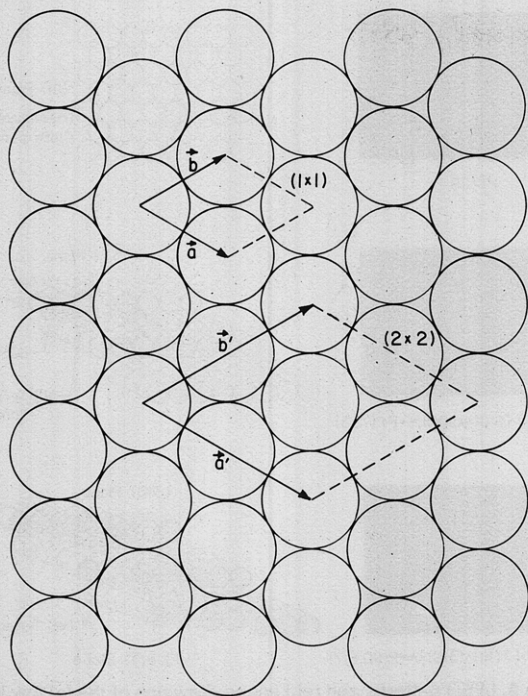


Figure 4. Real space unit cells of Pt(111)-(1X1) and Pt(111)-(2X2)-C₂H₂.

In real space the adsorbate mesh is related to the substrate mesh by the equations

$$\vec{a}' = m_{11}\vec{a} + m_{12}\vec{b} \quad (5a)$$

$$\vec{b}' = m_{21}\vec{a} + m_{22}\vec{b} \quad (5b)$$

where \vec{a}' and \vec{b}' are the vectors of the primitive adsorbate mesh and the coefficients m_{11} , m_{12} , m_{21} , and m_{22} define the matrix

$$M = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}$$

The coefficients of the two matrices M and M^* are related by the following equations:

$$m_{11} = \frac{m_{22}^*}{m_{11}^*m_{22}^* - m_{21}^*m_{12}^*} \quad (6a)$$

$$m_{12} = \frac{-m_{21}^*}{m_{11}^*m_{22}^* - m_{21}^*m_{12}^*} \quad (6b)$$

$$m_{21} = \frac{-m_{12}^*}{m_{11}^*m_{22}^* - m_{21}^*m_{12}^*} \quad (6c)$$

$$m_{22} = \frac{m_{11}^*}{m_{11}^*m_{22}^* - m_{21}^*m_{12}^*} \quad (6d)$$

so that if either M or M^* is known the other may be readily calculated. In LEED experiments M^* is determined by visual inspection of the diffraction pattern and then transformed to give M which defines the surface structure in real space.

For the case of acetylene adsorption on Pt(111) visual inspection of the LEED patterns in Figure 3 gives $M^* = \begin{pmatrix} 1/2 & 0 \\ 0 & 1/2 \end{pmatrix}$. From employing eq 6a through 6d the matrix M is found to be $\begin{pmatrix} 2 & 0 \\ 0 & 2 \end{pmatrix}$, so $\vec{a}' = 2\vec{a}$ and $\vec{b}' = 2\vec{b}$ as depicted in Figure 4.

In addition to the matrix method of denoting surface structures, another system, originally proposed by Wood,³ is also used. While the matrix notation can be applied to any system, Wood's notation can only be used when the angle between the adsorbate vectors \vec{a}' and \vec{b}' is the same as the angle between the substrate vectors \vec{a} and \vec{b} . If this condition is met, then the surface structure is labeled using the general form $(n \times m)R\Phi^\circ$ or $c(n \times m)R\Phi^\circ$, depending on whether the unit mesh is primitive or centered. In Wood's notation the adsorbate unit mesh is related to substrate

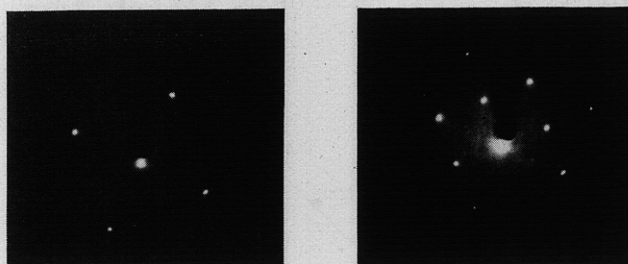


Figure 5. LEED patterns of (a) clean Rh(100) at 74 eV and (b) oxygen-covered Rh(100) at 85 eV.

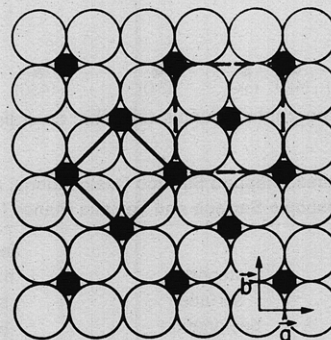


Figure 6. Real space units cells of the $(2 \times 2)R45^\circ\text{-O}$ (solid lines) and $c(2 \times 2)\text{-O}$ (dashed lines) on the Rh(100) surface.

unit mesh by the scale factors n and m where

$$|\vec{a}'| = n|\vec{a}| \quad (7a)$$

$$|\vec{b}'| = m|\vec{b}| \quad (7b)$$

$R\Phi^\circ$ indicates a rotation of the adsorbate unit mesh by Φ° from the substrate unit mesh. For $\Phi = 0$ the $R\Phi^\circ$ label is omitted, so the surface structure in Figure 4 is labeled as a (2×2) . The label for the total system refers to the type of substrate, the surface structure formed by the adsorbate and the adsorbate. The platinum-acetylene system shown in Figure 4 would be labeled as Pt(111)- $\begin{pmatrix} 2 & 0 \\ 0 & 2 \end{pmatrix}$ -C₂H₂ in matrix notation and as Pt(111)-(2 X 2)-C₂H₂ in Wood's notation. Wood's notation is more commonly used, and the matrix notation is usually only applied to systems where the angle between the adsorbate vectors differs from the angle between substrate vectors.

An example of an adsorbate which has a centered unit mesh is shown in Figures 5 and 6. In Figure 5 diffraction patterns from a clean Rh(100) surface and a Rh(100) surface after exposure to oxygen are shown. By visual inspection it can be seen that $M^* = \begin{pmatrix} 1/2 & -1/2 \\ 0 & 1/2 \end{pmatrix}$, so using eq 6a through 6d yields $M = \begin{pmatrix} -1 & 1 \\ 1 & 1 \end{pmatrix}$. M defines the primitive unit mesh of the adsorbate, which is drawn in with solid lines in Figure 6. This unit mesh is labeled as $(\sqrt{2} \times \sqrt{2})R45^\circ$ in Wood's notation. Since the centered unit mesh drawn in with dotted lines in Figure 6 also describes the adsorbate mesh, another way of labeling this structure would be $c(2 \times 2)$. The total system is labeled as Rh(100)- $\begin{pmatrix} -1 & 1 \\ 1 & 1 \end{pmatrix}$ -O, Rh(100)- $(\sqrt{2} \times \sqrt{2})R45^\circ\text{-O}$ or Rh(100)- $c(2 \times 2)\text{-O}$. Of these three labels only the first two refer to the primitive unit mesh of the oxygen surface structure.

IV. Types of Substrates Used in LEED Studies

Low Miller index surfaces of metallic single crystals are the most commonly used substrates in LEED investigations. The reasons for the widespread use of the low index surfaces are that they have the lowest surface free energy and therefore are the most stable, have the highest rotational symmetry, and are the most densely packed. Also, in the case of transition metals and semiconductors they are chemically less reactive than the

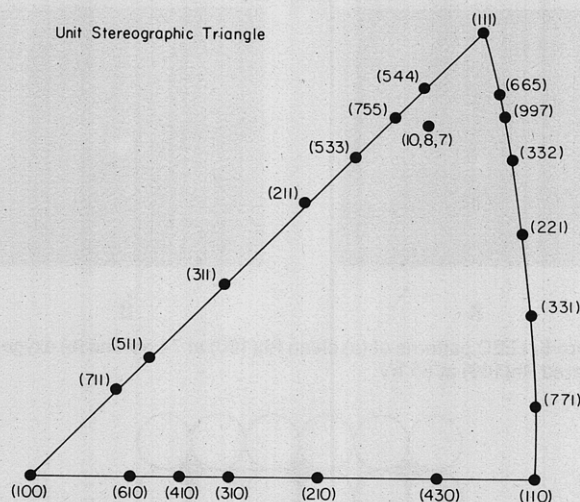


Figure 7. Unit stereographic triangle for cubic crystals.

TABLE I. Miller Indices, Stepped Surface Designations, and Angles between the Macroscopic Surface and Terrace Planes for fcc Crystals

Miller index	stepped surface designation	angle between macroscopic surface and terrace, deg
(544)	(S)-[9(111)X(100)]	6.2
(755)	(S)-[6(111)X(100)]	9.5
(533)	(S)-[4(111)X(100)]	14.4
(211)	(S)-[3(111)X(100)]	19.5
(311)	(S)-[2(111)X(100)]	29.5
(311)	(S)-[2(100)X(111)]	25.2
(511)	(S)-[3(100)X(111)]	15.8
(711)	(S)-[4(100)X(111)]	11.4
(665)	(S)-[12(111)X(111)]	4.8
(997)	(S)-[9(111)X(111)]	6.5
(332)	(S)-[6(111)X(111)]	10.0
(221)	(S)-[4(111)X(111)]	15.8
(331)	(S)-[3(111)X(111)]	22.0
(331)	(S)-[2(110)X(111)]	13.3
(771)	(S)-[4(110)X(111)]	5.8
(610)	(S)-[6(100)X(100)]	9.5
(410)	(S)-[4(100)X(100)]	14.0
(310)	(S)-[3(100)X(100)]	18.4
(210)	(S)-[2(100)X(100)]	26.6
(210)	(S)-[2(110)X(100)]	18.4
(430)	(S)-[4(110)X(100)]	8.1
(10,8,7)	(S)-[7(111)X(310)]	8.5

higher Miller index crystal faces.

The metal substrates used in the LEED experiments have either face-centered cubic (fcc), body-centered cubic (bcc), or hexagonal closed-packed (hcp) crystal structures. For the cubic metals the (111), (100), and (110) planes are the low Miller index surfaces, and they have threefold, fourfold, and twofold rotational symmetry, respectively. The top layer of a (111) surface actually has sixfold symmetry, but the rotational symmetry of the top three layers together is threefold. Since the near surface region can influence where gases adsorb on the surface and the LEED I-V curves exhibit threefold rotational symmetry at normal incidence, the (111) surface will be considered to have threefold rotational symmetry. Although most of the adsorption studies have been carried out on fcc and bcc crystals, there have also been several studies reported on hcp crystals. For hcp metals the basal or (0001) plane is the surface most frequently studied by LEED investigations, and it is the most densely packed plane having threefold rotational symmetry. Again the top layer of the (0001) surface has sixfold rotational symmetry, but the rotational symmetry of the top two layers together is threefold.

In the last few years LEED studies of high Miller index or

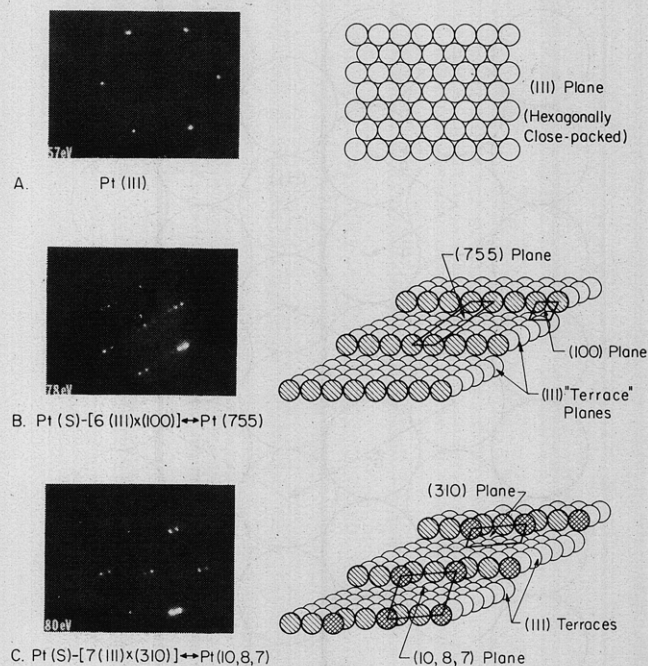


Figure 8. LEED patterns and real space drawings of the (a) low index, (b) stepped, and (c) kinked platinum surfaces.

stepped surfaces have become more frequent. Some of the first LEED studies of stepped surfaces were carried out on UO_2 crystals by Ellis and Schwobel⁴ in 1968, but only recently have there been many studies of gas adsorption on stepped surfaces. Almost all of the high Miller index surface studies have been on fcc metals, where the atomic structure of these surfaces consists of periodic arrays of terraces and steps. A nomenclature which is more descriptive of the actual surface configuration has been developed for these surfaces.⁵ Using this nomenclature a Pt(755) surface would be designated as a Pt(S)-[6(111)X(100)] surface which indicates it is a stepped surface consisting of six-atom-wide (111) terraces separated by one-atom-high (100) steps. In Table I the stepped surface nomenclature for several high Miller index surfaces of fcc crystals has been tabulated. In Figure 7 the locations of these high Miller index surfaces are shown on the unit stereographic triangle. As can be seen from that figure all the stepped surfaces which have low Miller index type steps lie on the [100], [110], and [111] zone lines. For surfaces which lie inside the unit stereographic triangle the steps themselves have steps, and this type of surface is classified as a kinked surface. The only kinked surface for which surface structures have been reported is the Pt(10,8,7) or Pt(S)-[7(111)X(310)] surface. The real space drawings and LEED patterns of the platinum (111), (755), and (10,8,7) surfaces are shown in Figure 8.

