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A Michelson Interferometer Using Electron Waves*

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An electron interferometer of the Michelson type is realized. Monoenergetic 25 keV electrons emitted from a line source 1000 Å in width are deflected by 90° in a magnetic Castaing prism and reflected on two mirrors M_1 and M_2 held at a potential ΔU_M negative with respect to the cathode. In the experiment the mirrors are represented by height differences on the surface of an silvered glass plate. The reflected electrons are once more deflected by the magnetic prism behind which the coherent partial beams 1 and 2 reflected on the mirrors M_1 and M_2, respectively, are superimposed using an electrostatic biprism to form two-beam interferences. The observed fringe shift indicates a phase shift due to differences in height between the equipotentials reflecting the partial beams 1 and 2. It is estimated that path differences less than the electron wavelength of 0.08 Å can be observed.

Michelson's interferometer is one of the most interesting devices for the production of two-beam interferences of visible light. The principle is shown schematically in Fig. 1. Already in its first realization in 1881, Michelson used amplitude splitting in order to produce two coherent parts of the beam: The wave emitted from a source L is partly trans-

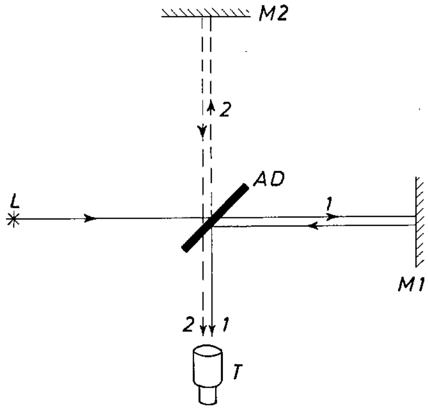

Fig. 1. Optical Michelson interferometer. L Light source; AD Amplitude Splitter; M_1 and M_2 Mirrors; *1* and *2* Coherent partial beams; T Telescope

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mitted (beam 1) through the semitransparent mirror AD while another part (beam 2) is reflected on the surface. The part of beam 1 which is reflected on mirror M_1 and AD is reunited with the part of beam 2 which is reflected on M_2 and transmitted through AD. The interference phenomena are observed in a telescope T adjusted to infinity. It is an important condition for this experiment that a sharp spectral line is used. In most cases the Cd 6438, 4916 Å line was used. Photographic recording permits a fringe shift of one thousandth of a fringe width to be measured. This corresponds to a displacement of 10^{-7} cm = 10 Å of one of the mirrors.

Since the wavelength λ_{El} of electrons in the practicable energy range is very much smaller than that of visible light (for an electron energy of 50 keV, λ_{El} equals 0.05 Å as compared with 5000 Å for visible light), the realization of a Michelson interferometer for electrons is rendered very difficult. We have, however, set up an arrangement permitting to realize in principle a Michelson electron interferometer. The arrangement is shown schematically in Fig. 2.

Instead of the amplitude splitting used in the optical interferometer we have preferred wave front splitting using the electrostatic biprism[1] which is more convenient for electron waves. 25 keV electrons emitted from a linear electron source ES 1000 Å in width are first deflected by 90° in a magnetic prism MF according to Castaing[2] and then reflected at equipotentials corresponding to the electron energy in front of the mirrors M_1 and M_2, respectively, which are held at a negative potential $-\Delta U_M$ with respect to the cathode. The mirror surfaces are highly polished and covered with a vacuum-deposited metallic layer. The coherent beams reflected on the mirrors are once more deflected in the magnetic field, and superimposed behind a biprism BP. In the plane of observation IP two-beam interferences are formed. The electron-optical properties of the system consisting of deflector and mirrors produce an image of the mirror surfaces in the same plane of observation IP.

In order to test the function of the setup, the two mirrors M_1 and M_2 were replaced by one mirror with variations of the height profile on it (see M_1 and M_2 in the lower part of Fig. 2). The height profile was produced as follows:

A well polished glass plate was covered with a vacuum-deposited Ag-layer about 500 Å in thickness. The randomly distributed disturbances on this surface served as an object for first investigations; experiments with artificially prepared height profiles did not yet succeed. The equipotentials in front of the object show corresponding indentations which

