Title:

Analysis of the assumptions and results of the Ives-Stilwell experiment including energy and mass defect transformations and emitter eigenmode superposition.

Introduction:

The Ives-Stilwell experiment [1] (I-S) was intended to demonstrate the time dilation-induced difference in directional readings of the length of light quanta emitted from a fast moving object, predicted in the Special Theory of Relativity (STR). The assumptions were based on the axiom that the speed of light is constant towards each observer and equal to c, and on the resulting postulate of time dilation. The assumptions omitted the influence of a possible ether, which was eliminated from the 20th century theories by the experiments of Michelson-Morley, Kennedy-Thorndik, Sagnac, and their successors. The results of the experiment (I-S) were interpreted as the influence of both the relativistic Doppler effect based on the STR axiom of constant speed of light and the relativistic time reduction effect for a fast moving object. In this paper, I attempt to interpret the results both in terms of these assumptions and the broader contextual interpretation. The study also includes an analysis of the preliminary assumptions of the experiment.

1. Preliminary assumptions of the Ives-Stilwell experiment

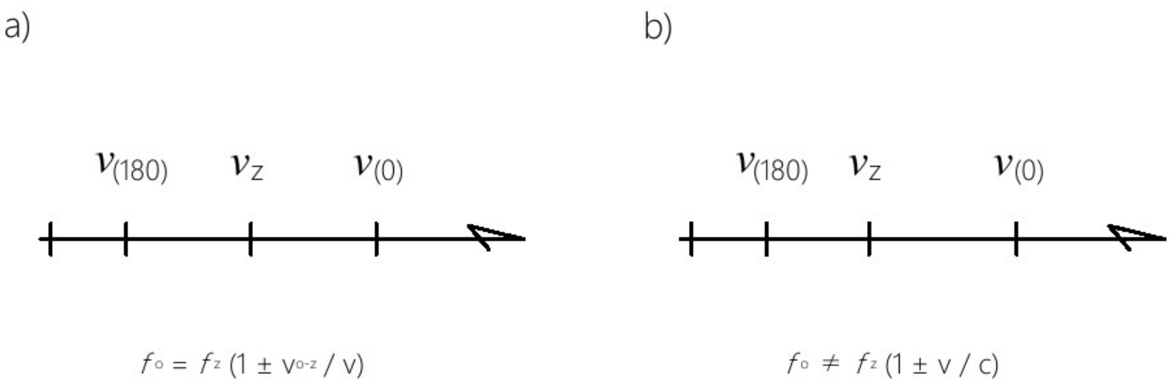
The emission of photons from accelerated hydrogen ions was observed in the experiment. The spectra of waves emitted in the direction congruent and opposite to the motion of the particles were compared assuming that the reference frequency is the frequency of emission from the state in which the ion is at rest. A possible symmetric distribution of deviations (1 + v/c and 1 - v/c) would indicate a classical Doppler effect. Distortions from symmetry would prove other than conventional mechanism of the effect, indicating STR.
The assumptions made for the experiment:
I) According to the external observer and according to STR, the speed of light is constant and equals c.
II) The systems of the external observer and the moving ion are inertial.
III) The speed of light is constant in all directions relative to the observer related to the ion system and equals c.
IV) There is no medium (ether) that carriers photons. The photon travels as an electromagnetic wave with a specific emission energy E_e, and the wavelength at the moment of emission has a finite value conventionally adopted as $\lambda_{e.}$.
V) All ions move at comparable speeds.
VI) The speed of light does not conventionally add up to the speed of the emitting system.
The expected value of the experiment is an asymmetric (with respect to the primary wave frequency) frequency distribution of the waves emitted in the direction congruent and opposite to the direction of the ion motion (Fig. 1b). A symmetric image (Fig. 1a) would contradict the STR assumptions. The starting point is the general formula for the Doppler effect for classical mechanics systems.

(1). $f_o = f_s (1 \pm v_{o\text{-}s} /v)$

where:

- f_s – assumed source frequency,
- f_o – frequency according to a stationary observer,
- $v_{o\text{-}s}$ – total speed of the observer and the source,
- v – speed of wave propagation in a given medium.