In calculating the stepped surface designations that are listed in Table I, it was assumed that the surfaces were stable in a monatomic step configuration, which is generally the case for the clean surfaces.⁶ This can readily be verified by LEED. In LEED patterns of stepped surfaces the step periodicity is superimposed on the terrace periodicity resulting in the splitting of the terrace diffraction spots into doublets or triplets at certain beam voltages. This splitting can be seen in the LEED pattern in Figure 8. The direction of the splitting is perpendicular to the step edge and the magnitude of the splitting is inversely proportional to the terrace width, so the terrace width can be obtained by measuring the splitting observed in LEED pattern. The step height can be determined from the formula

$$V_{00}(\text{singlet max}) = (150/4d^2)s^2 \quad (8)$$

where V_{00} are the voltages where a singlet intensity maximum of the (0,0) beam is observed, d is the step height, and s is an

TABLE II. Surface Structures on Substrates with Threefold Rotational Symmetry

surface	adsorbed gas	surface structure	ref		
Ag(111)	O ₂	(2×2)-O	1		
		($\sqrt{3}\times\sqrt{3}$)R30°-O	1		
		not adsorbed	146		
	I ₂	(4×4)-O	147, 148		
		($\sqrt{3}\times\sqrt{3}$)R30°-I	145, 149, 150		
	Cl ₂	($\sqrt{3}\times\sqrt{3}$)R30°-Cl	151		
		(10×10)-Cl	151		
	C ₂ H ₄ Cl ₂	AgCl(111)	152		
		($\sqrt{3}\times\sqrt{3}$)R30°-Cl	153, 154		
		(3×3)-Cl	153, 154		
	Br ₂	($\sqrt{3}\times\sqrt{3}$)R30°-Br	155		
		(3×3)-Br	155		
	Xe	hexagonal overlayer	156-160		
	Kr	hexagonal overlayer	156		
	CO+O ₂	(2× $\sqrt{3}$)-(CO+O ₂)	27		
NO	disordered	163			
Al(111)	O ₂	(4×4)-O	123		
Au(111)	O ₂	oxide	161		
		not adsorbed	162		
Be(001)	O ₂	adsorbed	162		
		disordered	22		
		disordered	22		
		not adsorbed	22		
		not adsorbed	22		
C(111), diamond	O ₂	adsorbed	16		
		not adsorbed	164		
	N ₂	not adsorbed	164		
	NH ₃	not adsorbed	164		
	H ₂ S	not adsorbed	164		
	H ₂	(1×1)-H	30		
	P	($\sqrt{3}\times\sqrt{3}$)R30°-P	30		
	C(0001), graphite	Xe	($\sqrt{3}\times\sqrt{3}$)R30°-Xe	165	
Kr		($\sqrt{3}\times\sqrt{3}$)R30°-Kr	166, 167, 174		
disordered		25			
CdS(0001)	O ₂	disordered	25		
Co(0001)	CO	($\sqrt{3}\times\sqrt{3}$)R30°-CO	168		
		hexagonal overlayer	168		
Cr(111)	O ₂	($\sqrt{3}\times\sqrt{3}$)R30°-O	169		
Cu(111)	O ₂	disordered	7, 170, 171		
		(7×7)-O	7, 8		
		($\sqrt{3}\times\sqrt{3}$)R30°-O	7, 8		
		(2×2)-O	115, 7, 8		
		(3×3)-O	8		
		(11×5)R5°-O	9		
		(2×2)R30°-O	115, 119		
		hexagonal	246		
		not adsorbed	26		
		($\sqrt{3}\times\sqrt{3}$)R30°	172, 173		
		($\sqrt{7/3}\times\sqrt{7/3}$)R49.1°	172, 173		
		(3/2×3/2)	173		
		($\sqrt{3}\times\sqrt{3}$)R30°-Cl	151		
		(6 $\sqrt{3}\times 6\sqrt{3}$)R30°-Cl	151		
		(12 $\sqrt{3}\times 12\sqrt{3}$)R30°-Cl	151		
(4 $\sqrt{7}\times 4\sqrt{7}$)R19.2°-Cl	151				
H ₂	not adsorbed	7			
H ₂ S	($\sqrt{3}\times\sqrt{3}$)R30°-S	35			
	adsorbed	35			
Xe	($\sqrt{3}\times\sqrt{3}$)R30°-Xe	159			
Cu/Ni(111)	CO	disordered	173		
		disordered	173		
Fe(111)	O ₂	(6×6)-O	175		
		(5×5)-O	175		
		(4×4)-O	175		
		(2 $\sqrt{7}\times 2\sqrt{7}$)R19.1°-O	175		
		(2 $\sqrt{3}\times 2\sqrt{3}$)R30°-O	175		
		disordered	176		
		(3×3)-N	176		
		($\sqrt{19}\times\sqrt{19}$)R23.4°-N	176		
		($\sqrt{21}\times\sqrt{21}$)R10.9°-N	176		
		H ₂	adsorbed	177	
		Ge(111)	O ₂	disordered	17, 18
				(1×1)	19, 21
				(1×1)-P	19
		P	H ₂ S	(2×2)-S	37
				(2×1)-S	178

TABLE II (Continued)

surface	adsorbed gas	surface structure	ref
Ir(111)	H ₂ Se	(2X2)-Se	37
	H ₂ O	(1X1)-H ₂ O	121, 179
	I ₂	(1X1)-I	19
	O ₂	(2X2)-O	124, 180-184
		(2X1)-O	182
		Ir oxide	181
Mo(111)	CO	($\sqrt{3} \times \sqrt{3}$)R30°-CO	124, 180, 182, 183, 185, 186
		(2 $\sqrt{3} \times 2\sqrt{3}$)R30°-CO	180, 182, 183, 185, 186
	H ₂ O	not adsorbed	182
	H ₂	adsorbed	187
	NO	(2X2)-NO	188
	O ₂	(211) facets	14, 189
Nb(111)		(110) facets	189
		(4X2)-O	190
	H ₂ S	α (4X2)-H ₂ S	191
		MoS ₂ (0001)	191
	O ₂	(2X2)-O	192
		(1X1)-O	192
Ni(111)	O ₂	(2X2)-O	2-4, 116, 193, 194, 195-198
		($\sqrt{3} \times \sqrt{3}$)R30°-O	2, 5, 195
		($\sqrt{3} \times \sqrt{21}$)-O	116
		NiO(111)	4, 6, 116, 193, 194
	CO	($\sqrt{3} \times \sqrt{3}$)R30°-CO	195, 196, 199, 200
		hexagonal overlayer	200
		(2X2)-CO	3
		($\sqrt{3} \times \sqrt{3}$)R30°-O	5
		(2X $\sqrt{3}$)-CO	5
		($\sqrt{39} \times \sqrt{39}$)-C	5, 27
		disordered	198
		($\sqrt{7} \times \sqrt{7}$)R19.1°	195, 196
		α (4X2)	195, 196
	CO ₂	(2X2)-CO ₂	5
		($\sqrt{3} \times \sqrt{3}$)R30°-O	5
		(2X $\sqrt{3}$)-CO ₂	5
		($\sqrt{39} \times \sqrt{39}$)-C	5, 27
	H ₂	(1X1)-H	3
		(2X2)-H	29, 201, 202, 204
		disordered	203
	NO	α (4X2)-NO	193
		hexagonal overlayer	193
		(2X2)-O	193
		(6X2)-N	193
H ₂ S	(2X2)-S	36, 118, 197, 198, 205, 294	
	($\sqrt{3} \times \sqrt{3}$)R30°-S	36, 118	
	(5X5)-S	36	
	adsorbed	36	
H ₂ Se	(2X2)-Se	137	
	($\sqrt{3} \times \sqrt{3}$)R30°-Se	137	
Cl ₂	($\sqrt{3} \times \sqrt{3}$)R30°-Cl	206	
	($\frac{2}{4}$)-Cl	206	
N ₂	not adsorbed	131	
Pd(111)	O ₂	(2X2)-O	207
		($\sqrt{3} \times \sqrt{3}$)R30°-O	207
		(2X2)-PdO	207
	NO	α (4X2)-NO	208
		(2X2)-NO	208
	CO	($\sqrt{3} \times \sqrt{3}$)R30°-CO	209, 210
		hexagonal overlayer	209
		α (4X2)-CO	210
	H ₂	(1X1)-H	211, 212
	O ₂	(2X2)-O	10, 11, 213-217
Pt(111)		($\sqrt{3} \times \sqrt{3}$)-R30°-O	214, 215, 217
		not adsorbed	120
		(4 $\sqrt{3} \times 4\sqrt{3}$)R30°-O	214, 215
		PtO ₂ (0001)	214, 215
		(3X15)-O	217
	CO	($\sqrt{3} \times \sqrt{3}$)R30°-CO	218
		α (4X2)-CO	28, 120, 218, 219
		hexagonal overlayer	218

TABLE II (Continued)

surface	adsorbed gas	surface structure	ref
		(2×2)-CO	120
	H ₂	not adsorbed	120
		adsorbed	220, 221
	H ₂ +O ₂	($\sqrt{3}\times\sqrt{3}$)/R30°	11
	NO	disordered	222
	H ₂ O	($\sqrt{3}\times\sqrt{3}$)/R30°-H ₂ O	223, 224
		H ₂ O(111)	224
	S ₂	(2×2)-S	225-227, 247
		($\sqrt{3}\times\sqrt{3}$)/R30°-S	225-227, 247
		($\begin{smallmatrix} 4 & -1 \\ -1 & 2 \end{smallmatrix}$)-S	225, 226
		hexagonal	227
	N	disordered	228
Re(0001)	O ₂	(2×2)-O	23, 24, 229
	CO	not adsorbed	24
		(2×2)-CO	23
		disordered	230
		(2× $\sqrt{3}$)	230
	H ₂	not adsorbed	24
	N ₂	not adsorbed	24
Rh(111)	O ₂	(2×2)-O	12, 231
	CO	($\sqrt{3}\times\sqrt{3}$)/R30°-CO	231
		(2×2)-CO	12, 231
	CO ₂	($\sqrt{3}\times\sqrt{3}$)/R30°-CO	231
		(2×2)-CO	231
	H ₂	adsorbed	231
	NO	α (4×2)-NO	231
		(2×2)-NO	231
Ru(0001)	O ₂	(2×2)-O	12, 232, 248
	CO	($\sqrt{3}\times\sqrt{3}$)/R30°-CO	12, 233, 248
		(2×2)-CO	12, 248
	CO ₂	($\sqrt{3}\times\sqrt{3}$)/R30°-CO ₂	12
		(2×2)-CO ₂	12
	H ₂	(1×1)-H	234
	N ₂	adsorbed	234
	NH ₃	(2×2)-NH ₃	234, 235
		($\sqrt{3}\times\sqrt{3}$)/R30°-NH ₃	235
Si(111)	O ₂	disordered	17, 20, 21
	N ₂	(8×8)-N	34
	P	(6 $\sqrt{3}\times 6\sqrt{3}$)-P	132, 133
		(1×1)-P	132
		(2 $\sqrt{3}\times 2\sqrt{3}$)-P	132
		(4×4)-P	133
	Cl ₂	disordered	138
		(7×7)-Cl	138, 236
		(1×1)-Cl	138, 236
	I ₂	(1×1)-I	133
	H ₂	(1×1)-H	237
		(7×7)-H	237
	NH ₃	(8×8)-N	238
	PH ₃	(7×7)-P	239
		(1×1)-P	239
		(6 $\sqrt{3}\times 6\sqrt{3}$)-P	239
		(2 $\sqrt{3}\times 2\sqrt{3}$)-P	239
Ti(0001)	O ₂	(1×1)-O	18
	CO	(1×1)-CO	18, 240
		(2×2)-CO	240
	N ₂	(1×1)-N	241, 242
		($\sqrt{3}\times\sqrt{3}$)/R30°-N	241, 242
Th(111)	O ₂	disordered	243
		ThO ₂ (111)	243
	CO	disordered	243
		ThO ₂ (111)	243
UO ₂ (111)	O ₂	(3×3)-O	13
		(2 $\sqrt{3}\times 2\sqrt{3}$)/R30°-O	13
W(111)	O ₂	disordered	244
		(211) facets	15
Zn(0001)	O ₂	(1×1)-O	122
		ZnO(0001)	245
Zn(000 $\bar{1}$)	O ₂	($\sqrt{3}\times\sqrt{3}$)/R30°-O	122

TABLE III. Surface Structures on Substrates with Fourfold Rotational Symmetry

surface	adsorbed gas	surface structure	ref		
Ag(100)	O ₂	disordered	146		
	C ₂ H ₄ Cl ₂	$\alpha(2 \times 2)$ -Cl	154, 249		
	Se	$\alpha(2 \times 2)$ -Se	250		
Al(100)	O ₂	disordered	42-44		
Au(100)	H ₂ S	(2×2) -S	251		
		$\alpha(2 \times 2)$ -S	251		
		(6×6) -S	251		
		$\alpha(4 \times 4)$ -S	251		
		CO	disordered	252	
		Xe	disordered	252	
		O ₂	disordered	16	
C(100), diamond	N ₂	not adsorbed	164		
		not adsorbed	164		
		not adsorbed	164		
		not adsorbed	164		
		not adsorbed	164		
		not adsorbed	164		
Co(100)	CO	$\alpha(2 \times 2)$ -CO	253		
		(2×2) -C	253		
		O ₂	(2×2) -O	254	
		$\alpha(2 \times 2)$ -O	254		
		$\alpha(2 \times 2)$ -O	255		
Cr(100)	O ₂	Cr ₂ O ₃ (310)	256		
		(1×1) -O	9, 45		
		(2×1) -O	9, 45, 46		
Cu(100)	O ₂	$(2 \times 4)R45^\circ$ -O	7, 47, 246, 261		
		(2×3) -O	119		
		$\alpha(4 \times 4)$ -O	119		
		$\alpha(2 \times 2)$ -O	171, 246, 257-260, 263, 264		
		(2×2)	171		
		$(2 \times 2\sqrt{2})R45^\circ$	259, 262-264		
		hexagonal	259		
		(410) facets	259		
		CO	$\alpha(2 \times 2)$ -CO	125, 126, 265	
		hexagonal overlayer	126, 127, 265		
		(2×2) -C	26, 125		
		N ₂	(1×1) -N	49	
		$\alpha(2 \times 2)$ -N	47, 132, 258, 261, 266		
		H ₂ S	adsorbed	35	
			(2×2) -S	35, 260, 262	
(2×1) -S	128				
Te	(2×2) -Te	267			
Xe	hexagonal overlayer	159			
Fe(100)	O ₂	$\alpha(2 \times 2)$ -O	60, 269-271, 274		
		(1×1) -O	144, 268, 271, 272		
		FeO(100)	60, 269, 270, 272, 273		
		FeO(111)	270		
		FeO(110)	272		
		disordered	273, 276		
		CO	$\alpha(2 \times 2)$ -CO	275	
		H ₂ S	$\alpha(2 \times 2)$ -S	276, 277	
		H ₂	adsorbs	177	
		NH ₃	disordered	176	
		$\alpha(2 \times 2)$ -N	176		
		$\alpha(2 \times 2)$	278		
		Fe/Cr(100)	O ₂	$\alpha(2 \times 2)$ -O	279
				$\alpha(4 \times 4)$ -O	279
Oxide	280				
Ge(100)	O ₂	disordered	17, 18		
		(3×3) -I	19		
Ir(100)	O ₂	(2×1) -O	48, 281		
		(5×1) -O	48		
		$\alpha(2 \times 2)$ -CO	48		
		(2×2) -CO	48		
	CO	(1×1) -CO	282		
		$\alpha(2 \times 2)$ -CO ₂	48		
		(2×2) -CO ₂	48		
		(7×20) -CO ₂	48		
		(1×1) -NO	188		
		adsorbed	281		
	Kr	(3×5) -Kr	283		
		Kr(111)	283		
		disordered	61, 62		
	Mo(100)	O ₂	$\alpha(2 \times 2)$ -O	61-64, 284	
$(\sqrt{5} \times \sqrt{5})R26^\circ$ -O			61, 62, 189, 190, 284		