1 Möllenstedt, G., Düker, H.: Z. Physik **145**, 377 (1956).

2 Castaing, R., Slodzian, G.: Optique des rayons x et microanalyse, p. 48. Paris: Hermann 1965.

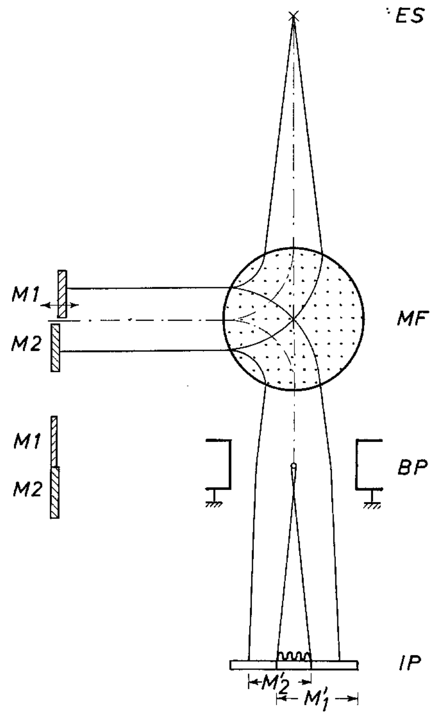

Fig. 2. Schematic representation of an electron interferometer of the Michelson type. *ES* Linear Electron Source, 1000 Å in width, 25 keV; *MF* Magnetic deflection prism according to R. Castaing; M_1 and M_2 Electron mirrors in different distances, realized by height steps on a mirror; *BP* Electron biprism; M_1' and M_2' Coherent superpositions of the partial waves in the plane of observation *IP*

become flatter and wider with increasing distance from the mirror surface.

Each part of the beam is reflected in front of a corresponding detail of the structure and therefore travels a path length in general different from that of another part of the beam[3].

This difference in path length, which gives rise to a shift in the interference fringes behind the biprism, depends very sensitively on the closest distance of approach of the electrons to the mirror surface which, in turn, depends on the potential difference between mirror and cathode.

A variation of the mirror potential of the order of a fraction of a volt is sufficient to produce observable variations in the fringe pattern. If the mirror is strongly negative, so that the electrons return at a larger

