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Some Electron Interference Experiments and Their Theoretical Interpretation

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Description and interpretation of some interference experiments in which an electron wave front is split up in two or more coherent parts by means of material diaphragms, electric or magnetic fields.

The following is a short survey over some research works on electron interference done in Tübingen.

1. Measurement of inner potential in an electron interferometer (M. Keller)

In an electrostatic biprism (Möllenstedt and Düker 1956) a monochromatic electron beam from a fine linear source (width 170 Å) is split up in two coherent parts which, when recombined in a plane of observation behind the biprism, give a pattern of parallel equidistant fringes of which more than 2000 could be observed. If one of the partial beams is passing through a phase shifting object, a fringe shift corresponding to the increase of the electron optical path length can be measured (Fig. 1). The phase objects were prepared by evaporating the material to be investigated through a fine mesh screen on a carbon film with a uniform layer of the same material. The thicknesses of the substrate and of the evaporated steps were measured by light optical multiple beam interferometry (Tolansky 1948). From the electron optical refraction index the following values of inner potentials were calculated: C (evaporated): 7,8±0,6 V; Al: 13,0±0,4 V; Cu: 23,5±0,6 V; Ag: 17≈22 V; Au: 22≈27 V. The inner potentials of Ag and Au varied with the rate of evaporation. The measured values of the inner potential were independent on thickness of substrate, steps, electron energy, current density and time of irradiation.

2. Interference phenomena in the caustic of a magnetic quadrupole lens (E. Krimmel)

In the electrostatic biprism the beam is interrupted by the charged thread. Krimmel's original intention was to realize a magnetic biprism in which there was no material obstacle between the two coherent parts of the split up beam. For this purpose he used a magnetic quadrupole which formed two antiparallel homogeneous fields on both sides of the beam axis. The resulting interference

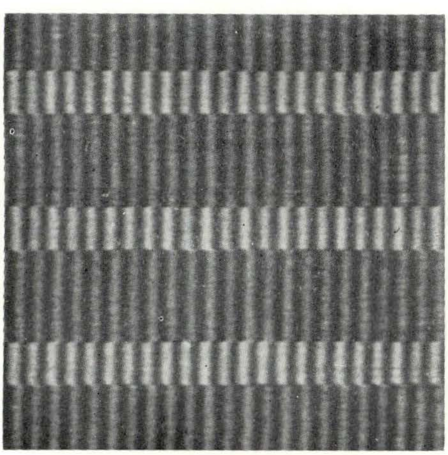


Fig. 1. Shift of fringes in the electron interferometer (Keller).

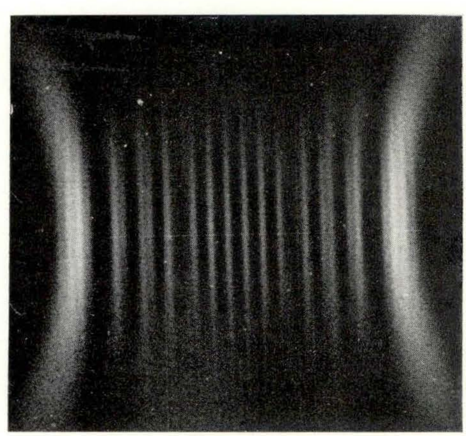


Fig. 2. Interference in the caustic of a magnetic quadrupole (Krimmel).

pattern, however, was not that characteristic for the superposition of two beams from two linear coherent sources but of three. The observed pattern (Fig. 2) can well be explained by constructing the envelope and the orthogonal trajectories of the electron rays and calculating the intensity distribution by means of the Kirchhoff formula. A general expression for the intensity distribution in the near vicinity of any regular caustic surface was derived.

3. Interference microscopy (R. Buhl)

In an electron interference microscope, in contrast to a normal electron microscope, the imaging beam is split up in two coherent parts by an electrostatic biprism. Each of these two parts forms a normal electron microscopical image in the image plane conjugate to the specimen plane (Fig. 3). But since these two images are shifted from each other by the action of the biprism they overlap within a narrow strip in which interference fringes can be observed. If the electron optical index of refraction within one of the two strips in the specimen corresponding to this image strip varies, the difference in electron optical path length in the specimen can be calculated from the shift of the fringes in the image (Fig. 4).