TABLE III (Continued)

surface	adsorbed gas	surface structure	ref
		(2X2)-O	61, 189, 190
		$\alpha(4X4)$ -O	62, 189, 284
		(2X1)-O	189, 190
		(6X2)-O	284
		(3X1)-O	284
		(1X1)-O	284
	CO	disordered	62
		(1X1)-CO	62, 64, 285, 286
		$\alpha(2X2)$ -CO	64, 285, 286
		(4X1)-CO	64
	H ₂	$\alpha(4X2)$ -H	77
		(1X1)-H	77
	N ₂	(1X1)-N	62
		$\alpha(2X2)$ -N	287
	H ₂ S	(1X1)-S	130
		($\sqrt{5} \times \sqrt{5}$)-S	130, 288
		$\alpha(2X2)$ -S	130
		MoS ₂ (100)	288
NaCl(100)	Xe	hexagonal overlayer	289
Nb(100)	O ₂	$\alpha(2X2)$ -O	192, 290
		(1X1)-O	192, 290
		(3X10)-NbO ₂	290
	N ₂	(5X1)-N	290
Ni(100)	O ₂	(2X2)-O	2, 49-51, 198, 296-299, 310
		$\alpha(2X2)$ -O	2, 6, 52-57, 197, 198, 290-299, 310, 340
		(2X1)-O	198
		NiO(100)	6, 297-299, 310
		NiO(111)	298, 299
	CO	$\alpha(2X2)$ -CO	54, 55, 68, 129, 198, 300-302
		(2X2)-CO	69
		hexagonal overlayer	129, 301, 302
		(2X2)-C	198
	CO ₂	(2X2)-O + $\alpha(2X2)$ -CO	76
	N ₂	not adsorbed	80, 81
	H ₂	disordered	198, 203, 211
		$\alpha(2X2)$ -H	301
	CO + H ₂	$\alpha(3X3)$	301
	H ₂ S	(2X2)-S	36, 118, 197, 198
		$\alpha(2X2)$ -S	36, 118, 197, 198, 293, 294, 303, 304, 340
		(2X1)-S	198
		$\alpha(2X2)$ -H ₂ S	304
	H ₂ Se	(2X2)-Se	197, 198
		$\alpha(2X2)$ -Se	142, 197, 198, 293, 294, 305, 340
		(2X1)-Se	198
		$\alpha(4X2)$ -Se	305
	Te	(2X2)-Te	197, 198, 306
		$\alpha(2X2)$ -Te	197, 198, 294, 305, 340
		(2X1)-Te	198
		$\alpha(4X2)$ -Te	305, 306
	SO ₂	$\alpha(2X2)$ -SO ₂	86
		(2X2)-SO ₂	86
NiO(100)	H ₂	adsorbed	307
		Ni(100)	307
	H ₂ S	Ni(100)-C(2X2)-S	308
	Cl ₂	disordered	309
Pd(100)	CO	disordered	70
		$\alpha(4X2)$ -CO	70
		$\alpha(2X2)$ -CO	210
		(2X4)R45°-CO	71, 209, 210
		hexagonal overlayer	209, 210
	Xe	hexagonal overlayer	311
Pt(100)	O ₂	not adsorbed	120, 312
		adsorbed	312, 315
		($2\sqrt{2} \times 2\sqrt{2}$)R45°-O	215, 313
		PtO ₂ (0001)	215
		(5X1)-O	315
		(2X1)-O	315
	CO	$\alpha(4X2)$ -CO	28, 72, 73, 120, 314, 316
		($3\sqrt{2} \times \sqrt{2}$)R45°-CO	28, 72, 73, 316
		($\sqrt{2} \times \sqrt{5}$)R45°-CO	72, 73
		(2X4)-CO	10

TABLE III (Continued)

surface	adsorbed gas	surface structure	ref
		(1X3)-CO	10
		(1X1)-CO	120, 312, 314, 316
		$\alpha(2 \times 2)$ -CO	312, 316
	H ₂	adsorbed	312, 317
		(2X2)-H	72, 74
		not adsorbed	312
	CO+H ₂	$\alpha(2 \times 2)$ -(CO+H ₂)	72, 74
	NO	(1X1)-NO	318
		$\alpha(4 \times 2)$ -NO	319
	N	disordered	228
	H ₂ S	(2X2)-S	247, 320
		$\alpha(2 \times 2)$ -S	247, 320, 321
	S ₂	(2X2)-S	225, 226
		$\alpha(2 \times 2)$ -S	225, 226
Rh(100)	O ₂	(2X2)-O	231
		$\alpha(2 \times 2)$ -O	231
		$\alpha(2 \times 8)$ -O	58
	CO	$\alpha(2 \times 2)$ -CO	231
		hexagonal overlayer	231
		(4X1)-CO	58
	CO ₂	$\alpha(2 \times 2)$ -CO	231
		hexagonal overlayer	231
	H ₂	adsorbed	231
	NO	$\alpha(2 \times 2)$ -NO	231
Si(100)	O ₂	(1X1)-O	17, 18, 20
		(111) facets	17, 18, 20
	H ₂	(1X1)-H	322-324
		(2X1)-H	237
		(1X1)-H	325
		(2X2)-H	325
	NH ₃	(111) facets	238
	I ₂	(3X3)-I	326
Sr(100)	O ₂	SrO(100)	327
Ta(100)	O ₂	(2X8/9)-O	328
		$\alpha(3 \times 1)$ -O	328
		(4X1)-O	328
	CO	$\alpha(3 \times 1)$ -O	328
	CO ₂	$\alpha(3 \times 1)$ -O	328
	NO	$\alpha(3 \times 1)$ -O	328
	N ₂	adsorbed	328
Th(100)	O ₂	disordered	329
		ThO ₂	329
	CO	disordered	329
V(100)	O ₂	(1X1)-O	65
		(2X2)-O	65
	H ₂	disordered	65
W(100)	O ₂	disordered	330
		(4X1)-O	66, 330-333, 336
		(2X2)-O	330-334
		(2X1)-O	66, 67, 330-336
		(3X3)-O	331, 333, 335
		$\alpha(2 \times 2)$ -O	333
		$\alpha(8 \times 2)$ -O	333
		(3X1)-O	333
		(1X1)-O	333
		(8X1)-O	333
		(4X4)-O	333, 335
		(110) facets	333
	CO	disordered	75
		$\alpha(2 \times 2)$ -CO	66, 75
	H ₂	$\alpha(2 \times 2)$ -H	66, 78, 79, 337, 411
		(2X5)-H	79
		(4X1)-H	79
		(1X1)-H	411
	CO ₂	disordered	338
		(2X1)-O	338
		$\alpha(2 \times 2)$ -CO	338
	NO	(2X2)-NO	339
		(4X1)-NO	339
		(2X2)-O	339
		(4X1)-O	339
		(2X1)-O	339

TABLE III (Continued)

surface	adsorbed gas	surface structure	ref
	N ₂	$\alpha(2 \times 2)$ -N	68, 82, 131
	NH ₃	disordered	84
		$\alpha(2 \times 2)$ -NH ₂	84
		(1X1)-NH ₂	84
	N ₂ O	(1X1)-N ₂ O	143
		(4X1)-N ₂ O	143
	CO+N ₂	(4X1)-(CO+N ₂)	82

TABLE IV. Surface Structures on Substrates with Twofold Rotational Symmetry

surface	adsorbed gas	surface structure	ref	surface	adsorbed gas	surface structure	ref
Ag(110)	O ₂	(2X1)-O	146, 341-344	Ir(110)	O ₂	(1X2)-O	347
		(3X1)-O	146, 341-343		CO	(2X2)-CO	347, 348
		(4X1)-O	146, 341, 342			(4X2)-CO	348
		(5X1)-O	146, 341		H ₂	adsorbed	347
		(6X1)-O	146, 341		N ₂	not adsorbed	347
		(7X1)-O	146	LaB ₈ (110)	O ₂	(1X1)-O	349
	NO	disordered	345	Mo(110)	O ₂	(2X2)-O	62, 63, 100
	C ₂ H ₄ Cl ₂	(2X1)-Cl	154			(2X1)-O	62, 63, 100
		$\alpha(4 \times 2)$ -Cl	154			(1X1)-O	62, 63
	Xe	hexagonal overlayer	159			disordered	350
Al(110)	O ₂	(331) facets	123		CO	(1X1)-CO	62, 100
		(111) facets	122			$\alpha(2 \times 2)$ -CO	94
Au(110)	H ₂ S	(1X2)-S	251		CO ₂	disordered	94
		$\alpha(4 \times 2)$ -S	251		H ₂	adsorbed	100
C(110), diamond	O ₂	not adsorbed	164		N ₂	(1X1)-N	62
	N ₂	not adsorbed	164		H ₂ S	(2X2)-S	351
	NH ₃	not adsorbed	164			$\alpha(2 \times 2)$ -S	351
	H ₂ S	not adsorbed	164			(1X1)-S	351
Cr(110)	O ₂	(3X1)-O	140			$\alpha(1 \times 3)$ -S	351
		(100) facets	140, 256			$\alpha(1 \times 5)$ -S	351
		Cr ₂ O ₃ (0001)	140, 256			(1X3)-S	351
Cu(110)	O ₂	(2X1)-O	7-9, 45, 46, 246			$\alpha(1 \times 7)$ -S	351
		$\alpha(6 \times 2)$ -O	8, 9, 45, 46, 246			(1X4)-S	351
		(5X3)-O	8, 115			(1X5)-S	351
	CO	ordered 1D	26			$\alpha(1 \times 11)$ -S	351
		(2X3)-CO	26			$(-\frac{2}{1} \frac{2}{1})$ -S	351
		(2X1)-CO	255	Mo(211)	O ₂	(2X1)-O	105
		hexagonal overlayer	255			(1X2)-O	105
						(1X3)-O	105
	H ₂	not adsorbed	7			$\alpha(4 \times 2)$ -O	105
	H ₂ O	disordered	26		CO	disordered	105
	H ₂ S	$\alpha(2 \times 3)$ -S	35		H ₂	(1X2)-H	105
		adsorbed	35		N ₂	not adsorbed	105
	Xe	$\alpha(2 \times 2)$ -Xe	159	Na(110)	O ₂	NaO(111)	352
		hexagonal overlayer	159	Nb(110)	O ₂	(3X1)-O	101
Cu/Ni(110)	O ₂	(2X1)-O	134			NbO(111)	192
	CO	(2X1)-CO	134			NbO(110)	192
		(2X2)-CO	134			NbO(220)	192
	H ₂ S	$\alpha(2 \times 2)$ -S	134			oxide	101
Fe(110)	O ₂	$\alpha(2 \times 2)$ -O	87, 88, 99		CO	disordered	101
		$\alpha(3 \times 1)$ -O	87, 88, 99			(3X1)-O	101
		(2X8)-O	98			(1X1)-H	111
		FeO(111)	87, 88, 99, 269	Ni(110)	O ₂	(2X1)-O	2, 3, 51, 57, 83, 89-92, 99, 198, 353-355
		(2X1)-O	141				2, 51, 83, 89, 91, 92, 94, 198, 353-355
	CO	$(\frac{3}{0} -\frac{2}{4})$ -CO	346			(3X1)-O	2, 51, 83, 89, 91, 92, 94, 198, 353-355
	N ₂	$(\frac{3}{0} -\frac{2}{4})$ -N ₂	346				2, 89
	H ₂	(2X1)-H	177			(5X1)-O	51, 354, 355
		(3X1)-H	177			NiO(100)	6, 51, 83, 91, 198, 354, 355
		(1X1)-H	177				2, 94
	H ₂ S	(2X4)-S	114			(1X1)-CO	198
		(1X2)-S	114		CO	$\alpha(2 \times 1)$ -CO	353, 356, 359
Fe/Cr(110)	O ₂	Cr ₂ O ₃ (0001)	280			(2X1)-CO	356-358
		amorphous oxide	279			$\alpha(2 \times 2)$ -CO	359
Ge(110)	O ₂	disordered	17, 18				
		(1X1)-O	17, 18				
	H ₂ S	(10X5)-S	178				

TABLE IV (Continued)

adsorbed				adsorbed				
surface	gas	surface structure	ref	surface	gas	surface structure	ref	
Pd(110)	H ₂	(4X2)-CO	359	Si(110)	H ₂	(1X1)-H	375	
		(1X2)-H	59, 81, 94, 110, 198, 203, 353, 360	Si(311)	NH ₃	adsorbed	238	
	NO	(2X3)-N	361	Ta(100)	O ₂	(3X1)-O	101, 102	
		(2X1)-O	361			oxide	101, 102	
	H ₂ O	(2X1)-H ₂ O	110		CO	disordered	101, 102	
	H ₂ S	α (2X2)-S	36, 198, 205, 294			(3X1)-O	101, 102	
		(3X2)-S	36		H ₂	(1X1)-H	102	
	H ₂ Se	α (2X2)-Se	137	Ta(211)	N ₂	not adsorbed	101	
		CO+O ₂	(3X1)-(CO+O ₂)	91		O ₂	(3X1)-O	101, 102
	O ₂	(1X3)-O	95			oxide	101, 102	
		(1X2)-O	95		CO	disordered	101, 102	
	CO	α (2X4)-O	95			(3X1)-O	102	
		(5X2)-CO	95		H ₂	(1X1)-H	102	
		(2X1)-CO	95, 209		N ₂	disordered	102	
		(4X2)-CO	209			(311) facets	102	
α (2X2)-CO		209		TiO ₂ (100)	O ₂	disordered	376	
Pt(110)	H ₂	(1X2)-H	212		H ₂ O	disordered	376	
		(2X1)-O	11, 363	V(110)	O ₂	(3X1)-O	101	
	O ₂	(4X2)-O	11		CO	disordered	101	
		adsorbed	362			(3X1)-O	101	
	α (2X2)-O	PtO(100)	363	W(110)	O ₂	(2X1)-O	57, 103, 377-387	
			363			α (2X2)-O	104	
	CO	(1X1)-CO	139, 364			(2X2)-O	104, 387	
		(2X1)-CO	366			(1X1)-O	104	
	C ₃ O ₂	(1X1)-C ₃ O ₂	365			α (14X7)-O	57, 103, 104	
	NO	(1X1)-NO	222, 364			α (21X7)-O	104	
	CO+NO	(1X1)-(CO+NO)	364			α (48X16)-O	104	
		H ₂ S	α (2X6)-S	247, 367, 368		WO ₃ (100)	388	
	Rh(110)	O ₂	(2X3)-S	247, 367, 368		WO ₃ (111)	388	
			(4X3)-S	247, 367, 368		CO	disordered	109
		(4X4)-S	α (2X4)-S	247, 367, 368			α (9X5)-CO	109
disordered			247, 367			(1X1)-CO	379	
O ₂		(1X3)-O	96, 97			α (2X2)-CO	379	
		α (2X4)-O	96, 97			(2X7)-CO	389	
α (2X8)-O		(2X2)-O	96, 97			α (4X1)-CO	389	
		(2X3)-O	96, 97			(3X1)-CO	389	
(1X2)-O		(4X1)-CO	96, 97			(4X1)-CO	389	
		(1X3)-O	96, 97			(5X1)-CO	389, 390	
CO		(2X1)-CO	369			(2X1)-(C+O)	389, 390	
		α (2X2)-C	369			α (9X5)-(C+O)	389	
Ru(10 $\bar{1}0$)		O ₂	(2X1)-CO	370, 371		CO+O ₂	α (11X5)- (CO+O ₂)	93
			α (4X2)-O	370, 371		H ₂	(2X1)-H	136
		(2X1)-O	α (2X6)-O	370		I ₂	(2X2)-I	391
	(7X1)-O		370			(2X1)-I	391	
	α (4X8)-O	(7X1)-O	370	W(211)	O ₂	(2X1)-O	15, 106- 108, 403, 404	
		disordered	371			(1X2)-O	15, 106, 404	
	H ₂	not adsorbed	371			(1X1)-O	106, 107, 403, 404	
	N ₂	not adsorbed	371			(1X3)-O	106	
		α (4X2)-(N+O)	370, 371			(1X4)-O	106, 404	
	(2X1)-(N+O)	(2X1)-O	371			CO	disordered	108
		α (4X2)-O	371				α (6X4)-CO	108
	α (2X6)-O	α (4X2)-O	371				(2X1)-CO	108
		(7X1)-O	370				α (2X4)-CO	108
	CO	(7X1)-O	370			H ₂	(1X1)-H	112
		α (4X8)-O	370			NH ₃	α (4X2)-NH ₂	113
(2X1)-N	(2X1)-N	371			CO+O ₂	(1X1)-(CO+O ₂)	108	
	α (4X2)-N	371				(1X2)-(CO+O ₂)	108	
Ru(101)	O ₂	$\begin{pmatrix} 1 & 1 \\ 3 & 0 \end{pmatrix}$ -O	374	W(210)	CO	(2X1)-CO	138	
		$\begin{pmatrix} 5 & 1 \\ 6 & 0 \end{pmatrix}$ -O	374			(1X1)-CO	138	
	CO	$\begin{pmatrix} 4 & 1 \\ 9 & 0 \end{pmatrix}$ -O	374		N ₂	(2X1)-N	131	
		$\begin{pmatrix} 1 & 1 \\ 3 & 0 \end{pmatrix}$ -CO	372	W(310)	N ₂	(2X1)-N	131	
	NO	$\begin{pmatrix} 1 & 1 \\ 2 & 0 \end{pmatrix}$ -C	372	ZnO(10 $\bar{1}0$)	O ₂	α (2X2)-N	131	
disordered		373			(1X1)-O	392		

integer. By combining the terrace width and step height with the angle between the terrace and step planes, the macroscopic surface plane can be determined. This calculated macroscopic surface can then be compared with back reflection Laue X-ray diffraction results for the same surface.