Fig. 1



As an asymmetric image was obtained, the experimenters concluded that the changes in the wave frequency depend on the time dilation of the moving emitter.

2. Analysis of preliminary assumptions and experimental results (I-S)

First of all, the reliance on the Doppler effect must be based on references. The previously quoted formula (1) is similar to the initial one,

(2). $f_o = f_s (v \pm v_0)/(v \mp v_s)$

which, for a stationary observer and a moving source, such as a locomotive for instance , takes the form

(3) $f_o = f_s v /(v \mp v_s)$

and its distribution is asymmetric as that which is supposed to prove time dilation, and which has not yet been considered here.

The assumption in line with STR that the speed of light is constant, with respect to a stationary observer, results in the formula to be verified, which by definition gives an image consistent with the assumptions (Fig. 1b).

(4) $f_o = f_s (c \pm 0)/(c \mp v_s) \rightarrow f_r = f_s v /(v \mp v_s) \rightarrow$ symmetric distribution.

Assuming that v = c and vo = 0, the formula for the frequency observed by a stationary observer has the form

(5) $fo = fs\ c/(c \mp vs)$

and, after taking into account time dilatation,

(6) $fo = \gamma^{-1} fs\, c/(c \mp vs)$
where γ is the Lorentz factor

Therefore, the experimental result (I - S) confirms the classical frequency asymmetry associated with emission from the moving system, irrespective of its speed compared to the speed of light. Additionally, the basic analysis of the results does not consider the energy changes of the system. Since, depending on the direction of emission, either congruent or opposite to the direction of the system’s motion, photons with energy different from the primary emitted E_e are obtained, it should be assumed that the system at the moment of emission is either accelerated at the expense of increasing the wavelength or decelerated at the expense of decreasing it.
In the case of a transverse effect, the direction of the system’s motion should change. This point was not investigated in this experiment. These effects occur, but because of the energy ratio of the atom and the photon, they may be imperceptible without a special approach to the subject. Changes in the photon energy in the context of STR and the thesis that the speed of light is constant towards each observer and equals c are hardly acceptable. After all, the position of the observer does not matter. To begin with, this speed is related to both the entire photon and any designated part of it. If something is moving away or approaching us at a certain speed, then the same speed has every part indicated by us and it does not depend on whether this something is divisible or not. In this case it is a quantum, which by its nature is indivisible. The only exception to this rule is when the object changes its dimension during the observed motion, but this case does not occur at the moment. Since the formation of a photon takes place at a specific time and place, i.e. in the vicinity of the electron changing its orbit, only this moment is taken into account. For the observer related to the ion system, the speed of light/quanta propagation is the same in each direction and is $c = \lambda_e/f_e$. Thus, regardless of the direction of motion, after a lapse of time this wavefront is at a distance of $t_e c$. Therefore, in accordance with STR, the Doppler effect cannot be assumed to arise in this reference system. On the other hand, for a stationary observer related to the measuring apparatus and the ion moving relative to it, the time in the ion system has dilated according to the Lorentz factor γ. Thus $t_e\gamma = t_{so}$, where t_e is the emission time and t_{so} is the stationary observer time. This factor is positive regardless of the direction of motion. Therefore, the reddening should be visible and the same for each direction of emission, which contradicts the experimental results. In accordance with STR, by the time one atomic clock cycle has passed in the ion system, the γ cycle has passed in the stationary observer system. Literally – one full cycle was over and another or yet another cycle was in progress. This, after all, is what the paradox of twins is all about. I draw attention here to the logical construction – at the time when (which takes the form of universal time) in the ion system ..., then at the same time in the stationary observer system ... . The introduction of the universal time is contradictory to the assumptions of STR and, at the same time, everywhere in the considerations this time is implicitly introduced. Additionally, there is the fact that the non-uniform event takes place in the emitter and the stationary observer systems. The emitted quantum energy and the energy read are different. $E_e \neq E_{so}$, where E_e is the emission energy and E_{so} is the energy read by a stationary observer. The basic scenario that has been adopted is the one in which the emission of a photon from a moving ion is coupled to the direction and speed of emission. That is, from the beginning of the emission to its end, the ion travelled a certain distance, and during this time the wavefront travelled a distance calculated from the emission point, moving at speed c. The end of the photon emission occurred after the emission time t_e in the location shifted by the value $t_e v$. Therefore, without taking into account time dilation, the photon length should be $\lambda = (c - v)t_e$.

