

### The Origin of the "Extra Rings" in Electron Diffraction Patterns<sup>1</sup>

The diffraction patterns produced by electrons differ from the diffraction pattern produced by x-rays not only in the intensity distribution but also in the appearance of new lines.

These can be produced (a) by surface layers, since cross gratings may also produce sharp rings and (b) by the refraction of electrons on "electron smooth" surfaces. If the electron beam enters and leaves at the same crystal surface the Bragg equation  $\sin \vartheta = n\lambda/2d$  has to be replaced by  $\sin \vartheta' = n\lambda/2d(1 - 4d^2 V_0/150n^2)^{1/2}$  and this may lead also to the appearance of lines not existing in the x-ray diffraction pattern. For low velocity electrons it has been found<sup>2</sup> that between the ordinary interference maxima there appear new maxima at a distance halfway between the regular maxima (so-called "fractional orders"). It has been assumed that these are due to an adsorbed gas layer (e.g., hydrogen).<sup>4</sup>

In the case of fast electrons, rings have been observed which are entirely inside the ordinary diffraction pattern and which also have been interpreted as fractional orders.<sup>5</sup> There is no theoretical reasoning to lead to the existence of such fractional orders.

During the last two years we have been using a new method<sup>6</sup> for making thin films for electron diffraction. The substance to be investigated is deposited in a high vacuum upon a volatile material which is later pumped off, leaving the free film. For most experiments purest naphthalene has been used. The following substances have been investigated: aluminum, cadmium, copper, cuprous oxide, gold, lead, lead oxide, nickel, silicon and silver. For all these substances we have found electron diffraction patterns containing sharp "inner rings" in positions similar to those reported by Rupp for gold. It is possible to interpret these rings as fractional orders of the ordinary interference maxima. Such an interpretation would necessarily lead to the expectation that the values of  $\sin \vartheta/\lambda$  are different for different substances. Table I gives a summary of the values of  $\sin \vartheta/\lambda$

TABLE I.  $\sin \vartheta/\lambda$  for various substances and "inner rings."

Ag		0.107	0.121	0.134	(0.141)		0.178
Al	0.077		.121		.137		
Au		.106	.121	.134			.178
Cu+Cu <sub>2</sub> O		.106	.120	.134			
Cd		.108	.118		.138		
Ni		.105	.120	.133			.174
Pb	0.058	0.080	.105	.121		.138	
Si		.107	.120	.133			0.146
Au(R)	0.054	.061	.072	.082	.108	.124	.176
C <sub>10</sub> H <sub>8</sub>		.068	.077	.108	.120	.134	.140 .147 0.165 .175

as observed in our experiments. For comparison we have added the values from Rupp's work on gold. (Au(R) in table).

The values of  $\sin \vartheta/\lambda$  are identical for the different substances indicating that the diffraction pattern is not due to the substance itself but to an adsorbed surface layer. Since our films were produced by depositing on naphthalene we suspected that a thin layer of naphthalene might be responsible for the diffraction pattern observed.<sup>7</sup> An x-ray

powder pattern of the naphthalene used in our experiments gave values for  $\sin \vartheta/\lambda$ , most of which are identical with the ones of the extra inner electron diffraction rings. The similar values which Rupp has found for  $\sin \vartheta/\lambda$  in the absence of naphthalene are apparently due to adsorbed layers of organic substances which have similar spacing due to the similar C-C distances. Rupp states expressly that his rings cannot be due to traces of grease vapor since at the high voltages used (200 kv) the vacuum would break down in the presence of vapor. We have found that the adsorbed layers cannot be driven off by heating the film up to 500°C and also withstand electron bombardment.

The fact that the rings appear extremely sharp leads to the conclusion that we are dealing not only with thin crystal layers but with random orientated cross gratings. Also in this case, as has been shown by Laue,<sup>8</sup> sharp diffraction patterns are observed. This conclusion is further supported by the intensity distribution which shows characteristic differences from the distribution in space lattices.<sup>9</sup> The intensity sets in sharply at a certain angle and falls off from there. In some of our diffraction patterns we observe a blackening starting from one ring and filling continuously the interval on the plate to the next ring.

Recently we have been able to obtain thin films for electron diffraction by depositing on ammonium chloride which is later driven off by heating to 200°C in a vacuum. In this case no "inner rings" have been observed.

That these rings can be produced by contact with organic vapors (grease, oil) we have shown in the following manner: Two gold films have been made under exactly the same conditions. One film was exposed to organic vapors (from a grease joint), the other one was held in a perfect vacuum. The first film gave "inner rings," the second not. After exposing the second film to grease vapor the "inner rings" have been observed too. Our experiments seem to indicate that even the presence of small naphthalene nuclei, so sparsely distributed that they themselves will not give a diffraction pattern, will induce the deposition of other organic matter which will then produce cross gratings responsible for the "inner rings" observed.

Summarizing we conclude that the so-called fractional orders, as observed in the diffraction of fast electrons, are due to adsorbed layers of organic substances forming thin crystalline layers and random orientated cross gratings.

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<sup>2</sup> K. Lark-Horovitz and H. J. Yearian, *Phys. Rev.* **43**, 376 (1933).

<sup>3</sup> L. H. Germer, *Zeits. f. Physik* **54**, 408 (1929); E. Rupp, *Ann. d. Physik* **5**, 453 (1930).

<sup>4</sup> This interpretation, however, is difficult to understand because of the strong intensity of the fractional orders.

<sup>5</sup> E. Rupp, *Ann. d. Physik* **10**, 933 (1931).

<sup>6</sup> K. Lark-Horovitz, H. J. Yearian and E. M. Purcell, *Phys. Rev.* **45**, 123 (1934); J. D. Howe and E. M. Purcell, *Phys. Rev.* **47**, 329 (1935).

<sup>7</sup> The experiments with Au, Ag, Cu, Cu<sub>2</sub>O, Cd, Ni deposited on naphthalene and interpreted as above have been reported at the Pittsburgh meeting of the Am. Phys. Soc.

<sup>8</sup> M. Laue, *Zeits. f. Krist.* **82**, 127 (1932).

<sup>9</sup> A. Steinheil, *Zeits. f. Physik* **89**, 50 (1934).