The stepped surface nomenclature has mainly been used for fcc metals, but there are a few studies where it has been applied to bcc and hcp metals. In these investigations the surfaces had fairly low step densities so the macroscopic surface was within a few degrees of a low index face.

TABLE V. Surface Structures on Stepped Substrates

surface	adsorbed gas	surface structure	ref	surface	adsorbed gas	surface structure	ref
Ag(211)	Xe	hexagonal overlayer	159		H ₂	2(1d)-H	120, 221
Ag(331)	O ₂	disordered	393			adsorbed	396
		Ag(110)-(2X1)-O	393			Pt(S)-[12(111)X2(100)]	396
	Cl ₂	(6X1)-Cl	393	Pt(S)-[9(111)X(100)]	H ₂	2(1d)-H	221
Au(S)-[6(111)X(100)]	O ₂	oxide	161	Pt(S)-[9(111)X(111)]	O ₂	(2X2)-O	397-399
Cu(210)	O ₂	(410),(530) facets	259			not adsorbed	120
Cu(211)	Xe	hexagonal overlayer	156		CO	disordered	120
	Kr	hexagonal overlayer	156		H ₂	(2X2)-H	120
Cu(311)	Xe	hexagonal overlayer	394			adsorbed	400
	CO	adsorbed	394	Pt(S)-[12(111)X(111)]	NO	(2X2)-NO	401
Cu(841)	O ₂	(410),(100) facets	259		NH ₃	disordered	401
Cu(S)-[3(100)X(100)]	CO	not adsorbed	132	Re(S)-[14(0001)-X(1011)]	CO	(2X2)-CO	230
	N ₂	(1X2)-N	132			(2X1)-C	230
Cu(S)-[4(100)X(100)]	O ₂	(1X1)-O	132			2(1d)-O	402
	CO	not adsorbed	132	Rh(331)	O ₂	($\frac{1}{2}$ $\frac{2}{3}$)-O	402
	N ₂	(1X3)-N	132			($\frac{1}{7}$ $\frac{2}{7}$)-O	402
Cu(S)-[4(100)X(111)]	H ₂ S	8(1d)-S	35			facets	402
Ir(S)-[6(111)X(100)]	O ₂	(2X1)-O	182		CO	($\frac{1}{3}$ $\frac{2}{3}$)-CO	402
	CO	disordered	182			($\frac{1}{2}$ $\frac{2}{3}$)-CO	402
	H ₂ O	not adsorbed	182			hexagonal overlayer	402
	H ₂	adsorbed	187		CO ₂	($\frac{1}{3}$ $\frac{2}{3}$)-CO	402
Ni(210)	O ₂	facets	395			($\frac{1}{2}$ $\frac{2}{3}$)-CO	402
	N ₂	Ni(100)- (6√2X√2)R45°-N	395			hexagonal overlayer	402
		Ni(110)-(2X3)-N	395		H ₂	adsorbed	402
Pd(210)	CO	(1X1)-CO	209, 210		NO	disordered	402
		(1X2)-CO	209, 210			($\frac{1}{3}$ $\frac{1}{3}$)-O	402
Pd(311)	CO	(2X1)-CO	209	Rh(S)-[6(111)X(100)]	O ₂	(2X2)-O	402
		3(1d)-CO	209			Rh(S)-[12(111)X- 2(100)]-(2X2)-O	402
Pd(S)-[9(111)X(111)]	CO	(√3X√3)R30°-CO	209			Rh(111)-(2X2)-O	402
		hexagonal overlayer	209		CO	(√3X√3)-R30°-CO	402
Pt(S)-[4(111)X(100)]	H ₂	facets	221			(2X2)-CO	402
Pt(S)-[6(111)-(100)]	O ₂	2(1d)-O	120		CO ₂	(√3X√3)-R30°-CO	402
		Pt(111)-(2X2)-O	215			(2X2)-CO	402
		Pt(111)-	215		H ₂	adsorbed	402
		(√3X√3)R30°-O			NO	(2X2)-NO	402
		Pt(111)-	215	W(S)-[6(110)X(110)]	O ₂	(2X1)-O	382
		(√79X√79)- R18°7'-O		W(S)-[8(110)X(112)]	O ₂	(2X1)-O	382
		Pt(111)-(4X2√3)- R30°-O	215	W(S)-[10(110)X(011)]	O ₂	(2X1)-O	405
		Pt(111)-3(1d)-O	215	W(S)-[12(110)X(110)]	O ₂	(2X1)-O	382
	CO	disordered	120	W(S)-[16(110)X(112)]	O ₂	(2X1)-O	382
				W(S)-[24(110)X(011)]	O ₂	(2X1)-O	405

The stability of stepped surfaces is an important consideration in LEED studies. Although these surfaces have higher surface free energies than the low index faces, most of the clean stepped surfaces are stable in a single step height configuration from room temperature to the melting point of the metals.⁶ When gases are adsorbed on these surfaces, however, their stability can noticeably change. Some surfaces reconstruct, forming multiple height steps and large terraces. Other high index surfaces form large low index facets while some retain the single step height configuration. In one study several high Miller index surfaces of platinum have been investigated to determine their stability when clean, oxygen covered, and carbon covered.⁶

There have been several LEED studies on semiconductor surfaces such as Ge and Si. For clean semiconductor surfaces reconstruction is the rule rather than the exception. In fact, on some surfaces such as Si(111) by changing the temperature different reconstructed surfaces are observed.⁷ A few studies have been carried out on metal oxide substrates. There have been studies on the epitaxial growth of metal oxides on metal single crystals. This is generally carried out by exposing the metal crystal to oxygen at a temperature sufficiently high enough to promote oxide growth. There has been a LEED study of Xe adsorbed on NaCl, but because of severe electron beam damage on the alkali halide substrates, very little work has been done using ionic crystal surfaces.

V. Surface Structures of Adsorbates

Tables II-VI list the surface structures observed in LEED experiments when various gasses are adsorbed on surfaces. Because of a large increase in the number of studies of organic molecule adsorption and adsorption studies on stepped surfaces, separate tables for these two categories have been made. Tables II-VI contain over 800 surface structures.

The surface structures of gases adsorbed on substrates of threefold, fourfold, and twofold rotational symmetry are listed in Tables II, III, and IV, respectively. Most of the substrates in these tables are low index faces and the gases adsorbed are, for the most part, small inorganic molecules such as H₂, O₂, N₂, CO, and NO. Inspection of the tables permits one to propose two general rules that are usually obeyed during the adsorption of these small molecules: (1) the observed surface structures have the same rotational symmetry as the substrate, and (2) the unit cell of the surface structure is the smallest allowed by the molecular dimensions and adsorbate-adsorbate interactions. There is a definite trend for an adsorbate to form identical surface structures on the same crystal face of several different substrates. For example, oxygen forms a (2X2) structure on the hexagonal faces of Ag, Cu, Ir, Nb, Ni, Pd, Pt, Re, Rh, and Ru. CO initially forms a (√3X√3)R30° surface structure on most hexagonal metal surfaces and then compresses into a close-

TABLE VI. Surface Structures Formed by Adsorption of Organic Compounds

surface	adsorbed gas	surface structure	ref	
Ag(110)	HCN	disordered	407	
	C ₂ N ₂	disordered	407	
Au(111)	C ₂ H ₄	not adsorbed	161	
	<i>n</i> -heptane	not adsorbed	161	
	cyclohexene	not adsorbed	161	
	benzene	not adsorbed	161	
	naphthalene	disordered	161	
Au(S)-[6(111)X(100)]	C ₂ H ₄	not adsorbed	161	
	<i>n</i> -heptane	not adsorbed	161	
	cyclohexene	not adsorbed	161	
	benzene	not adsorbed	161	
	naphthalene	disordered	161	
Cu(111)	C ₂ H ₄	not adsorbed	26	
	Fe-phthalocyanine	adsorbed	408	
	Cu-phthalocyanine	adsorbed	408	
	H-phthalocyanine	adsorbed	408	
	glycine	(8X8)	409	
	L-alanine	(2√13X2√13)R13°40'	409	
	L-tryptophan	($\begin{smallmatrix} 7 & 1 \\ -2 & 4 \end{smallmatrix}$)	409	
	D-tryptophan	($\begin{smallmatrix} -8 & 1 \\ -2 & 4 \end{smallmatrix}$)	409	
	Cu(100)	C ₂ H ₄	(2X2)	26
		Fe-phthalocyanine	($\begin{smallmatrix} 5 & -2 \\ 2 & 5 \end{smallmatrix}$)	408
Cu-phthalocyanine		($\begin{smallmatrix} 5 & -2 \\ 2 & 5 \end{smallmatrix}$)	408	
H-phthalocyanine		($\begin{smallmatrix} 5 & -2 \\ 2 & 5 \end{smallmatrix}$)	408	
glycine		(4X2)	409	
L-alanine		($\begin{smallmatrix} 8 & -4 \\ 4/5 & 8/5 \end{smallmatrix}$)	409	
L-tryptophan		($\begin{smallmatrix} 2 & 1 \\ 2 & -1 \end{smallmatrix}$)	409	
D-tryptophan		(4X4)	409	
Cu(110)		C ₂ H ₄	ord. 1D	26
		Cu(S)-[3(100)X(100)]	CH ₄	not adsorbed
C ₂ H ₄	not adsorbed		132	
Cu(S)-[4(100)X(100)]	CH ₄	not adsorbed	132	
	C ₂ H ₄	not adsorbed	132	
Fe(100)	C ₂ H ₄	α(2X2)-C	274	
Ir(111)	C ₂ H ₂	(√3X√3)R30°	187	
	C ₂ H ₄	(9X9)-C	187	
		(√3X√3)R30°	187	
		(9X9)-C	187	
	cyclohexane	disordered	187	
	benzene	(9X9)-C	187	
		(3X3)	187	
		(9X9)-C	187	
	Ir(100)	C ₂ H ₂	disordered	281, 410
		C ₂ H ₄	α(2X2)-C	281, 410
disordered			410	
α(2X2)-C			410	
benzene	disordered	410		
	C ₂ H ₄	disordered	347	
		(1X1)-C	347	
benzene	disordered	347		
	(1X1)-C	347		
Ir(S)-[6(111)X(100)]	C ₂ H ₂	(2X2)	187	
	C ₂ H ₄	(2X2)	187	
	cyclohexane	(2X2)	187	
	benzene	disordered	187	
Mo(100)	CH ₄	α(4X4)-C	286	
		α(2X2)-C	286	
		α(6√2X2√2)R45°-C	286	
		(1X1)-C	286	
		(2X2)	117	
Ni(111)	CH ₄	(2X√3)	117	
		(2X2)	117	
		(√7X√7)R19°-C	29	
	C ₂ H ₂	(2X2)	412, 413	
	C ₂ H ₄	(2X2)	29, 39, 412	
	C ₂ H ₆	(2X2)	39, 117	
	cyclohexane	(2X√3)	117	
		(2√3X2√3)R30°	414	
		(2√3X2√3)R30°	414, 415	
		(2X2)	117	
Ni(100)	CH ₄	(2X2)	117	
		(2X2)	117	
	C ₂ H ₂	α(2X2)	416	
	(2X2)	416		

TABLE VI (Continued)

surface	adsorbed gas	surface structure	ref
Ni(110)	C ₂ H ₄	c(4X2)	417
		(2X2)-C	417
		c(2X2)	88, 416
		(2X2)	416
		c(4X2)	417
		(2X2)-C	417
	C ₂ H ₆	($\sqrt{7} \times \sqrt{7}$)R19°-C	88
		c(2X2)	117
		(2X2)	117
	benzene	c(4X4)	415
	CH ₄	(2X2)	117
		(4X3)	117
	C ₂ H ₄	(4X5)-C	117, 418
		(2X3)-C	418
		(2X1)-C	419-421
		(4X5)-C	419, 420
		graphite overlayer	420
		(2X2)	117
C ₂ H ₆	(4X3)	422	
C ₅ H ₁₂	(4X5)	422	
Pt(111)	C ₂ H ₂	(2X1)	28
		(2X2)	423-425
	C ₂ H ₄	(2X2)	40, 424, 425
		(2X1)	28
		2(1d)-C	221
		graphite overlayer	221, 426
	n-butane	($\begin{smallmatrix} 2 & 1 \\ -1 & 2 \end{smallmatrix}$)	427
		($\begin{smallmatrix} 2 & 1 \\ -5 & 5 \end{smallmatrix}$)	427
		($\begin{smallmatrix} 3 & -2 \\ 2 & 5 \end{smallmatrix}$)	427
		($\begin{smallmatrix} 2 & 1 \\ 0 & 3 \end{smallmatrix}$)	427
		($\begin{smallmatrix} 2 & 1 \\ -1 & 3 \end{smallmatrix}$)	427
	n-pentane	($\begin{smallmatrix} 2 & 1 \\ 0 & 8 \end{smallmatrix}$)	427
	n-hexane	(2X2)	221
	n-heptane	($\begin{smallmatrix} 2 & 1 \\ -1 & 4 \end{smallmatrix}$)	427
	n-octane	($\begin{smallmatrix} 1 & -1 \\ 1 & 5 \end{smallmatrix}$)	427
	cyclohexane	disordered	221
		(2X2)	221
	benzene	graphite overlayer	221
($\begin{smallmatrix} -2 & 2 \\ 4 & 5 \end{smallmatrix}$)		221, 429	
($\begin{smallmatrix} 0 & -2 \\ 0 & 4 \end{smallmatrix}$)		428	
($\begin{smallmatrix} 4 & -2 \\ 0 & 5 \end{smallmatrix}$)		428	
($\begin{smallmatrix} -2 & 2 \\ 4 & 4 \end{smallmatrix}$)		429	
toluene	3(1d)	221, 430	
	(4X2)	430	
naphthalene	graphite overlayer	430	
	(6X6)	224, 429	
Pt(100)		naphthalene (001)	224
	pyridine	(2X2)	429
	m-xylene	2.6(1d)	430
	mesitylene	3.4(1d)	430
	tert-butylbenzene	disordered	430
	n-butylbenzene	disordered	430
	aniline	3(1d)	430
	nitrobenzene	3(1d)	430
	cyanobenzene	3(1d)	430
	C ₂ H ₂	c(2X2)	28, 72, 321, 431, 432
		c(2X2)	28, 72, 313, 321, 431
	C ₂ H ₄	graphite overlayer	313, 426
		(511), (311) facets	426
	benzene	disordered	432
		2(1d)	429
naphthalene	(1X1)	429	
pyridine	(1X1)	429	
toluene	c(2X2)	429	
	3(1d)	430	
m-xylene	3(1d)	430	
mesitylene	3(1d)	430	
tert-butylbenzene	disordered	430	
n-butylbenzene	disordered	430	
aniline	disordered	430	
nitrobenzene	disordered	430	
cyanobenzene	disordered	430	
C ₂ N ₂	(1X1)	433	