However, inaccuracies arise. At the moment of the emission end, the wavefront is at a distance L = (c– v)t_e, which contradicts STR assumptions. Relative to the observer related to the ion system, light should be travelling at speed c and the wavefront should be at distance L = cte. This cannot be attributed to the problem of non-simultaneity of events, because we have, first of all, non-identity of events, i.e. two different images of one photon with different energy. Another inaccuracy is the contradiction with the law of conservation of energy. The energy of the emitted photon is $E_e = h\, c/\lambda \rightarrow E_e = h\, c/ct_e$, i.e. $E_e = h/t_e$ and we assume that such energy has been emitted. On the other hand, for a stationary observer, the energy of the read photon is $E_{so} = h\, c/(c \mp v)\, t_e$. In the geometrical description of the effect there is nothing to justify the change in photon energy and the duality of the same event. In the classical Doppler effect, this principle is absolutely preserved. Not in the simplified formula, which combines two independent phenomena in the geometrical interpretation of motion without considering the third participant of the event, which is the material medium carrying the waves and to which speeds are related, but by taking into account the compression or decompression of this medium in the description of the event and, consequently, the changes of energy and its dispersion. This phenomenon is not taken into consideration here.
At the end of this section, I would like to draw attention to another fundamental contradiction presents in descriptions of relativistic Doppler effect and confirmed in the experiment (I-S). Here I will use the quotation. "Suppose that a source emits short signals with frequency $f' = f/\Delta t'$…". The experiment (I-S) does not describe a change in the frequency of a single pulse sequence, but a change in the wavelength relative to its constant duration, by changing the output frequency of a single and indivisible pulse which is a quantum with the full consequence of the differences between these phenomena. The quantum and each of its indicated elements according to STR moves at a speed c relative to the observer related to the ion, so it should not change its length. In contrast, the intervals between pulses are subject to changes according to the classical Doppler effect.

3. Analysis of the phenomenon described in the experiment (I-S) considering the energy balance.

3.1. Preliminary remarks

Photon emission from an ion system occurs when, according to the classical picture, an electron changes its orbit. When the electron is knocked out of its unstable equilibrium state on a higher orbit, it gives up the excitation energy, returning to a stable state under given conditions, i.e. to its primary orbit. Staying of the electron on a specific orbit is always connected with a certain tolerance of the energy level. Very small tolerances would cause instability of the system, resulting in the lack of even short-term maintenance of the excited state, and this time is necessary for acceleration of the system. In such a case, the emission energy E_e should be referred to as the energy difference between the average permitted levels. The emission time is not synonymous with the period of the emitted wave. It can be shorter or longer. The quantum creation mechanism is not known to us. However, the creation time is the same for all phenomena related to this emission. In further considerations, we will define it as the transition time t_t. I would also like to draw attention to the historical determinism of energy. Each particle of energy in the form of matter or wave is conditioned by the principle of continuity of energy conservation and is shaped by a sequence of historical processes. Therefore, there is no possibility for us to suddenly consider something that appeared from nowhere and in any form. Considering the relativistic Doppler effect, the transverse

effect and the experimental proof (I-S), I will use a theoretical example involving extreme kinetic states of an excited ion.
For an ion with a relative, in a given reference system, rest mass equal to m_r, the relativistic rest energy of the atom is $E_{ir} = m_r c^2$. The absorption by an atom of energy corresponding to the excitation energy causes the atom mass to increase by the value resulting from the energy increase.