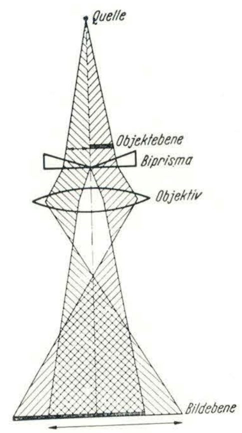


Fig. 3. Electron interference microscope (Buhl).

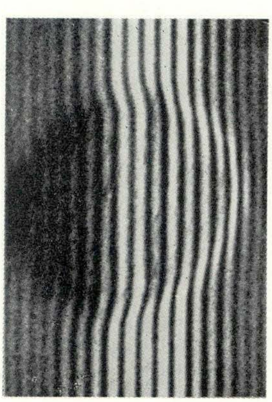
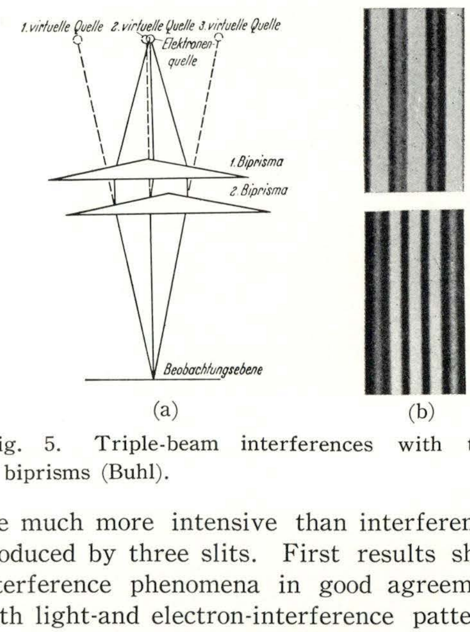


Fig. 4. Interference microscopical image of a 231 Å thick Al disk on an Al substrate (Buhl).

4. Production of triple-beam interferences with two electrostatic biprisms (R. Buhl)

In an arrangement consisting of two electrostatic biprisms, in which the threads and the linear electron source are parallel but not exactly coplanar, the electron beam is split up in three coherent parts, one passing on each side of both threads, and one between them (Fig. 5). Such triple beam-interferences



(a) (b)

Fig. 5. Triple-beam interferences with two biprisms (Buhl).

are much more intensive than interferences produced by three slits. First results show interference phenomena in good agreement with light-and electron-interference patterns known from experiments with three slits and with theory. It is intended to use such triple-beam-interferences for the measurement of inner potentials and for interference microscopy.

5. Interferences with three and more slits (C. Jönsson)

Fine slits of 50 μ length, 0,3 μ width and 1 μ mutual distance were prepared in the following way: A glass plate covered with an evaporated silver film of about 200 Å thickness was irradiated with an electron line focus.

A contamination film of very low electrical conductivity is formed at places subjected to high current density. These places remain free of copper in a subsequent electrolytic treatment. When the copper film is stripped a self supporting grating is obtained. The interference phenomena observed with 1, 2, 3, 4 and 5 slits are in good agreement with the results of corresponding light optical experiments and with theory (Fig. 6).

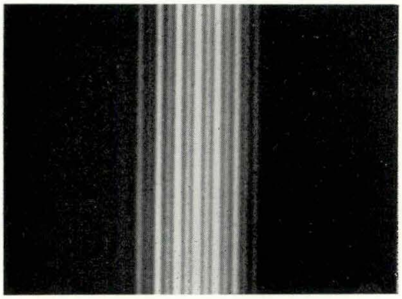


Fig. 6. Electron diffraction by three equidistant slits (Jönsson).

6. Wide separation of partial beams (W. Bayh)

For some experiments it is desirable to have the interfering partial beams wide apart, e.g. for the investigation of phase shifts by magnetic flux confined to a solenoid coil. In this case one biprism thread is not sufficient.

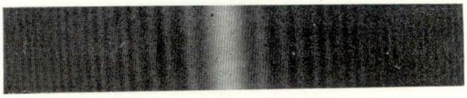


Fig. 7. Interference with widely separated beams (Bayh).

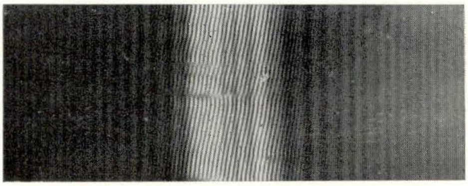


Fig. 8. Interference pattern in case of misalignment (Bayh).