TABLE VI (Continued)

surface	adsorbed gas	surface structure	ref
Pt(110)	HCN	$(-1 \frac{2}{3})$	434
		$\alpha(2 \times 4)$	434
		(1 × 1)	434
Pt(S)-[4(111)X(100)]	C ₂ N ₂	(1 × 1)	407, 435
	C ₂ H ₄	disordered	221
		graphite overlayer	221
		facets	221
	cyclohexane	disordered	221
	<i>n</i> -heptane	(4 × 2)-C	221
		(4 × 2)	221
	benzene	(4 × 2)-C	221
		disordered	221
	toluene	graphite overlayer	221
		facets	221
disordered		221	
Pt(S)-[6(111)X(100)]	C ₂ H ₄	2(1d)-C	221
		(2 × 2)	120, 221
		$(-\frac{3}{2} \frac{2}{3})$ -C	221
	cyclohexane	$(-\frac{2}{3} \frac{1}{3})$ -C	221
		$(-\frac{1}{2} \frac{1}{2})$ -C	221
		$\sqrt{19} \times \sqrt{19} R23.4^\circ$ -C	426
	graphite overlayer	426	
	2(1d)	221	
	<i>n</i> -heptane	(2 × 2)	221
		$(-\frac{1}{2} \frac{1}{2})$	221
	benzene	(9 × 9)-C	221
		3(1d)	221
		(9 × 9)-C	221
	toluene	disordered	221
		(9 × 9)-C	221
		disordered	221
	Pt(S)-[7(111)X(310)]	C ₂ H ₄	(9 × 9)-C
disordered			221
graphite overlayer		221	
cyclohexane		disordered	221
<i>n</i> -heptane		disordered	221
benzene		disordered	221
toluene		disordered	221
Pt(S)-[9(111)X(100)]	C ₂ H ₄	graphite overlayer	221
		adsorbed	221
	cyclohexane	disordered	221
		(2 × 2)	221
		$(-\frac{1}{2} \frac{1}{2})$	221
	<i>n</i> -heptane	(5 × 5)-C	221
		(2 × 2)-C	221
		$(-\frac{1}{2} \frac{1}{2})$ -C	221
	benzene	2(1d)-C	221
		disordered	221
		$(-\frac{1}{2} \frac{1}{2})$ -C	221
toluene	graphite overlayer	221	
	3(1d)	221	
	graphite overlayer	221	
Pt(S)-[9(111)X(111)]	C ₂ H ₄	disordered	120
		graphite overlayer	398, 399
	N	disordered	228
Pt(S)-[5(100)X(111)]	C ₂ H ₄	graphite overlayer	426
		(511), (311) and (731) facets	426
Re(0001)	C ₂ H ₂	disordered	436
		(2 × √3)R30°-C	436
	C ₂ H ₄	disordered	436
		(2 × √3)R30°-C	436
Rh(111)	C ₂ H ₂	$\alpha(4 \times 2)$	231
		$\alpha(4 \times 2)$	231
	C ₂ H ₄	(8 × 8)-C	231
		(2 × 2)R30°-C	231
		(√19 × √19)R23.4°-C	231
	benzene	(2√3 × 2√3)R30°-C	231
		(12 × 12)-C	231
$\alpha(2 \times 2)$		231	
Rh(100)	C ₂ H ₂	$\alpha(2 \times 2)$	231
		$\alpha(2 \times 2)$	231
	C ₂ H ₄	$\alpha(2 \times 2)$ -C	231
Rh(331)	C ₂ H ₂	graphite overlayer	231
		$(-\frac{1}{3} \frac{1}{3})$	402
	C ₂ H ₄	$(-\frac{1}{3} \frac{1}{3})$	402
		graphite overlayer	402

TABLE VI (Continued)

surface	adsorbed gas	surface structure	ref
Rh(S)-[6(111)X(100)]	C ₂ H ₂	disordered	402
	C ₂ H ₄	disordered (111),(100) facets	402 402
Si(111)	C ₂ H ₂	disordered	437
Si(311)	C ₂ H ₂	c(1X1)	135
		(2X1)	135
		(3X1)	135
	C ₂ H ₄	c(1X1)	135
		(2X1)	135
(3X1)	135		
Ta(100)	C ₂ H ₄	adsorbed	328
W(111)	CH ₄	(6X6)-C	41
W(100)	CH ₄	(5X1)-C	41
W(110)	C ₂ H ₄	(15X3)R α -C	41
		(15X12)R α -C	41

packed hexagonal overlayer of CO at high coverage. This hexagonal overlayer of CO has also been observed on some surfaces having fourfold rotational symmetry. Several adsorption studies of the inert gases Xe and Kr have been reported. These studies were carried out at low temperatures since the interaction between these gases and surfaces is weak. In all cases a hexagonal overlayer of the inert gas was formed. This hexagonal overlayer has been analyzed for Xe on Ag(111) and found to correspond to the (111) plane of the fcc inert gas solid.^{8,9}

The surface structures observed for gas adsorption on stepped surfaces are listed in Table V. In this table the stepped surfaces are denoted by either their Miller index label or stepped surface designation, depending on which system was used by the original author. By using Table I one may convert back and forth between these two systems. Most of the studies in this table have been performed in the last few years. It is interesting to compare the surface structures formed on stepped surfaces with those formed on the low index faces given in Tables II-IV. For stepped surfaces with fairly large terrace widths (~six to eight atoms or larger), the surface structure that forms on the terrace is generally the same one that forms on the low index face. The surface structures on the low index surfaces tend to be more well ordered than those on the stepped surfaces. An example of this is the existence of several one-dimensional structures on stepped surfaces. The one-dimensional structures cause streaks to occur in the LEED patterns and are denoted as n -(1d) structures in the tables, with $n - 1$ is the number of streaks between rows of the substrate diffraction spots. Also, the adsorption of gases may cause faceting of the substrate owing to the high surface free energy of stepped surfaces.

The surface structures formed upon adsorption of organic molecules on several substrates are listed in Table VI. This table includes both chemisorption and physisorption structures since many of the organic molecules only adsorb at low temperatures. Ethylene and acetylene are the two most widely studied organic molecules. There has also been an I-V analysis of the (2X2) surface structures formed by these two molecules on Pt(111).¹⁰⁻¹² As can be seen from Table VI, adsorption on platinum surfaces has been the most widely studied. For some larger organic molecules both monolayer and multilayer structures have been reported. The multilayer structures formed by phthalocyanines and amino acids on copper^{13,14} grow at room temperature, while the n -paraffins on Pt(111)¹⁵ only form multilayer structures at low temperatures. As seen from Table VI there have also been several adsorption studies of organic molecules on stepped surfaces. More LEED studies of organic adsorbates on a larger variety of substrates are needed before correlations or trends among their surface structures can be made.

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VI. Text References

- (1) G. A. Somorjai and L. L. Kesmodel, *MTP Int. Rev. Sci., Phys. Chem., Ser. Two*, **7**, 1 (1975).
- (2) G. A. Somorjai and L. L. Kesmodel, *Trans. Am. Crystallogr. Assoc.*, **13**, 67 (1977).
- (3) E. A. Wood, *J. Appl. Phys.*, **35**, 1306 (1964).
- (4) W. P. Ellis and R. L. Schwoebel, *Surf. Sci.*, **11**, 82 (1968).
- (5) B. Lang, R. W. Joyner, and G. A. Somorjai, *Surf. Sci.*, **30**, 454 (1972).
- (6) D. W. Blakely and G. A. Somorjai, *Surf. Sci.*, **65**, 419 (1977).
- (7) W. Mönch, *Adv. Solid State Phys.*, **13**, 241 (1973).
- (8) N. Stone, M. A. Van Hove, S. Y. Tong, and M. B. Webb, *Phys. Rev. Lett.*, **40**, 243 (1978).
- (9) P. I. Cohen, J. Unguris, and M. B. Webb, *Surf. Sci.*, **58**, 429 (1976).
- (10) L. L. Kesmodel, R. C. Baetzold, and G. A. Somorjai, *Surf. Sci.*, **66**, 299 (1977).
- (11) P. C. Stair and G. A. Somorjai, *J. Chem. Phys.*, **66**, 573 (1977).
- (12) L. L. Kesmodel, L. H. Dubois, and G. A. Somorjai, *Chem. Phys. Lett.*, **56**, 267 (1978).
- (13) J. C. Buchholz and G. A. Somorjai, *J. Chem. Phys.*, **66**, 573 (1977).
- (14) L. L. Atanasoska, J. C. Buchholz, and G. A. Somorjai, *Surf. Sci.*, **72**, 189 (1978).
- (15) L. E. Firment and G. A. Somorjai, *J. Chem. Phys.*, **66**, 2901 (1977).

VII. References for Tables II-VI

- (1) K. Müller, *Z. Naturforsch., Teil A*, **20**, 153 (1965).
- (2) A. U. MacRae, *Surf. Sci.*, **1**, 319 (1964).
- (3) L. H. Germer, E. J. Schneiber, and C. D. Hartman, *Phil. Mag.*, **5**, 222 (1960).
- (4) R. L. Park and H. E. Farnsworth, *Appl. Phys. Lett.*, **3**, 167 (1963).
- (5) T. Edmonds and R. C. Pitkethly, *Surf. Sci.*, **15**, 137 (1969).
- (6) A. U. Macrae, *Science*, **139**, 379 (1963).
- (7) G. Ertl, *Surf. Sci.*, **6**, 208 (1967).
- (8) N. Takahashi et al., *C. R. Acad. Sci., Ser. B*, **269**, 618 (1969).
- (9) G. W. Simmons, D. F. Mitchell, and K. R. Lawless, *Surf. Sci.*, **8**, 130 (1967).
- (10) C. W. Tucker, Jr., *Surf. Sci.*, **2**, 516 (1964).
- (11) C. W. Tucker, Jr., *J. Appl. Phys.*, **35**, 1897 (1964).
- (12) J. T. Grant and T. W. Haas, *Surf. Sci.*, **21**, 76 (1970).
- (13) W. P. Ellis, *J. Chem. Phys.*, **48**, 5695 (1968).
- (14) J. Ferrante and G. C. Barton, NASA Technical Note D-4735, 1968.
- (15) N. J. Taylor, *Surf. Sci.*, **2**, 544 (1964).
- (16) J. B. Marsh and H. E. Farnsworth, *Surf. Sci.*, **1**, 3 (1964).
- (17) R. E. Schlier and H. E. Farnsworth, *J. Chem. Phys.*, **30**, 917 (1959).
- (18) H. E. Farnsworth, R. E. Schlier, T. H. George, and R. M. Buerger, *J. Appl. Phys.*, **29**, 1150 (1958).
- (19) J. J. Lander and J. Morrison, *J. Appl. Phys.*, **34**, 1411 (1963).
- (20) J. J. Lander and J. Morrison, *J. Appl. Phys.*, **33**, 2089 (1962).
- (21) G. Rovida et al., *Surf. Sci.*, **14**, 93 (1969).
- (22) R. O. Adams, "The Structure and Chemistry of Solid Surfaces", G. A. Somorjai, Ed., Wiley, New York, 1969.
- (23) H. E. Farnsworth and D. M. Zehner, *Surf. Sci.*, **17**, 7 (1969).
- (24) G. J. Dooley and T. W. Haas, *Surf. Sci.*, **19**, 1 (1970).
- (25) B. D. Campbell, C. A. Haque, and H. E. Farnsworth in ref 22.
- (26) G. Ertl, *Surf. Sci.*, **7**, 309 (1967).
- (27) T. Edmonds and R. C. Pitkethly, *Surf. Sci.*, **17**, 450 (1969).
- (28) A. E. Morgan and G. A. Somorjai, *J. Chem. Phys.*, **51**, 3309 (1969).
- (29) J. C. Bertolini and G. Dalmaj-Imelik, *Colloq. Int. CNRS*, (7-11 July 1969).
- (30) J. J. Lander and J. Morrison, *Surf. Sci.*, **4**, 241 (1966).
- (31) L. H. Germer and A. U. MacRae, *J. Chem. Phys.*, **36**, 1555 (1962).
- (32) A. J. van Bommel and F. Meyer, *Surf. Sci.*, **8**, 381 (1967).
- (33) J. J. Lander and J. Morrison, *J. Chem. Phys.*, **37**, 729 (1962).
- (34) R. Heckingbottom in ref 22.
- (35) J. L. Domange and J. Oudar, *Surf. Sci.*, **11**, 124 (1968).
- (36) M. Perdureau and J. Oudar, *Surf. Sci.*, **20**, 80 (1970).
- (37) A. J. van Bommel and F. Meyer, *Surf. Sci.*, **8**, 381 (1967).
- (38) J. V. Florio and W. D. Robertson, *Surf. Sci.*, **18**, 398 (1969).
- (39) J. C. Bertolini and G. Dalmaj-Imelik, *Rapport Institut de Recherche sur la Catalyse, Villeurbanne*, 1969.

