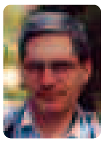
Fresnel's paradox, the Michelson experiment, and Einstein's axiom



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Üblicherweise wird das Michelson-Experiment als erste Grundlage der Relativitätstheorie gesehen. Zu dieser Grundlage wurde es aber erst nach Konstruktion der Relativitätstheorie. Es wird daran erinnert, dass der Michelson-Versuch zunächst das Fresnelsche Paradoxon der Aberration der Wellenfronten neu konstatierte.

Wellenfronten zeigen bei universell definierter Gleichzeitigkeit keine Aberration. Es war dieses Paradoxon, das Fresnel zwang, sich mit der Aberration von Wellengruppen zu begnügen. Diese Aberration von Wellengruppen erforderte allerdings wegen des Relativitätsprinzips die Existenz eines Äthers, der frei durch alle Materie strömte. Michelsons Experiment zeigte jedoch, dass dieser Äther von der Erde wie eine Atmosphäre mitgenommen wird. Erst Einsteins Axiom der Unabhängigkeit der Lichtgeschwindigkeit von der Bewegung des Messgeräts implizierte eine Aberration der Wellenfronten und machte Fresnels Konstruktion überflüssig. Deshalb wurde in der Folge das Ergebnis des Michelson-Experiments (gegen die begründeten Einwände Michelsons) als elementare Bestätigung des Einsteinschen Axioms angesehen.

In general, the result of the Michelson experiment is interpreted as the first foundation of the theory of relativity. This interpretation, however, is post festum. The experiment was designed to test the consequences of the effect of aberration in the wave picture of the propagation of light. When Young and Fresnel replaced the emanation picture with the wave picture, Fresnel found that there was no longer a way to produce an aberration of light wave-fronts. This was the only drawback of the wave picture of light propagation.

Fresnel explained the observable aberration as an effect on a wave group, and the aberration of wave-fronts is pushed into the unobservable background. The aberration of wave groups, nevertheless, requires a unique reference system of isotropic light propagation, and in order not to give up relativity, it must be material, i.e. some ether. This ether must be freely floating (just as an abstract reference system does with ease), and it was hard for Fresnel to convince his contemporaries of such a concept, given the fact that Copernicus had to convince people about the inverse, namely that the earth drags its atmosphere along while orbiting the sun.

Material or not, Fresnel's explanation implies anisotropic light propagation for the moving earth, and Michelson was the first to be able to measure this anisotropy with his interferometer. His conclusion was that Fresnel's explanation is wrong and that the ether is dragged along by the earth like an atmosphere. The paradox of aberration rose from the ashes.

With this interpretation, the experiment was just one of many, and there was no need for Einstein to cite it in particular when he found out that the axiom of an observer-independent velocity of light solves the known problems of electrodynamics in general and wave propagation in particular. There is no contradiction to his later attitude to see in the result of the Michelson experiment a basic backing of his axiom (although Michelson's experiment does not imply or prove the axiom, of course).

The aberration is a simple fact of the geometry of space-time, and the consequence of the aberration of wave-fronts is the relativity of simultaneity (Fig. 1).

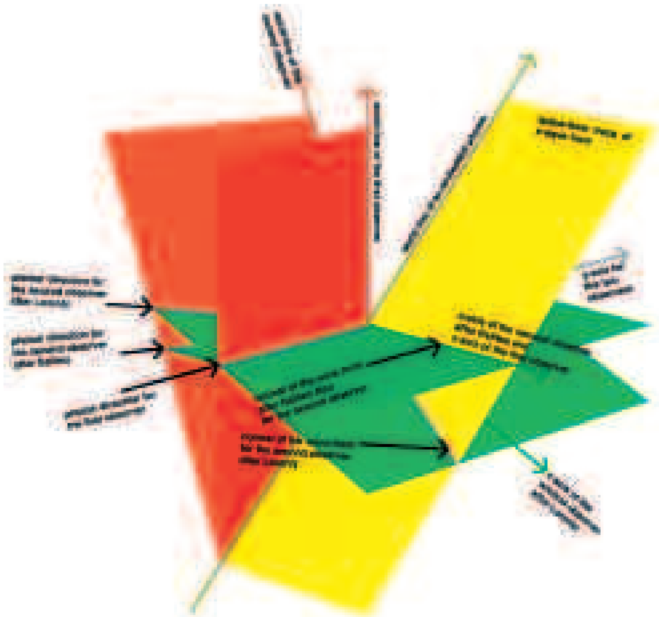

Fig.1 Aberration. A wave front is moving in the y direction, together with embedded particles. While the aberration of the particles depends on the behaviour of the projections of the particles' world-lines, the aberration of the wave-fronts depends on the behaviour of the intersections of the wave's trace. There is no aberration of the wave-front without relativity of simultaneity. The demand of equal aberration of wave-fronts and particles implies the Lorentz group.