An arrangement suitable for this purpose makes use of three biprism threads parallel and coplanar with the line source. The first and third thread have a negative and the second thread a positive charge. The fringe distance can be controlled by the charge of the third thread, and the beam separation is maximal near the second thread. It was possible to observe two-beam-interferences with a beam separation of as much as 60 μ (Fig. 7). It is to be noted that in case of a small misalignment the interference fringes are not parallel with the outer Fresnel fringes even if no coil or wire conducting magnetic flux is used within the arrangement (Fig. 8).

DISCUSSION

M. Blackman: The value of the inner potential of copper (23 volts) seems rather high. What does the Bethe theory give?

F. Lenz: I did not say that the agreement of theoretical and experimental values is very good, but it may be said that the order of magnitude is the same and that a general trend of increasing inner potential with increasing packing density can be observed. Differences of theoretical and experimental values of 2 or 3 volts may in the present stage be regarded as not too great.

R. Uyeda: (1) Is your result reproducible? (2) Do you think that the packing of amorphous carbon is loose? Or do you think that the packing is dense but with many vacancies?

F. Lenz: The measured values of inner potential were well reproducible. The values for carbon are averaged over 350 single measurements ranging from 7.1 to 8.9 eV. As to the packing density in evaporated carbon films, we concluded from electron diffraction images, which showed no sharp line, that the packing density would be lower than that of graphite or diamond.

P.P. Ewald: Some measurements were made by A. H. White and myself about 15 years ago upon the structure of deposited carbon. The crystallite size was exceedingly small with abnormally wide spacing normal to the basal plane but usual spacings within this plane.

L.F. MAYER: I would like to ask Dr. Lenz whether the experiment with the coil can be considered as an experimental proof of Aharonov and Bohm's theory?

F. LENZ: The experiment of Bayh to obtain widely separated coherent beams were made in connection with Aharonov and Bohm's paper on the significance of potentials in electron interference experiments. In a letter from Prof. Möllenstedt which I received a week ago, he informed me that they have succeeded in winding a solenoid coil of $12\,\mu$ diameter in Tübingen and that, with increasing electric current through this coil, a continuous movement of the interference fringes can be observed.

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Effets de Diffraction et d'Interférence dans les Images Electroniques; Formation de l'Image en Optique Electronique

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La théorie de la formation de l'image développée par les opticiens (optique de Fourier) est largement applicable en optique électronique. Les différences techniques entre l'optique classique et l'optique électronique sont secondaires à ce point de vue. Les effets de diffraction et d'interférence se traduisent de la même manière dans les deux cas, comme on le voit par l'influence d'un défaut de mise au point, ou l'influence de l'ouverture du condenseur. Ces résultats montrent qu'il est possible d'étendre à l'optique électronique les techniques de l'optique: microscopie interférentielle et contraste de phase, pour obtenir sur les objets des informations que ne contient pas l'image normale. La principale difficulté est la nécessité de respecter les conditions optiques de ces techniques, à l'échelle imposée par l'optique électronique.

The theory of image formation, which was developed for optics (Fourier optics) is to a large extent applicable to electron optics. From this point of view, the technical differences between classical optics and electron optics are negligible. Diffraction and interference effects can be interpreted in the same way in both cases, as can be seen by the influence of imperfect focussing or by that of the condenser opening.

These results show that optical techniques (interferential and phase contrast microscopy) can be applied to electron optics, in order to obtain, on the object, information that is not revealed by the normal image. The main difficulty arises from the fact that the optical conditions of these techniques must be obeyed on the scale of electron optics.

Le problème de la formation de l'image en microscopie électronique comprend deux parties distinctes:

1) l'action de la traversée de l'objet sur l'onde électronique incidente.

2) l'action du système de lentilles sur l'onde transmise par l'objet.

La première partie ne pose guère de problème en optique. Elle pose un problème délicat en optique électronique, en particulier pour une lame cristalline, parce que la longueur d'onde associée aux électrons est du même ordre que les dimensions atomiques. Nous parlerons très peu de cette partie, qui fait l'objet de recherches importantes. Nous dirons seulement que, si l'objet est assez mince pour donner de bonnes images, la fraction la plus importante de l'onde transmise