- (40) D. L. Smith and R. P. Merrill, *J. Chem. Phys.*, **52**, 5861 (1970).
- (41) M. Boudart and D. F. Ollis in ref 22.
- (42) F. Jons, *J. Phys. Chem. Solids*, **28**, 2155 (1967).
- (43) S. M. Bedair, F. Hoffmann, and H. P. Smith, Jr., *J. Appl. Phys.*, **39**, 4026 (1968).
- (44) H. H. Farrell, Ph.D. Dissertation, University of California—Berkeley, 1969.
- (45) L. K. Jordan and E. J. Scheibner, *Surf. Sci.*, **10**, 1373 (1968).
- (46) L. Trepte, C. Menzel-Kopp, and E. Mensel, *Surf. Sci.*, **8**, 223 (1967).
- (47) R. N. Lee and H. E. Farnsworth, *Surf. Sci.*, **3**, 461 (1965).
- (48) J. T. Grant, *Surf. Sci.*, **18**, 228 (1969).
- (49) R. E. Schlier and H. E. Farnsworth, *J. Appl. Phys.*, **25**, 1333 (1954).
- (50) H. E. Farnsworth and J. Tuul, *J. Phys. Chem. Solids*, **9**, 48 (1958).
- (51) J. W. May and L. H. Germer, *Surf. Sci.*, **11**, 443 (1968).
- (52) R. E. Schlier and H. E. Farnsworth, *Adv. Catal.*, **9**, 434 (1957).
- (53) L. H. Germer and C. D. Hartman, *J. Appl. Phys.*, **31**, 2085 (1960).
- (54) H. E. Farnsworth and H. H. Madden, Jr., *J. Appl. Phys.*, **32**, 1933 (1961).
- (55) R. L. Park and H. E. Farnsworth, *J. Chem. Phys.*, **43**, 2351 (1965).
- (56) L. H. Germer, *Adv. Catal.*, **13**, 191 (1962).
- (57) L. H. Germer, R. Stern, and A. U. MacRae, "Metal Surfaces", ASM, Metals Park, Ohio, 1963, p. 287.
- (58) C. W. Tucker, Jr., *J. Appl. Phys.*, **37**, 3013 (1966).
- (59) C. A. Haque and H. E. Farnsworth, *Surf. Sci.*, **1**, 378 (1964).
- (60) A. J. Pignocco and G. E. Pellissier, *J. Electrochem. Soc.*, **112**, 1188 (1965).
- (61) H. K. A. Kann and S. Feuerstein, *J. Chem. Phys.*, **50**, 3618 (1969).
- (62) K. Hayek and H. E. Farnsworth, *Surf. Sci.*, **10**, 429 (1968).
- (63) H. E. Farnsworth and K. Hayek, *Suppl. Nuovo Cimento*, **5**, 2 (1967).
- (64) G. J. Dooley and T. W. Haas, *J. Chem. Phys.*, **52**, 461 (1970).
- (65) K. K. Vijai and P. F. Packman, *J. Chem. Phys.*, **50**, 1343 (1969).
- (66) P. J. Estrup in ref 22.
- (67) J. Anderson and W. E. Danforth, *J. Franklin Inst.*, **279**, 160 (1965).
- (68) M. Onchi and H. E. Farnsworth, *Surf. Sci.*, **11**, 203 (1968).
- (69) R. A. Armstrong in ref 22.
- (70) J. C. Tracy and P. W. Palmberg, *J. Chem. Phys.*, **51**, 4852 (1969).
- (71) R. L. Park and H. H. Madden, *Surf. Sci.*, **11**, 188 (1968).
- (72) A. E. Morgan and G. A. Somorjai, *Surf. Sci.*, **12**, 405 (1968).
- (73) C. Burggraf and A. Mosser, *C. R. Acad. Sci., Ser. B*, **268**, 1167 (1969).
- (74) A. E. Morgan and G. A. Somorjai, *Trans. Am. Crystallogr. Assoc.*, **4**, 59 (1968).
- (75) J. Anderson and P. J. Estrup, *J. Chem. Phys.*, **46**, 563 (1967).
- (76) M. Onchi and H. E. Farnsworth, *Surf. Sci.*, **13**, 425 (1969).
- (77) G. J. Dooley and T. W. Haas, *J. Chem. Phys.*, **51**, 993 (1970).
- (78) P. W. Tamm and L. D. Schmidt, *J. Chem. Phys.*, **51**, 5352 (1969).
- (79) P. J. Estrup and J. Anderson, *J. Chem. Phys.*, **45**, 2254 (1966).
- (80) H. H. Madden and H. E. Farnsworth, *J. Chem. Phys.*, **34**, 1186 (1961).
- (81) J. W. May and L. H. Germer in ref 22.
- (82) P. J. Estrup and J. Anderson, *J. Chem. Phys.*, **46**, 567 (1967).
- (83) T. L. Park and H. E. Farnsworth, *J. Appl. Phys.*, **35**, 2220 (1964).
- (84) P. J. Estrup and J. Anderson, *J. Chem. Phys.*, **49**, 523 (1968).
- (85) E. Margot et al., *C. R. Acad. Sci., Ser. C*, **270**, 1261 (1970).
- (86) N. W. Tideswell and J. M. Ballingal, *J. Vac. Sci. Technol.*, **7**, 496 (1970).
- (87) F. Portele, *Z. Naturforsch. Teil A*, **24**, 1268 (1969).
- (88) G. Dalmai-Imelik and J. C. Bertolini, *C. R. Acad. Sci.*, **270**, 1079 (1970).
- (89) L. H. Germer and A. U. MacRae, *J. Appl. Phys.*, **33**, 2923 (1962).
- (90) L. H. Germer and A. U. MacRae, Robert Welch Foundation Research Bulletin No. 11, 1961, p. 5.
- (91) R. L. Park and H. E. Farnsworth, *J. Chem. Phys.*, **40**, 2354 (1964).
- (92) L. H. Germer, J. W. May, and R. J. Szostak, *Surf. Sci.*, **7**, 430 (1967).
- (93) J. W. May, L. H. Germer, and C. C. Chang, *J. Chem. Phys.*, **45**, 2383 (1966).
- (94) A. G. Jackson and M. P. Hooker, *Surf. Sci.*, **6**, 297 (1967).
- (95) G. Ertl and P. Rau, *Surf. Sci.*, **15**, 443 (1969).
- (96) C. W. Tucker, Jr., *J. Appl. Phys.*, **38**, 2696 (1967).
- (97) C. W. Tucker, Jr., *J. Appl. Phys.*, **37**, 4147 (1966).
- (98) A. J. Pignocco and G. E. Pellissier, *Surf. Sci.*, **7**, 261 (1967).
- (99) K. Moliere and F. Portele in ref 22.
- (100) T. W. Haas and A. G. Jackson, *J. Chem. Phys.*, **44**, 2921 (1966).
- (101) T. W. Haas, A. G. Jackson, and M. P. Hooker, *J. Chem. Phys.*, **46**, 3025 (1967).
- (102) T. W. Haas in ref 22.
- (103) L. H. Germer, *Phys. Today*, 19 (July 1964).
- (104) L. H. Germer and J. W. May, *Surf. Sci.*, **4**, 452 (1966).
- (105) G. J. Dooley and T. W. Haas, *J. Vac. Sci. Technol.*, **7**, 49 (1970).
- (106) C. C. Chang and L. H. Germer, *Surf. Sci.*, **8**, 115 (1967).
- (107) J. C. Tracy and J. M. Blakeley in ref 22.
- (108) C. C. Chang, *J. Electrochem. Soc.*, **115**, 354 (1968).
- (109) J. W. May and L. H. Germer, *J. Chem. Phys.*, **44**, 2895 (1966).
- (110) L. H. Germer and A. U. MacRae, *Proc. Natl. Acad. Sci. U.S.A.*, **48**, 997 (1962).
- (111) T. W. Haas, *J. Appl. Phys.*, **39**, 5854 (1968).
- (112) D. L. Adams et al., *Surf. Sci.*, **22**, 45 (1970).
- (113) J. W. May, R. J. Szostak, and L. H. Germer, *Surf. Sci.*, **15**, 37 (1969).
- (114) D. H. Buckley, NASA Technical Note D-5689, 1970.
- (115) I. Marklund, S. Andersson, and J. Martinsson, *Ark. Fys.*, **37**, 127 (1968).
- (116) P. Legare and G. Marie, *J. Chim. Phys. Phys.-Chim. Biol.*, **68** (7-8), 1206 (1971).
- (117) G. Marie, J. R. Anderson, and B. B. Johnson, *Proc. R. Soc. London, Ser. A*, **320**, 227 (1970).
- (118) T. Edmonds, J. J. McCarron, and R. C. Pitkethly, *J. Vac. Sci. Technol.*, **8** (1), 68 (1971).
- (119) K. Okado, T. Halsushika, H. Tomita, S. Motov, and N. Takalashi, *Shinku*, **13** (11), 371 (1970).
- (120) B. Lang, R. W. Joyner, and G. A. Somorjai, *Surf. Sci.*, **30**, 454 (1972).
- (121) M. Henzler and J. Töpler, *Surf. Sci.*, **40**, 388 (1973).
- (122) H. Van Hove and R. Leyser, *Phys. Status Solidi A*, **9** (1), 361 (1972).
- (123) S. M. Bedair and H. P. Smith, Jr., *J. Appl. Phys.*, **42**, 3616 (1971).
- (124) J. T. Grant, *Surf. Sci.*, **25**, 451 (1971).
- (125) R. W. Joyner, C. S. McKee, and M. W. Roberts, *Surf. Sci.*, **26**, 303 (1971).
- (126) J. C. Tracy, *J. Chem. Phys.*, **56** (6), 2748 (1971).
- (127) M. A. Chesters and J. Pritchard, *Surf. Sci.*, **28**, 460 (1971).
- (128) R. W. Joyner, C. S. McKee, and M. W. Roberts, *Surf. Sci.*, **27**, 279 (1971).
- (129) J. C. Tracy, *J. Chem. Phys.*, **56** (6), 2736 (1971).
- (130) D. Tabor and J. M. Wilson, *J. Cryst. Growth*, **9**, 60 (1971).
- (131) D. L. Adams and L. H. Germer, *Surf. Sci.*, **27**, 21 (1971).
- (132) J. Perdureau and G. E. Rhead, *Surf. Sci.*, **24**, 555 (1971).
- (133) P. W. Palmberg, *Surf. Sci.*, **25**, 104 (1971).
- (134) G. Ertl and J. Kuppers, *Surf. Sci.*, **24**, 104 (1971).
- (135) R. Heckingbottom and P. R. Wood, *Surf. Sci.*, **23**, 437 (1970).
- (136) K. J. Matysik, *Surf. Sci.*, **29**, 324 (1972).
- (137) G. E. Becker and H. D. Hagstrum, *Surf. Sci.*, **30**, 505 (1972).
- (138) D. L. Adams and L. H. Germer, *Surf. Sci.*, **32**, 205 (1972).
- (139) H. P. Bonzel and R. Ku, *Surf. Sci.*, **33**, 91 (1972).
- (140) P. Michel and Ch. Jardin, *Surf. Sci.*, **36**, 478 (1973).
- (141) A. Melmad and J. J. Carroll, *J. Vac. Sci. Technol.*, **10**, 164 (1973).
- (142) H. D. Hagstrum and G. E. Becker, *Phys. Rev. Lett.*, **22**, 1054 (1969); *J. Chem. Phys.*, **54**, 1015 (1971).
- (143) W. H. Weinberg and R. P. Merrill, *Surf. Sci.*, **32**, 317 (1972).
- (144) P. B. Sewell, D. F. Mitchell, and M. Cohen, *Surf. Sci.*, **33**, 535 (1972).
- (145) F. Forstmann, W. Berndt, and P. Büttner, *Phys. Rev. Lett.*, **30**, 17 (1973).
- (146) H. A. Engelhardt and D. Menzel, *Surf. Sci.*, **57**, 591 (1976).
- (147) H. Albers, W. J. J. Van der Wal, and G. A. Bootsma, *Surf. Sci.*, **68**, 47 (1977).
- (148) G. Rovida, F. Pratesi, M. Maglietta, and E. Ferroni, *Surf. Sci.*, **43**, 230 (1974).
- (149) W. Berndt, *Proc. Int. Conf. Solid Surf.*, **2nd**, 653 (1974).
- (150) F. Forstmann, *Proc. Int. Conf. Solid Surf.*, **2nd**, 657 (1974).
- (151) P. J. Goddard and R. M. Lambert, *Surf. Sci.*, **87**, 180 (1977).
- (152) Y. Tu and J. M. Blakely, *J. Vac. Sci. Technol.*, **15**, 563 (1978).
- (153) G. Rovida, F. Pratesi, M. Maglietta, and E. Ferroni, *Proc. Int. Conf. Solid Surf.*, **2nd**, 117 (1974).
- (154) G. Rovida and F. Pratesi, *Surf. Sci.*, **51**, 270 (1975).
- (155) P. J. Goddard, K. Schwaha, and R. M. Lambert, *Surf. Sci.*, **71**, 351 (1978).
- (156) R. H. Roberts and J. Pritchard, *Surf. Sci.*, **54**, 687 (1976).
- (157) N. Stone, M. A. Van Hove, S. Y. Tong, and M. B. Webb, *Phys. Rev. Lett.*, **40**, 243 (1978).
- (158) G. McElhiney, H. Papp, and J. Pritchard, *Surf. Sci.*, **54**, 617 (1976).
- (159) M. A. Chesters, M. Hussian, and J. Pritchard, *Surf. Sci.*, **35**, 161 (1973).
- (160) P. I. Cohen, J. Unguris, and M. B. Webb, *Surf. Sci.*, **58**, 429 (1976).
- (161) M. A. Chesters and G. A. Somorjai, *Surf. Sci.*, **52**, 21 (1975).
- (162) D. M. Zehner and J. F. Wendelken, *Proc. Int. Vac. Congr. 7th, and Int. Conf. Solid Surf.*, **3rd**, 517 (1977).
- (163) P. J. Goddard, J. West, and R. M. Lambert, *Surf. Sci.*, **71**, 447 (1978).
- (164) P. G. Lurie and J. M. Wilson, *Surf. Sci.*, **65**, 453 (1977).
- (165) J. Suzanne, J. P. Coulomb, and M. Bienfait, *Surf. Sci.*, **40**, 414 (1973).
- (166) M. D. Chinn and S. C. Fain, Jr., *J. Vac. Sci. Technol.*, **14**, 314 (1977).
- (167) H. M. Kramer and J. Suzanne, *Surf. Sci.*, **54**, 659 (1976).
- (168) M. E. Bridge, C. M. Comrie, and R. M. Lambert, *Surf. Sci.*, **67**, 393 (1977).
- (169) C. Jardin and P. Michel, *Surf. Sci.*, **71**, 575 (1978).
- (170) F. H. P. M. Habraken, E. P. Kieffer, and G. A. Bootsma, *Proc. Int. Vac. Congr. 7th, and Int. Conf. Solid Surf.*, **3rd**, 877 (1977).
- (171) L. McDonnel and D. P. Woodruff, *Surf. Sci.*, **46**, 505 (1974).
- (172) J. Kessler and F. Thieme, *Surf. Sci.*, **67**, 405 (1977).
- (173) C. Bennndorf, K. H. Gressman, and F. Thieme, *Surf. Sci.*, **61**, 646 (1976).
- (174) M. D. Chinn and S. C. Fain, Jr., *Phys. Rev. Lett.*, **39**, 146 (1977).
- (175) S. Nakanishi and T. Horiguchi, *Proc. Int. Vac. Congr., 7th, and Int. Conf. Solid Surf.*, **3rd** A2727 (1977).
- (176) M. Grunze, F. Bozso, G. Ertl, and M. Weiss, *Appl. Surf. Sci.*, **1**, 241 (1978).
- (177) F. Bozso, G. Ertl, M. Grunze, and M. Weiss, *Appl. Surf. Sci.*, **1**, 103 (1978).
- (178) B. Z. Olshansky, S. M. Repinsky, and A. A. Shklyav, *Surf. Sci.*, **64**, 224 (1977).
- (179) S. Sinharoy and M. Henzler, *Surf. Sci.*, **51**, 75 (1975).
- (180) V. P. Ivanov, G. K. Boreshov, V. I. Savchenko, W. F. Egelhoff, Jr., and W. H. Weinberg, *J. Catal.*, **48**, 269 (1977).
- (181) H. Conrad, J. Kuppers, F. Nitschké, and A. Plagge, *Surf. Sci.*, **69**, 668 (1977).
- (182) D. I. Hagen, B. E. Nieuwenhuys, G. Rovida, and G. A. Somorjai, *Surf. Sci.*, **57**, 632 (1976).
- (183) J. Kuppers and A. Plagge, *J. Vac. Sci. Technol.*, **13**, 259 (1976).
- (184) V. P. Ivanov, G. K. Boreshov, V. I. Savchenko, W. F. Egelhoff, Jr., and W. H. Weinberg, *Surf. Sci.*, **61**, 207 (1976).
- (185) C. M. Comrie and W. H. Weinberg, *J. Vac. Sci. Technol.*, **13**, 264 (1976).
- (186) C. M. Comrie and W. H. Weinberg, *J. Chem. Phys.*, **64**, 250 (1976).
- (187) B. E. Nieuwenhuys, D. I. Hagen, G. Rovida, and G. A. Somorjai, *Surf. Sci.*, **59**, 155 (1976).
- (188) J. Kanski and T. N. Rhodin, *Surf. Sci.*, **65**, 63 (1977).
- (189) L. J. Clark, *Proc. Int. Vac. Congr. 7th, and Int. Conf. Solid Surf.*, **3rd**, A2725 (1977).
- (190) H. M. Kennett and A. E. Lee, *Surf. Sci.*, **48**, 606 (1975).
- (191) J. M. Wilson, *Surf. Sci.*, **59**, 315 (1976).