$$\Delta m = E_{ex} / c^2$$

where E_{ex} is the excitation energy. In further considerations, we assume that the excitation energy is equal to the primary emission energy E_{pe} radiated from the excited to the ground state, irrespective of the speed of the emitting object, so:

$$E_{ex} = E_{pe}$$

This assumption is important because it is not known whether this equality is certainly maintained in a real event, where the energy of the entire system changes as its speed increases. Both cases concern the energy related to the electron leap between energy levels and not the total energy of the photon leaving the system, which in further considerations will be described as the emission energy – E_e. As a result of the atom excitation in the system, an additional mass $\Delta m = E_{ex} / c^2$ appeared, which was accelerated to the speed v, and thus the kinetic energy related to this mass appeared. All the extra energy associated with the initial excitation and acceleration of the emerging mass should be utilised at the instant where the emission occurs and which we have defined as the transition time t_t. This is due to the fact that during this time, which is greater than zero, the mass related to the photon disappears, and so does the kinetic energy associated with it. For particles whose speed is higher than the limiting speed, the supplied energy can be smaller than the excitation energy. It is completed at the expense of the system kinetic energy. Primary emission, on the other hand, always generates full emission and the system energy is reduced by this entire value. This phenomenon is used in cooling of atoms. When the system absorbs energy greater than the excitation energy, the excess energy is used to recoil the system. The excitation or relaxation energy itself does not change the kinetic energy of the whole system. The changes take place inside the particle structure as if a deformed wheel was balanced. Thus, excited stationary particles do not experience recoil due to primary emission. Speed-endowed particles will experience changes in kinetic energy associated with the appearance or disappearance of mass attributed to the energy of the emitted photon. The lack of recoil of stationary particles is similar and discussed in the description of the Mössbauer effect, see for example [2]. The internal energy of a particle changes but not its linear kinetic energy.

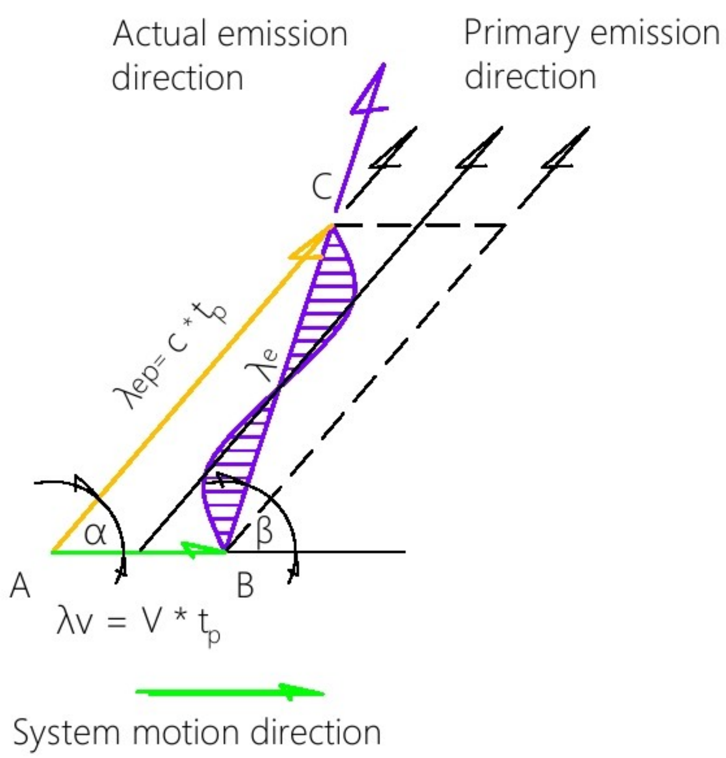
3.2. Analysis of the event described by the experiment

Assuming theoretically that at the instant of excitation, the hydrogen ion was at rest and had the rest mass m_{rhi} and absorbed the excitation energy m_e, then as a result of the acceleration of the system, at the moment of emission, the hydrogen ion was endowed with the total mass equal to:

$$m_{thi} = m_{rhi} + m_{khi} + m_{ex} + m_{kex}$$

where: m_{thi} – total mass/energy of hydrogen ion, m_{khi} – kinetic mass of hydrogen ion, m_{ex} – excitation energy/mass, m_{kex} – kinetic mass of excitation mass/energy. Since m_{rhi} is the only invariant in further considerations, changes related to the emission $m_e = m_{ex}$ and, consequently, to the disappearance of the mass m_{kex} and the additional mass associated with additional energy emission, may cause changes only in m_{khi}. Thus, if from a moving system, due to the appearance of the necessary initial conditions in a statistically random place (at point A (Fig. 2), there was a spontaneous primary emission of energy at a random angle α, then a photon (or rather a prophoton) during the previously described transition time t_t has travelled the distance $\lambda_{pe} = c\ t_t$ reaching point C.

