THE PRINCIPLE OF RELATIVITY IN OPTICS

WALTER RITZ (1878-1909)

A translation of:
Prinzip der Relativität in der Optic
Gesammelte Werke, Œuvers, (Gauthier-Villars, Paris, 1911) pp. 509-518 .

A fundamental principle of mechanics, the Principle of Relativity, says, that uniform translation of a mechanical system has no effect on its internal interactions. The same holds for the absolute orientation of the system in space: i.e., an arbitrary rotation of the axes, does not change the form of the equations at all. These two statements can be combined to: the equations of motion remain unaltered if one, in place of the coordinates x,y,z, introduces new coordinates by means of linear transformations

$$\begin{aligned} x' &= \alpha_1 x + \beta_1 y + \gamma_1 z + v_1 t, \\ y' &= \alpha_2 x + \beta_2 y + \gamma_2 z + v_2 t, \\ z' &= \alpha_3 x + \beta_3 y + \gamma_3 z + v_3 t, \end{aligned}$$

where the α,β,γ are the direction cosines, that must satisfy so-called orthogonality conditions, and $\vec{v}$ is the translation velocity of the system.

The same pertains naturally to those effects, that are based on mechanical precesses within the matter of the system, such as acoustic, thermodynamic, etc.

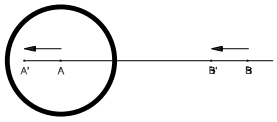
In sharp contrast, however, optical and electrodynamic processes do not conform in principle. Two theories, as is well known, have been competing for quite some time in the arena of optics. The *emission hypothesis* and the *undulatory or aether theory*. According to the first, energy is ejected from a luminous object in all directions. Whereas the second holds, that wavelike motion is engendered in aether that is considered to fill all space. Depending on which theory we select, the effect of translation of the source on the system has quite different consequences.

Let us first consider the emission theory. The energy parcels are ejected with a constant and uniform initial impulse, they then propagate in straight lines until they encounter another body, which deflects them. All these process steps are considered to be purely mechanical, so that the relativity principle is respected. When a body lights up, the ejected parcels form a uniformly expanding sphere for which the center remains collocated with the source particle, whether it is taken to be at rest or in uniform motion. Thus, optical phenomena are not altered by uniform translation.

For the *undulation theory,* the situation is different. If the medium of undulation, the aether, is at rest, and if the source particle is also at rest, then light would also expand away from the source in the form of a sphere. However, if the source particle is in motion, this process proceeds quite differently in that propagation is oriented on the aether instead of the source. After a give time, the following diagram depicts the situation. *The undulation theory implies, therefore, that motion of the source affects optical phenomena.*

Nowadays it is well known, that the emission theory for light, at least in the form that NEWTON gave it, has not withstood critical analysis, while the wave theory satisfactorily explains all optical effects. It was expected, for example, that the motion of the Earth must

have an influence on optical processes. so that when one uses sources that move together with the earth, the position of interference patterns etc. should depend on the orientation of the apparatus with respect to the Earth's motion, in other words, from the orientation with respect to the fixed stars. In any case, the theory in its fully developed formulation as found by LORENTZ, shows that this effect is very small and is expressed by *second order terms;* that is terms squared of the Earth's velocity over the speed of light; i.e., approximately one part in a hundred million.



The American physicist MICHELSON was the first to succeed at overcoming the difficult challenges of experimental verification. The surprising result was, that the expected influence of the motion of the Earth was not evident. Other experiments, some optical, some electrical, have verified this result, so that now one has become convinced that optical effects satisfy the relativity principle, and in this matter Nature is more scrupulous than physicists themselves.

Therefore, we are faced with the following dilemma: an *emission* theory satisfies the relativity principle, however, shall it be accepted generally, then it must undergo serious reformulations. The *undulatory* theory, that is otherwise completely satisfactory, is in conflict with the relativity principle. For the laws governing light, it is not only matter that is determinant, but also aether, for which its state of rest or motion is important. If one elects to exclude these aether effects, then deep changes in the concepts of 'time,' 'space' and 'motion' are necessary. The latter route is the one taken by LORENTZ, then EINSTEIN, and thereafter in a much deeper manner still, by MINKOWSKI, who is so sharply cleaved from science. In order to see what changes in the concept of 'time' are needed to reconcile the relativity principle with an undulatory theory, let us return to the figure. Let us regard A and B as two observers equipped with precision clocks. At time $t = 0$ let the first, A, launch a light pulse while B is to determine the time at which he registers it. Now it is known to be possible to place clocks at various points on the Earth that keep exact pace with its rotation so as to have the same rate. But, in order that they *simultaneously* indicate the same time, that is, run synchronously, it is necessary to accurately determine their geographical location. This could be achieved easily with an electrical signal that departed from one of the observers and propagated to the other at the speed of light. If, however, the time for B is determined using this method, then it is no longer possible to determine the speed of light, as, depending on the motion of the system, observer B will set his clock differently, and in order to determine this motion, he must have available to him other means to specify *simultaneity* at various locations. By means of various hypotheses we have to now *withdraw* this means from him.