- (192) R. Pantel, M. Bujor, and J. Bardolle, *Surf. Sci.*, **62**, 739 (1977).
- (193) H. Conrad, G. Ertl, J. Küppers, and E. E. Latta, *Surf. Sci.*, **50**, 296 (1975).
- (194) P. H. Holloway and J. B. Hudson, *Surf. Sci.*, **43**, 141 (1974).
- (195) H. Conrad, G. Ertl, J. Küppers, and E. E. Latta, *Surf. Sci.*, **57**, 475 (1976).
- (196) W. Erley, K. Besoche, and H. Wagner, *J. Chem. Phys.*, **66**, 5269 (1977).
- (197) P. M. Marcus, J. E. Demuth, and D. W. Jepsen, *Surf. Sci.*, **53**, 501 (1975).
- (198) J. E. Demuth and T. N. Rhodin, *Surf. Sci.*, **45**, 249 (1974).
- (199) G. Ertl, *Surf. Sci.*, **47**, 86 (1975).
- (200) K. Christmann, O. Schober, and G. Ertl, *J. Chem. Phys.*, **60**, 4719 (1974).
- (201) M. A. Van Hove, G. Ertl, W. H. Weinberg, K. Christmann, and H. J. Behm, *Proc. Int. Vac. Congr. 7th, and Int. Conf. Solid Surf.*, **3rd**, 2415 (1977).
- (202) H. Conrad, G. Ertl, J. Küppers, and E. E. Latta, *Surf. Sci.*, **58**, 578 (1976).
- (203) K. Christmann, O. Schober, G. Ertl, and M. Neumann, *J. Chem. Phys.*, **60**, 4528 (1974).
- (204) G. Casalone, M. G. Cattania, M. Simonetta, and M. Tescari, *Surf. Sci.*, **72**, 739 (1978).
- (205) J. E. Demuth, D. W. Jepsen, and P. M. Marcus, *Phys. Rev. Lett.*, **32**, 1182 (1974).
- (206) W. Erley and H. Wagner, *Surf. Sci.*, **66**, 371 (1977).
- (207) H. Conrad, G. Ertl, J. Küppers, and E. E. Latta, *Surf. Sci.*, **65**, 245 (1977).
- (208) H. Conrad, G. Ertl, J. Küppers, and E. E. Latta, *Surf. Sci.*, **65**, 235 (1977).
- (209) H. Conrad, G. Ertl, J. Koch, and E. E. Latta, *Surf. Sci.*, **43**, 462 (1974).
- (210) A. M. Bradshaw and F. M. Hoffman, *Surf. Sci.*, **72**, 513 (1978).
- (211) K. Christmann, G. Ertl, and O. Schober, *Surf. Sci.*, **40**, 61 (1973).
- (212) H. Conrad, G. Ertl, and E. E. Latta, *Surf. Sci.*, **41**, 435 (1974).
- (213) H. P. Bonzel and R. Ku, *Surf. Sci.*, **40**, 85 (1973).
- (214) B. Carrière, J. P. Deville, G. Maire, and P. Légaré, *Surf. Sci.*, **58**, 578 (1976).
- (215) P. Légaré, G. Maire, B. Carrière, and J. P. Deville, *Surf. Sci.*, **68**, 348 (1977).
- (216) J. A. Joebstl, *J. Vac. Sci. Technol.*, **12**, 347 (1975).
- (217) W. H. Weinberg, D. R. Monroe, V. Lampton, and R. P. Merrill, *J. Vac. Sci. Technol.*, **14**, 444 (1977).
- (218) G. Ertl, M. Neumann, and K. M. Streit, *Surf. Sci.*, **64**, 393 (1977).
- (219) S. L. Bernasek and G. A. Somorjai, *J. Chem. Phys.*, **60**, 4552 (1974).
- (220) K. Christmann, G. Ertl, and T. Pignet, *Surf. Sci.*, **54**, 365 (1976).
- (221) K. Baron, D. W. Blakely, and G. A. Somorjai, *Surf. Sci.*, **41**, 45 (1974).
- (222) C. M. Comrie, W. H. Weinberg, and R. M. Lambert, *Surf. Sci.*, **57**, 619 (1976).
- (223) L. E. Firment and G. A. Somorjai, *J. Chem. Phys.*, **63**, 1037 (1975).
- (224) L. E. Firment and G. A. Somorjai, *Surf. Sci.*, **55**, 413 (1976).
- (225) W. Heegemann, E. Bechtold, and K. Hayek, *Proc. Int. Conf. Solid Surf.*, **2nd**, 185 (1974).
- (226) W. Heegemann, K. H. Meister, E. Bechtold, and K. Hayek, *Surf. Sci.*, **49**, 161 (1975).
- (227) Y. Berthier, M. Perdereau, and J. Oudar, *Surf. Sci.*, **44**, 281 (1974).
- (228) K. Schwaka and E. Bechtold, *Surf. Sci.*, **66**, 383 (1977).
- (229) D. A. Gorodetsky and A. N. Knys, *Surf. Sci.*, **40**, 651 (1973).
- (230) M. Housley, R. Ducros, G. Piquard, and A. Cassuto, *Surf. Sci.*, **68**, 277 (1977).
- (231) D. G. Castner, B. A. Sexton, and G. A. Somorjai, *Surf. Sci.*, **71**, 519 (1978).
- (232) T. E. Madey, H. A. Engelhardt, and D. Menzel, *Surf. Sci.*, **48**, 304 (1975).
- (233) T. E. Madey and D. Menzel, *Proc. Int. Conf. Solid Surf.*, **2nd**, 229 (1974).
- (234) L. R. Danielson, M. J. Dresser, E. E. Donaldson, and J. T. Dickinson, *Surf. Sci.*, **71**, 599 (1978).
- (235) L. R. Danielson, M. J. Dresser, E. E. Donaldson, and D. R. Sandstrom, *Surf. Sci.*, **71**, 615 (1978).
- (236) K. C. Pandey, T. Sakurai, and H. D. Hagstrum, *Phys. Rev. B*, **16**, 3648 (1977).
- (237) H. Ibach and J. E. Rowe, *Surf. Sci.*, **43**, 481 (1974).
- (238) R. Heckingbottom and P. R. Wood, *Surf. Sci.*, **36**, 594 (1973).
- (239) A. J. van Bommel and J. E. Crombeen, *Surf. Sci.*, **36**, 773 (1973).
- (240) H. D. Shih, F. Jona, D. W. Jepsen, and P. M. Marcus, *J. Vac. Sci. Technol.*, **15**, 596 (1978).
- (241) H. D. Shih, F. Jona, D. W. Jepsen, and P. M. Marcus, *Phys. Rev. Lett.*, **36**, 798 (1976).
- (242) H. D. Shih, F. Jona, D. W. Jepsen, and P. M. Marcus, *Surf. Sci.*, **60**, 445 (1976).
- (243) R. Bastasz, C. A. Colmenares, R. L. Smith, and G. A. Somorjai, *Surf. Sci.*, **67**, 45 (1977).
- (244) T. E. Madey, J. J. Czyzewski, and J. T. Yates Jr., *Surf. Sci.*, **57**, 580 (1976).
- (245) W. N. Unertl and J. M. Blakely, *Surf. Sci.*, **69**, 23 (1977).
- (246) A. Oustry, L. Lafourcade, and A. Escout, *Surf. Sci.*, **40**, 545 (1973).
- (247) Y. Berthier, M. Perdereau, and J. Oudar, *Surf. Sci.*, **36**, 225 (1973).
- (248) J. C. Fuggle, E. Umbach, P. Feulner, and D. Menzel, *Surf. Sci.*, **64**, 69 (1977).
- (249) E. Zanazzi, F. Jona, D. W. Jepsen, and P. M. Marcus, *Phys. Rev. B*, **14**, 432 (1976).
- (250) A. Ignatiev, F. Jona, D. W. Jepsen, and P. M. Marcus, *Surf. Sci.*, **40**, 439 (1973).
- (251) M. Kostelitz, J. L. Domange, and J. Oudar, *Surf. Sci.*, **34**, 431 (1973).
- (252) G. McElhiney and J. Pritchard, *Surf. Sci.*, **60**, 397 (1976).
- (253) M. Maglietta and G. Rovida, *Surf. Sci.*, **71**, 495 (1978).
- (254) G. Rovida and M. Maglietta, *Proc. Int. Vac. Congr., 7th, and Int. Conf. Solid Surf.*, **3rd**, 963 (1977).
- (255) K. Horn, M. Hussain and J. Pritchard, *Surf. Sci.*, **63**, 244 (1977).
- (256) S. Ekelund and C. Leygraf, *Surf. Sci.*, **40**, 179 (1973).
- (257) L. McDonnell, D. P. Woodruff, and K. A. R. Mitchell, *Surf. Sci.*, **45**, 1 (1974).
- (258) G. G. Tibbetts, J. M. Burkstrand, and J. C. Tracy, *Phys. Rev. B*, **15**, 3652 (1977).
- (259) E. Legrand-Bonnyns and A. Ponslet, *Surf. Sci.*, **53**, 675 (1975).
- (260) G. G. Tibbetts, J. M. Burkstrand, and J. C. Tracy, *J. Vac. Sci. Technol.*, **13**, 362 (1976).
- (261) E. G. McRae and C. W. Caldwell, *Surf. Sci.*, **57**, 77 (1976).
- (262) J. R. Noonan, D. M. Zehner, and L. H. Jenkins, *Surf. Sci.*, **69**, 731 (1977).
- (263) P. Hoffmann, R. Unwin, W. Wyrobisch, and A. M. Bradshaw, *Surf. Sci.*, **72**, 635 (1978).
- (264) U. Gerhardt and G. Franz-Moller, *Proc. Int. Vac. Congr., 7th, and Int. Conf. Solid Surf.*, **3rd**, 897 (1977).
- (265) C. R. Brundie and K. Wandelt, *Proc. Int. Vac. Congr., 7th, and Int. Conf. Solid Surf.*, **3rd**, 1171 (1977).
- (266) J. M. Burkstrand, G. G. Kleiman, G. G. Tibbetts, and J. C. Tracy, *J. Vac. Sci. Technol.*, **13**, 291 (1976).
- (267) A. Salwen and J. Rundgren, *Surf. Sci.*, **53**, 523 (1975).
- (268) K. O. Legg, F. Jona, D. W. Jepsen, and P. M. Marcus, *Phys. Rev. B*, **16**, 5271 (1977).
- (269) C. Leygraf and S. Ekelund, *Surf. Sci.*, **40**, 609 (1973).
- (270) G. W. Simmons and D. J. Dwyer, *Surf. Sci.*, **48**, 373 (1975).
- (271) C. F. Brucker and T. N. Rhodin, *Surf. Sci.*, **57**, 523 (1976).
- (272) T. Horiguchi and S. Nakanishi, *Proc. Int. Conf. Solid Surf.*, **2nd**, 89 (1974).
- (273) M. Watanabe, M. Miyamura, T. Matsudaira, and M. Onchi, *Proc. Int. Conf. Solid Surf.*, **2nd**, 501 (1974).
- (274) C. Brucker and T. Rhodin, *J. Catal.*, **47**, 214 (1977).
- (275) F. Jona, K. O. Legg, H. D. Shih, D. W. Jepsen, and P. M. Marcus, *Phys. Rev. Lett.*, **40**, 1466 (1978).
- (276) T. Matsudaira, M. Watanabe, and M. Onchi, *Proc. Int. Conf. Solid Surf.*, **2nd**, 181 (1974).
- (277) K. O. Legg, F. Jona, D. W. Jepsen, and P. M. Marcus, *Surf. Sci.*, **66**, 25 (1977).
- (278) D. J. Dwyer and G. W. Simmons, *Surf. Sci.*, **64**, 617 (1977).
- (279) C. Leygraf, G. Hultquist, and S. Ekelund, *Surf. Sci.*, **51**, 409 (1975).
- (280) C. Leygraf and G. Hultquist, *Surf. Sci.*, **61**, 69 (1976).
- (281) T. N. Rhodin and G. Broden, *Surf. Sci.*, **60**, 466 (1976).
- (282) G. Broden and T. N. Rhodin, *Solid State Commun.*, **18**, 105 (1976).
- (283) A. Ignatiev, T. N. Rhodin, and S. Y. Tong, *Surf. Sci.*, **42**, 37 (1974).
- (284) R. Riwan, C. Guillot, and J. Paigne, *Surf. Sci.*, **47**, 183 (1975).
- (285) J. Lecante, R. Riwan, and G. Guillot, *Surf. Sci.*, **35**, 271 (1973).
- (286) C. Guillot, R. Riwan, and J. Lecante, *Surf. Sci.*, **59**, 581 (1976).
- (287) A. Ignatiev, F. Jona, D. W. Jepsen, and P. M. Marcus, *Surf. Sci.*, **49**, 189 (1975).
- (288) J. M. Wilson, *Surf. Sci.*, **53**, 330 (1975).
- (289) A. Glachant, J. P. Coulomb, and J. P. Biberian, *Surf. Sci.*, **59**, 619 (1976).
- (290) H. H. Farrell and M. Strongin, *Surf. Sci.*, **38**, 18 (1973).
- (291) H. H. Brongersma and J. B. Theeten, *Surf. Sci.*, **54**, 519 (1976).
- (292) Y. Murata, S. Ohtani, and K. Terada, *Proc. Int. Conf. Solid Surf.*, **2nd**, 837 (1974).
- (293) J. E. Demuth, D. W. Jepsen, and P. M. Marcus, *J. Vac. Sci. Technol.*, **11**, 190 (1974).
- (294) T. N. Rhodin and J. E. Demuth, *Proc. Int. Conf. Solid Surf.*, **2nd**, 167 (1974).
- (295) S. Andersson, B. Kasemo, J. B. Pendry, and M. A. Van Hove, *Phys. Rev. Lett.*, **31**, 595 (1973).
- (296) E. G. McRae and C. W. Caldwell, *Surf. Sci.*, **57**, 63 (1976).
- (297) P. H. Holloway and J. B. Hudson, *Surf. Sci.*, **43**, 123 (1974).
- (298) G. Dalmai-Imelik, J. C. Bertolini, and J. Rousseau, *Surf. Sci.*, **63**, 67 (1977).
- (299) D. F. Mitchell, P. B. Sewell, and M. Cohen, *Surf. Sci.*, **61**, 355 (1976).
- (300) S. Andersson and J. B. Pendry, *Surf. Sci.*, **71**, 75 (1978).
- (301) S. Andersson, *Proc. Int. Vac. Congr., 7th, and Int. Conf. Solid Surf.*, **3rd**, 1019 (1977).
- (302) K. Horn, A. M. Bradshaw, and K. Jacobi, *Surf. Sci.*, **72**, 719 (1978).
- (303) J. E. Demuth, D. W. Jepsen, and P. M. Marcus, *Surf. Sci.*, **45**, 733 (1974).
- (304) T. Matsudaira, M. Nishijima, and M. Onchi, *Surf. Sci.*, **61**, 651 (1976).
- (305) H. Froitzheim and H. D. Hagstrum, *J. Vac. Sci. Technol.*, **15**, 485 (1978).
- (306) G. E. Becker and H. D. Hagstrum, *J. Vac. Sci. Technol.*, **11**, 234 (1974).
- (307) J. M. Richard, M. Perdereau, and L. G. Dufour, *Proc. Int. Vac. Congr., 7th, and Int. Conf. Solid Surf.*, **3rd**, 847 (1977).
- (308) A. Steinbrunn, P. Dumas, and J. C. Colson, *Surf. Sci.*, **74**, 201 (1978).
- (309) F. P. Netzer and M. Prutton, *Surf. Sci.*, **52**, 505 (1975).
- (310) C. A. Pagageorgopoulos and J. M. Chen, *Surf. Sci.*, **52**, 40 (1975).
- (311) P. W. Palmberg, *Surf. Sci.*, **25**, 104 (1971).
- (312) C. R. Helms, H. P. Bonzel, and S. Kelemen, *J. Chem. Phys.*, **65**, 1773 (1976).
- (313) B. Lang, P. Légaré, and G. Maire, *Surf. Sci.*, **47**, 89 (1975).
- (314) G. Kneringer and F. P. Netzer, *Surf. Sci.*, **49**, 125 (1975).
- (315) G. Pirug, G. Broden, and H. P. Bonzel, *Proc. Int. Vac. Congr., 7th, and Int. Conf. Solid Surf.*, **3rd**, 907 (1977).
- (316) G. Broden, G. Pirug, and H. P. Bonzel, *Surf. Sci.*, **72**, 45 (1978).
- (317) F. P. Netzer and G. Kneringer, *Surf. Sci.*, **51**, 526 (1975).
- (318) H. P. Bonzel and G. Pirug, *Surf. Sci.*, **62**, 45 (1977).
- (319) H. P. Bonzel, G. Broden, and G. Pirug, *J. Catal.*, **53**, 96 (1978).
- (320) T. E. Fischer and S. R. Kelemen, *Surf. Sci.*, **69**, 1 (1977).
- (321) T. E. Fischer and S. R. Kelemen, *J. Vac. Sci. Technol.*, **15**, 607 (1978).
- (322) S. J. White and D. P. Woodruff, *Surf. Sci.*, **63**, 254 (1977).