3 Lenz, F.: Following paper.

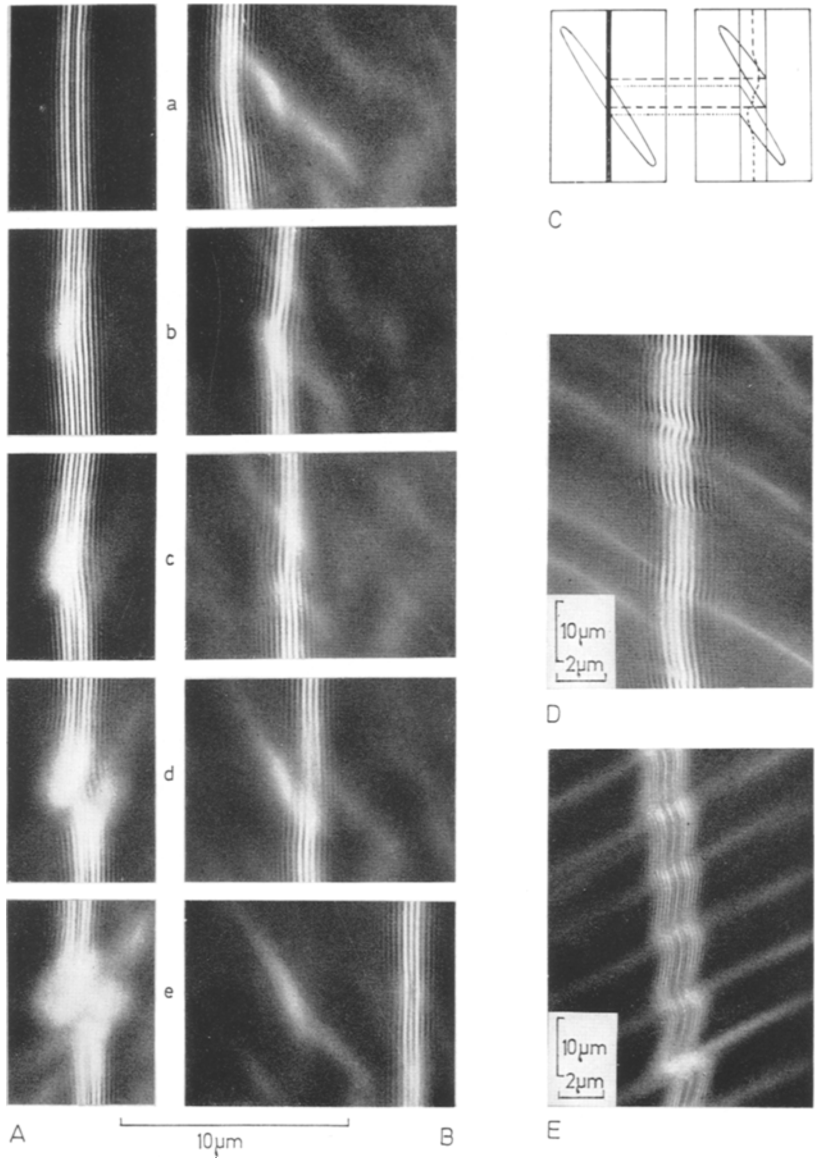

Fig. 3. Aa–e) Series of pictures with different potentials ΔU_M ($\Delta U_M = 7.6$, 4.7, 4.5, 4.2, 4.0 V). Ba–e) Series of pictures with different relative positions of the interference region and a certain object detail. C) Schematic diagram demonstrating the effect of "folding" the image plane by the biprism. D) Object with several small disturbances ($\Delta U_M = 4$ V). E) Object with grooves of varying depth and width (ca. 1 µm) drawn in an Al-layer with a fine diamond point: both partial beams are influenced in the same manner because the object is too rough. The interference field is swept as a whole with decreasing contrast

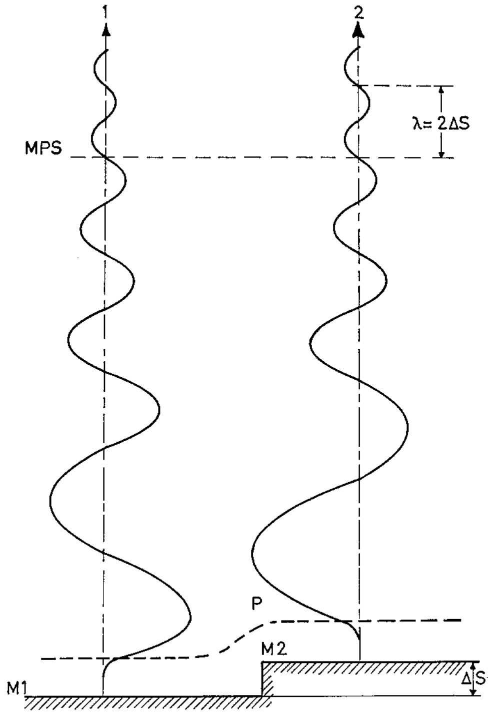

Fig. 4. Schematic visualization of the relation between a height difference ΔS on the mirror and the corresponding phase shift $\Delta\varphi$ in the reflected beam in the special case $\Delta S=\lambda/2, f=1$ i.e. $\Delta\varphi=2\pi$. (*MPS* Plane of Measurement of Phase Shift)

distance from the mirror, no phase shift is observed in the interferogram. If the mirror is made less negative, so that the electrons come closer, a phase shift becomes visible. This phase shift increases with increasing height difference and with decreasing retarding potential ΔU_M, as shown in Fig. 3A a–e. Fig. 3B a–e demonstrates the effect of the relative position of the interference region and image plane.

Under the simplifying assumption that a difference in height ΔS on the mirror surface displaces the whole retarding field by the same amount, and the wave fronts of the reflected electron wave by $f\cdot\Delta S$, a phase shift of 2π would be produced if $f\Delta S=\lambda_{\mathrm{El}}$ where λ_{El} is the electron wavelength before retardation and after reacceleration (Fig. 4) and f is a factor between 1 and 2^3. For 25 keV electrons, $\lambda_{\mathrm{El}}=0.08$ Å so that a step 0.04 to 0.08 Å in height on the mirror would produce a fringe shift by one fringe period.

The measurement of large path length differences is principally limited by the restricted monochromatism of the beam. The coherence length $\lambda^2/\Delta\lambda$ for 25 keV electrons with voltage variations below 1 V amounts to about 3700 Å corresponding to 49000 fringes. In the present stage it is hard to predict whether and how a mechanical, possibly thermal relative displacement of mirrors can be realized which is smooth enough to permit a continuous count of the movement of such fringes. We think, however, that the presented results show the principal feasibility of a Michelson electron interferometer using an arrangement of the type described. The experiments are being continued.

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