To do so, it is first of all required that all forces, including gravity, obey the same laws with respect to propagation, in particular velocity, so that it is not possible to check one against the other. Now, however, B could, taking his clock with him, simply travel to A and compare its rate and synchronization with A's clock, then return and carry out experiments. Here, absolute motion makes itself felt, in that the rate of a clock in a moving system so depends on motion itself, that synchronization via motion could be modified exactly by the appropriate amount and that upon return the modification of the synchronization could be reversed. The rate of the clocks, with which we determine time at various locations, is provided by the standard clock A, and depends on the motion of the $A - B$ system. 'Time' determined in this way is clearly a *relative concept.* Two events at separate locations can

no longer be considered simultaneous *uncritically*, as such no long makes sense. If they are simultaneous for one observer, generally they are not for another in relative motion. *Two times*, which are for the first *identical*, are not for the second. In so far as velocities are ratios of displacements in time, the *axioms of kinematics* are no longer valid, the *parallelogram law* of the addition of velocities is no longer valid. If a particle of radium ejects electrons in opposite directions, each with a velocity of $250,000$ km/sec., the relative velocity of the two is not $500,000$ km/sec., rather, as given by a complicated formula to be $296,000$ km/sec.; i.e., the relative velocity remains below the speed of light, even if the absolute velocities were the speed of light.

Physicists often considers an idealized "*solid body*." Such an entity would have to *instantaneously* transmit mechanical influences. Such can not happen. Thus, this idealization is inadmissible.

Even *mass* becomes a relative concept. It depends on its velocity, but not from absolute velocity, as in earlier theories, rather from the relative velocity with respect to the *observer*. Two distinct observers with different relative velocities will then attribute *simultaneously distinct values to the same mass*.

Having met all these conditions, it is impossible for an observer to determine if a system is in uniform translation without aid of external systems: the principle of relativity is thereby satisfied. A few years ago, exactly these conditions would have been taken as untenable for a theory. Nowadays, however, MAXWELL's equations have become to such an extent axiomatic for electrodynamics and optics, that it seems one is prepared to let them trump all competing claims. *This is a remarkable fate* for a theory for which in its discoverer's lifetime was virtually universally ignored.

The hypotheses proposed by EINSTEIN and LORENTZ can be combined to the statement that by certain linear substitutions of the coordinates and time, equations for natural phenomena remain unaltered:

$$\mathbf{x}' = [\overleftrightarrow{A}]\mathbf{x},$$

where $\mathbf{x}$, denotes the 4-vector x,y,z,t and $[\overleftrightarrow{A}]$, a matrix with 6 independent parameters.

The distinction here from earlier theories is that the time, t, is included. The actual *essentials* of this transformation were recognized first by MINKOWSKI. We have already stressed, that in the usual conception, natural phenomena are not dependant on their orientation to absolute space, but rather only on their relative orientation. In addition to space coordinates, MINKOWSKI introduced as a fourth coordinate, taken in appropriate units, imaginary time. In earlier versions of the hypotheses, it was taken simply, that in this new 4-dimensional space, natural phenomena are independent of their orientation in space. This statement is substantially more satisfying that the EINSTEIN-LORENTZ hypothesis, that for its part has the advantage, of revealing the influence of our customary concepts. The latter substantially simplify the *mathematical* formulation of special problems, which unfortunately I can not go into here.

How does this matter look, when we retain the *classical* variant of the relativity principle and the universality of time, and seek to so reformulate the emission hypothesis that it preserves the laws of geometrical optics with all their virtues?

Such a program would appear at first to be without prospects, in so far as the differential equations of optics have proved so successful. LORENTZ's electron theory has motivated us to seek deeper insight. LORENTZ showed that the partial differential equations of his electrodynamics and optics can be replaced by forces between the charges of the light source and, in the final analysis, those of the observer's retina. Such forces are not so unlike gravity, but are distinguished by being dependant not only on positions, but also

the velocity and acceleration of the source charges. This modification appeared already in WEBER's famous formulation of electrodynamics. Moreover, the interaction of charge A on B is not, as is the case for gravity, dependant on the position of A at the moment t, rather at an earlier time corresponding to that needed for propagation between A and B.

Considering that all velocities are small but finite, we may speak then, in stead of a propagating wave, of propagating energy, the law of propagation is the same so long as the matter is at rest with respect to the aether. Only the pictorial representation that we make of this process is different. In stead of a periodic variation of a vector of light, we imagine a similarly periodic variation of energy. Just the fact that, as experiments on light pressure show, propagating energy can be given a magnitude, as if it were a material body in motion, minifests the utility of the image. A canon that fires a projectile, suffers a recoil, so too, would an object emitting an energy ray. And it makes better sense to talk of an 'amount' of motion, than to consider, as LORENTZ's theory would have it, a process in which there is no real motion of anything, and the aether remains at rest.