- (323) S. J. White, D. P. Woodruff, B. W. Holland, and R. S. Zimmer, *Surf. Sci.*, **74**, 34 (1978).
- (324) S. J. White, D. P. Woodruff, B. W. Holland, and R. S. Zimmer, *Surf. Sci.*, **68**, 457 (1977).
- (325) T. Sakurai and H. D. Hagstrum, *Phys. Rev. B*, **14**, 1593 (1976).
- (326) J. J. Lander and J. Morrison, *J. Chem. Phys.*, **37**, 729 (1962).
- (327) A. P. Janssen and R. C. Schoonmaker, *Surf. Sci.*, **55**, 109 (1976).
- (328) M. A. Chesters, B. J. Hopkins, and M. R. Leggett, *Surf. Sci.*, **43**, 1 (1974).
- (329) T. N. Taylor, C. A. Colmenares, R. L. Smith, and G. A. Somorjai, *Surf. Sci.*, **54**, 317 (1976).
- (330) B. J. Hopkins, G. D. Watts, and A. R. Jones, *Surf. Sci.*, **52**, 715 (1975).
- (331) C. A. Papageorgopoulos and J. M. Chen, *Surf. Sci.*, **39**, 313 (1973).
- (332) A. M. Bradshaw, D. Menzel, and M. Steinkilberg, *Proc. Int. Conf. Solid Surf.*, **2nd**, 841 (1974).
- (333) E. Bauer, H. Poppa, and Y. Viswanath, *Surf. Sci.*, **58**, 578 (1976).
- (334) S. Prigge, H. Niehus, and E. Bauer, *Surf. Sci.*, **65**, 141 (1977).
- (335) J. L. Desplat, *Proc. Int. Conf. Solid Surf.*, **2nd**, 177 (1974).
- (336) P. E. Luscher and F. M. Propst, *J. Vac. Sci. Technol.*, **14**, 400 (1977).
- (337) R. Jaeger and D. Menzel, *Surf. Sci.*, **63**, 232 (1977).
- (338) B. J. Hopkins, A. R. Jones, and R. I. Winton, *Surf. Sci.*, **57**, 266 (1976).
- (339) S. Usami and T. Nakagima, *Proc. Int. Conf. Solid Surf.*, **2nd**, 237 (1974).
- (340) J. E. Demuth, D. W. Jepsen, and P. M. Marcus, *Phys. Rev. Lett.*, **31**, 540 (1973).
- (341) H. A. Engelhardt, A. M. Bradshaw, and D. Menzel, *Surf. Sci.*, **40**, 410 (1973).
- (342) G. Rovida and F. Pratesi, *Surf. Sci.*, **52**, 542 (1975).
- (343) W. Helland, F. Iberl, E. Taglauer, and D. Menzel, *Surf. Sci.*, **53**, 383 (1975).
- (344) E. Zanazzi, M. Maglietta, U. Bardi, F. Jona, D. W. Jepsen, and P. M. Marcus, *Proc. Int. Vac. Congr., 7th and Int. Conf. Solid Surf.*, **3rd**, 2447 (1977).
- (345) R. A. Marbrow and R. M. Lambert, *Surf. Sci.*, **61**, 317 (1976).
- (346) G. Gafner and R. Feder, *Surf. Sci.*, **57**, 37 (1976).
- (347) B. E. Nieuwenhuys and G. A. Somorjai, *Surf. Sci.*, **72**, 8 (1978).
- (348) J. L. Taylor and W. H. Weinberg, *J. Vac. Sci. Technol.*, **15**, 590 (1978).
- (349) E. B. Bas, P. Hafner, and S. Klausner, *Proc. Int. Vac. Congr. 7th and Int. Conf. Solid Surf.*, **3rd**, 881 (1977).
- (350) T. Miura and Y. Tuzi, *Proc. Int. Conf. Solid Surf.*, **2nd**, 85 (1974).
- (351) L. Peralta, Y. Berthier, and J. Oudar, *Surf. Sci.*, **55**, 199 (1976).
- (352) S. Andersson, J. B. Pendry, and P. M. Echenique, *Surf. Sci.*, **65**, 539 (1977).
- (353) J. Kùppers, *Surf. Sci.*, **36**, 53 (1973).
- (354) D. F. Mitchell and P. B. Sewell, *Proc. Int. Vac. Congr., 7th and Int. Conf. Solid Surf.*, **3rd**, 963 (1977).
- (355) D. F. Mitchell, P. B. Sewell, and M. Cohen, *Surf. Sci.*, **69**, 310 (1977).
- (356) H. H. Madden, J. Kùppers, and G. Ertl, *J. Chem. Phys.*, **58**, 3401 (1973).
- (357) H. H. Madden and G. Ertl, *Surf. Sci.*, **35**, 211 (1973).
- (358) H. H. Madden, J. Kùppers, and G. Ertl, *J. Vac. Sci. Technol.*, **11**, 190 (1974).
- (359) T. N. Taylor and P. J. Estrup, *J. Vac. Sci. Technol.*, **10**, 26 (1973).
- (360) T. N. Taylor and P. J. Estrup, *J. Vac. Sci. Technol.*, **11**, 244 (1974).
- (361) G. L. Price, B. A. Sexton, and B. G. Baker, *Surf. Sci.*, **60**, 506 (1976).
- (362) M. Wilf and P. T. Dawson, *Surf. Sci.*, **65**, 399 (1977).
- (363) R. Ducros and R. P. Merrill, *Surf. Sci.*, **55**, 227 (1976).
- (364) R. M. Lambert and C. M. Comrie, *Surf. Sci.*, **46**, 61 (1974).
- (365) P. D. Reed and R. M. Lambert, *Surf. Sci.*, **57**, 485 (1976).
- (366) R. M. Lambert, *Surf. Sci.*, **49**, 325 (1975).
- (367) Y. Berthier, J. Oudar, and M. Huber, *Surf. Sci.*, **65**, 361 (1977).
- (368) H. P. Bonzel and R. Ku, *J. Chem. Phys.*, **58**, 4617 (1973).
- (369) R. A. Marbrow and R. M. Lambert, *Surf. Sci.*, **67**, 489 (1977).
- (370) T. W. Orent and R. S. Hansen, *Surf. Sci.*, **67**, 325 (1977).
- (371) R. Ku, N. A. Gjostein, and H. P. Bonzel, *Surf. Sci.*, **64**, 465 (1977).
- (372) P. D. Reed, C. M. Comrie, and R. M. Lambert, *Surf. Sci.*, **59**, 33 (1976).
- (373) P. D. Reed, C. M. Comrie, and R. M. Lambert, *Surf. Sci.*, **72**, 423 (1978).
- (374) P. D. Reed, C. M. Comrie, and R. M. Lambert, *Surf. Sci.*, **64**, 603 (1977).
- (375) T. Sakurai and H. D. Hagstrum, *J. Vac. Sci. Technol.*, **13**, 807 (1976).
- (376) W. J. Lo, Y. W. Chung, and G. A. Somorjai, *Surf. Sci.*, **71**, 199 (1978).
- (377) M. A. VanHove, S. Y. Tong, and M. H. Elconin, *Surf. Sci.*, **64**, 85 (1977).
- (378) G. C. Wang, T. M. Lu, and M. G. Lagally, *Proc. Int. Vac. Congr., 7th and Int. Conf. Solid Surf.*, **3rd**, A2726 (1974).
- (379) J. M. Baker and D. E. Eastman, *J. Vac. Sci. Technol.*, **10**, 223 (1973).
- (380) J. C. Buchholz and M. G. Lagally, *J. Vac. Sci. Technol.*, **11**, 194 (1974).
- (381) J. C. Buchholz and M. G. Lagally, *Phys. Rev. Lett.*, **35**, 442 (1975).
- (382) K. Besocke and S. Berger, *Proc. Int. Vac. Congr. 7th and Int. Conf. Solid Surf.*, **3rd**, 893 (1977).
- (383) T. E. Madey and J. T. Yates, *Surf. Sci.*, **63**, 203 (1977).
- (384) T. Engel, H. Niehus, and E. Bauer, *Surf. Sci.*, **52**, 237 (1975).
- (385) J. C. Buchholz, G. C. Wang, and M. G. Lagally, *Surf. Sci.*, **49**, 508 (1975).
- (386) M. A. VanHove and S. Y. Tong, *Phys. Rev. Lett.*, **35**, 1092 (1975).
- (387) E. Bauer and T. Engel, *Surf. Sci.*, **71**, 695 (1978).
- (388) N. R. Avery, *Surf. Sci.*, **41**, 533 (1974).
- (389) Ch. Steinbrüchel and R. Gomer, *Surf. Sci.*, **67**, 21 (1977).
- (390) Ch. Steinbrüchel and R. Gomer, *J. Vac. Sci. Technol.*, **14**, 484 (1977).
- (391) N. R. Avery, *Surf. Sci.*, **43**, 101 (1974).
- (392) W. Göpel, *Surf. Sci.*, **62**, 165 (1977).
- (393) R. A. Marbrow and R. M. Lambert, *Surf. Sci.*, **71**, 107 (1978).
- (394) H. Papp and J. Pritchard, *Surf. Sci.*, **53**, 371 (1975).
- (395) R. E. Kirby, C. S. McKee, and M. W. Roberts, *Surf. Sci.*, **55**, 725 (1976).
- (396) G. Maire, P. Bernhardt, P. Lègaré, and G. Lindauer, *Proc. Int. Vac. Congr. 7th and Int. Conf. Solid Surf.*, **3rd**, 861 (1977).
- (397) K. Schwaha and E. Bechtold, *Surf. Sci.*, **65**, 277 (1977).
- (398) F. P. Netzer and R. A. Wille, *J. Catal.*, **51**, 18 (1978).
- (399) F. P. Netzer and R. A. Wille, *Proc. Int. Vac. Congr., 7th and Int. Conf. Solid Surf.*, **3rd**, 927 (1977).
- (400) K. Christmann and G. Ertl, *Surf. Sci.*, **60**, 365 (1976).
- (401) J. Gland, *Surf. Sci.*, **71**, 327 (1978).
- (402) D. G. Castner and G. A. Somorjai, *Surf. Sci.*, in press.
- (403) G. Ertl and M. Plancher, *Surf. Sci.*, **48**, 364 (1975).
- (404) B. J. Hopkins and G. D. Watts, *Surf. Sci.*, **44**, 237 (1974).
- (405) T. Engel, T. von dem Hagen, and E. Bauer, *Surf. Sci.*, **62**, 361 (1977).
- (406) E. Gillet, J. C. Chiarena, and M. Gillet, *Surf. Sci.*, **67**, 393 (1977).
- (407) M. E. Bridge, R. A. Marbrow, and R. M. Lambert, *Surf. Sci.*, **57**, 415 (1976).
- (408) J. C. Buchholz and G. A. Somorjai, *J. Chem. Phys.*, **66**, 573 (1977).
- (409) L. L. Atanasoska, J. C. Buchholz, and G. A. Somorjai, *Surf. Sci.*, **72**, 189 (1978).
- (410) G. Brodén, T. Rhodin, and W. Capehart, *Surf. Sci.*, **61**, 143 (1976).
- (411) C. A. Papageorgopoulos and J. M. Chen, *Surf. Sci.*, **39**, 283 (1973).
- (412) D. E. Eastman and J. E. Demuth, *Proc. Int. Conf. Solid Surf.*, **2nd**, 827 (1974).
- (413) J. E. Demuth, *Surf. Sci.*, **69**, 365 (1977).
- (414) G. Dalmaj-Imelik, J. C. Bertolini, J. Massardier, J. Rousseau, and B. Imelik, *Proc. Int. Vac. Congr., 7th and Int. Conf. Solid Surf.*, **3rd**, 1179 (1977).
- (415) J. C. Bertolini, G. Dalmaj-Imelik, and J. Rousseau, *Surf. Sci.*, **67**, 478 (1977).
- (416) C. Casalone, M. G. Cattania, M. Simonetta, and M. Tescari, *Surf. Sci.*, **62**, 321 (1977).
- (417) K. Horn, A. M. Bradshaw, and K. Jacobi, *J. Vac. Sci. Technol.*, **15**, 575 (1978).
- (418) F. C. Schouter, E. W. Kaleveld, and G. A. Bootsma, *Surf. Sci.*, **63**, 460 (1977).
- (419) J. G. McCarty and R. J. Madix, *J. Catal.*, **38**, 402 (1975).
- (420) J. G. McCarty and R. J. Madix, *J. Catal.*, **48**, 422 (1977).
- (421) N. M. Abbas and R. J. Madix, *Surf. Sci.*, **62**, 739 (1977).
- (422) G. Maire, J. R. Anderson, and B. B. Johnson, *Proc. R. Soc. London, Ser. A*, **320**, 227 (1970).
- (423) L. L. Kesmodel, R. C. Baetzold, and G. A. Somorjai, *Surf. Sci.*, **66**, 299 (1977).
- (424) P. C. Stair and G. A. Somorjai, *J. Chem. Phys.*, **66**, 573 (1977).
- (425) W. H. Weinberg, H. A. Deans, and R. P. Merrill, *Surf. Sci.*, **41**, 312 (1974).
- (426) B. Lang, *Surf. Sci.*, **53**, 317 (1975).
- (427) L. E. Firment and G. A. Somorjai, *J. Chem. Phys.*, **66**, 2901 (1977).
- (428) P. C. Stair and G. A. Somorjai, *J. Chem. Phys.*, **67**, 4361 (1977).
- (429) J. L. Gland and G. A. Somorjai, *Surf. Sci.*, **38**, 157 (1973).
- (430) J. L. Gland and G. A. Somorjai, *Surf. Sci.*, **41**, 387 (1974).
- (431) T. E. Fischer and S. R. Kelemen, *Surf. Sci.*, **69**, 485 (1977).
- (432) T. E. Fischer, S. R. Kelemen, and H. P. Bonzel, *Surf. Sci.*, **64**, 85 (1977).
- (433) F. P. Netzer, *Surf. Sci.*, **52**, 709 (1975).
- (434) M. E. Bridge and R. M. Lambert, *J. Catal.*, **46**, 143 (1977).
- (435) M. E. Bridge and R. M. Lambert, *Surf. Sci.*, **63**, 315 (1977).
- (436) R. Ducros, M. Housley, M. Alnot, and A. Cassuot, *Surf. Sci.*, **71**, 433 (1978).
- (437) Y. W. Chung, W. Siekhaus, and G. A. Somorjai, *Surf. Sci.*, **58**, 341 (1976).