Thus, one sees of course, that for finite velocities, the imagery of an 'aether,' can be replaced by that of 'emission,' even if in the expression for force depending on position, velocity, etc., nothing is altered. But even this is actually not necessary. One can in various ways replace in the formula for force in the LORENTZ formulation the absolute velocities that appear there, but which have no place in an emission theory.

Let us turn now to the case of moving bodies, where the difference between these two laws with respect to light propagation is evident, to the advantage of an emission theory for uniform translation, while there the principle of relativity is respected. Moreover, it is well known that an emission theory very simply explains *aberration;* it's superiority vis-a-vis an undulatory theory was already emphasized by KIRCHHOFF. Detailed analysis of other phenomena shows, that in fact other experimental results can also be explained satisfactorily.

Regarding further advantages of an *emission* theory over the LORENTZ-EINSTEIN theory, I hold that its *economy of though* can not be over stressed. It is truly disturbing, when in the analysis of some physical problem, there always arrises a conflict between intuitive imagery and the laws of kinematics.

Finally, I would like to highlight the greater symmetry it offers in the description of natural processes. Consider two identical moving electrons, according to the old relativity principle, there should be an expression for the force one exercises on the other that depends only on the relative position and velocity, and for which there is no reason for an inequality between action and reaction. This is not the case for the LORENTZ formulation, where the forces depend not on the relative velocity, rather on velocities relative to the aether; and there is in general an inequality between action and reaction. even for uniform motion. This has the consequence, that a charged condenser at an angle to the direction of the motion of the Earth would experience a different torque compared with an uncharged condenser, so that by discharging, a slight rotation should be induced. This experiment was done by TROUTON and NOBLE: no such torque difference was seen. The LORENTZ-EINSTEIN relativity theory does not remove this dissymmetry, rather it compensates it with other forces, e.g., molecular forces, and through dimensional changes of material bodies. The same was found also for light propagation, experiments show, that in a system in motion light still propagates in a symmetric fashion, as if in a motionless system, whereas the usual law of light propagation requires dissymmetry. The emission theory simply removes this dissymmetry from the basic formula, while EINSTEIN's theory compensates them with dissymmetry in the concept of time.

The most significant advantage of an emission theory is that it accommodates the possibility to model *gravitation* as an electrical side effect, and indeed in such a way that the gravitational constant can be deduced *a priori* from electrical and molecular constants.

As is well known, the electron theory poses the image of an atom as being built up out of an equal number of positive and negative charges. On the basis of this model, ZÖLLNER and MOSOTTI attempted to explain gravity by assuming that the attraction of unlike charges slightly out weighted the repulsion of like charges. The ratio between electric and gravitational forces is extremely small, about one part in 10^{36}. This fact alone is easy to take as evidence, that the gravitational constant is not *a priori* derivable from other constants. The situation is the opposite in an emission theory. The appearance of *magnetism* requires in fact, that some of the charges in an atom are in motion. Just to have a specific image, let us assume that the positive charges rotate with a high velocity, which is the same for all of them. Such an atom would not evidence an electrostatic force, but certainly an *electrodynamic* one. In any case, in reality we actually always are concerned with objects comprised of many atoms, in which rotation axes would have all possible orientations, so we must consider the *average.* In the LORENTZ theory, this average would be null, as the effect of electric force is independent of its motion and the average for the positive and negative charges is zero. The effect of *magnetic* forces is proportional to the absolute velocity of the charge and changes its sign in accord with that of its velocity, so that rotation in the opposite senses cancel out, resulting in no force.

Already in WEBER's theory the same electromagnetic forces were represented by introduction of only *relative velocities* in expressions for force, and the reversal of a velocity did not reverse the force. The question arises, therefore, whether in the *general expression for the force* that two electrons in the emission theory exercise on each other, if such terms could be introduced without inconsistencies, which depend on relative velocities, and for which the average is not zero. That this is really so, consider, for example, that fourth order terms in the relative velocity and the inverse of the square of the separation, where the force in along the line between the particles. The average is different from zero, while the terms, being of fourth order, yield an extraordinarily small value. The coefficient depends on the number of rotating charges and the square of the imagined common rotation velocity. *It suffices to set the number of rotating charges equal to the mass of the atom* in order to get a law of gravitation, and the value of the gravitational constant expressed in terms of the electrical and molecular constants.

In this way gravity would be derived from electric energy, the same would be true of kinetic energy (through the concept of electromagnetic mass) and other forms of energy. This gives us reason to hope, that natural phenomena satisfy a postulate of *unity of energy*, a postulate which in the special form proposed by LORD KELVIN, HEINRICH HERTZ and others, is: all energy is kinetic energy. Simultaneously, we may expect, that the distribution and movement of energy in space for the description of natural phenomena will take a particularly simple form.

Translated by A. F. KRACKLAUER,