Fig. 2



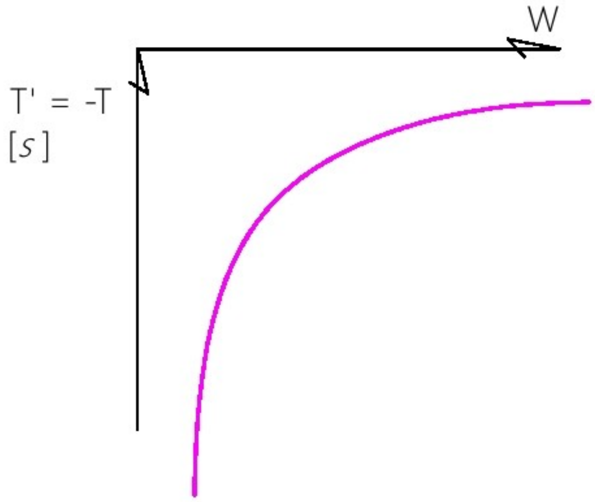
The transition time t_t is the time limiter for the kinetic mass decay which is the sum of the mass related to the excitation energy and the additional mass caused by the difference between the emission energy and the excitation energy, and associated with the kinetic energy of the hydrogen ion.

$$E_e - E_{pe} = E_{kex} + \Delta E_{khi} = \Delta E_{ke}$$

Thus, the total change in the emission energy relative to the primary emission energy takes place due to the total change in the total kinetic energy ΔE_{ke}, assuming, of course, that the primary emission energy is equal to the excitation energy.

We can treat its momentum as a matter/energy wave limited at that particular transition time t_t. Thus, the wavelength of the decaying kinetic emission mass is $\lambda_{\Delta ke} = v\ t_t$. If the energy emission is limited by the time t_t as a dependent quantity and by the speed v as a declarative quantity, then we can talk about the matter annihilation intensity relative to the energy wavelength. We obtain two vectors which cannot be added “normally”. Since the electromagnetic field is negative (Fig. 3), where an increase in the potential which is the period T' = -T from -∞ to 0 causes an increase in energy from 0 to +∞, the process of energy summation can only take place by subtracting these vectors.

Fig. 3



Thus, a B-C wave was created, defined by the formula:

$$\lambda_e = (\lambda_{pe}^2 + \lambda_v^2 - 2\, \lambda_{pe}\, \lambda_v \cos\alpha)^{1/2}$$

The emission of the wave λ_e occurred at an angle β recorded by an outside observer, and the angle is determined by what happened at the point of emission.

$$\cos\beta = (\lambda_{pe} \cos\alpha - \lambda_v) / \lambda_e$$

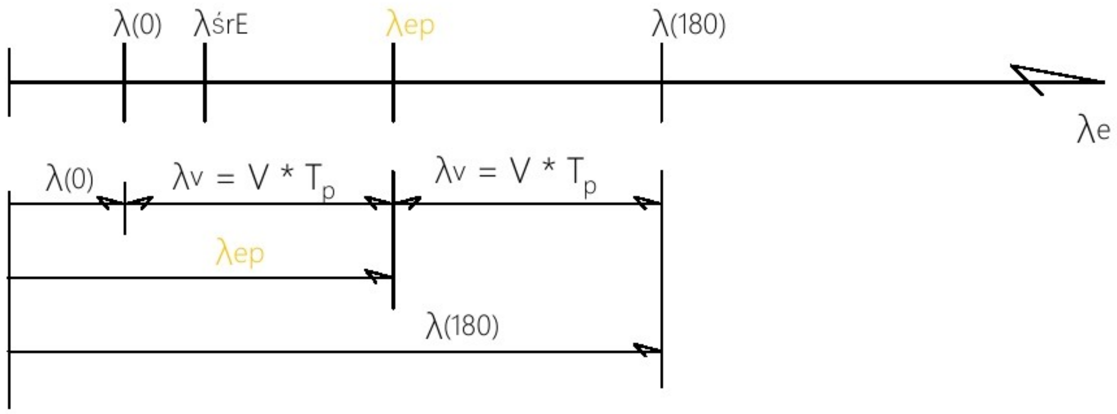
This description is true for any spontaneous emission regardless of the angle at which the primary emission occurs. Of course, it is not the case that both energy streams in the structures of the moving system are emitted first and then add up to form a total emission quantum. As usual, it is a continuous process over time t_t involving partial sums, and has a cause and effect relationship. It is the random and statistical primary emission angle that entails the forced effect of a mass defect. This defect cannot occur spontaneously causing a specific emission effect.
When analysing the experimental results, it should be noted that the wavelength variation range is symmetrical to the primary emission wavelength:

$$\lambda_{pe} = (\lambda(0) + \lambda(180)) / 2$$

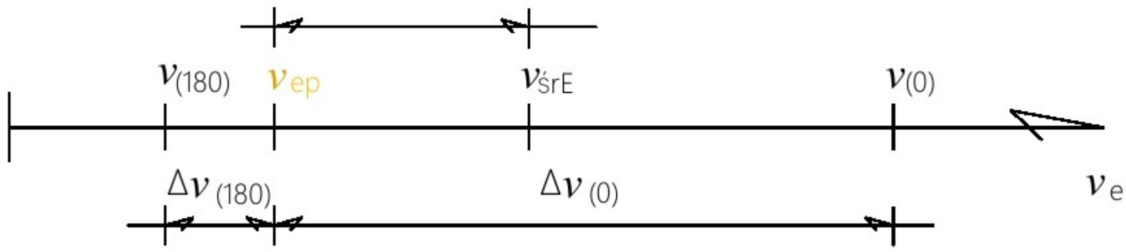
where: λ(0) is the final emission for angle α = 0° and λ(180), respectively, for angle α = 180°
However, this is the geometrical symmetry of the wave calculus. The wavelength for the average emission energy λ_{aE} is completely different (Fig. 4a). The translation of the plot into the frequency axis (Fig. 4b) shows a shift of the deviation symmetry towards violet with respect to the assumed emission frequency.

Fig. 4

a)



b)



The value Eν of the average emission energy ν_{aE} frequency deviation from the primary emission ν_e frequency is the expected value in this experiment and depends on the kinetic energy of that part of matter that was transformed into a quantum as a result of this primary emission. Thus, the experiment (I-S) fully confirms or at least does not contradict the presented reasoning and calculus. In further considerations, the direction and magnitude of the momentum transferred to the moving system can also be determined.

In these descriptions, it should be taken into account that the primary emission quantum described by us is in fact not an electromagnetic wave in our understanding. It can be assumed that it is a state of directional transition of energy between systems and that is why I earlier used the term 'prophoton'. In order to leave the system, irreversible emission at the electron level must change the energy of the whole system and this cannot be considered separately.

3.3. Final analysis and conclusions.

In the assumptions for the experiment and description of the phenomenon, we consistently adhere to the STR canon that a later and uncertain event determines the course of the earlier and certain event. In the case of the experiment (I-S), this dissonance of the logic of events is not so glaring, because although there is a strict invariable sequence of events, it happens in such a short interval of time and place that for the observer's perception it is the unity of the experiment. But how to explain the influence of the observer on the emission of radiation from the galaxy GN-z11 from which the light flew to us 13.4 billion years? At that time, there was no Earth and even less our observer. Let us note that the emission of a photon from an accelerated hydrogen ion, the reddening of the spectrum from the galaxy observed by the Hubble telescope, or the never realised school thought experiment with the emission of light from the floor of a moving car, are exactly the same processes. It is just a matter of including the relevant components in the results. For example, the effect of time dilation in evaluating the spectrum, or the fact that the emission of a photon from the floor of a stationary car is not the same as the emission from a moving car.

Accepting as correct the assumption that the phenomenon of photon emission from a moving material system is described by the formulas

$$\lambda_e = (\lambda_{pe}^2 + \lambda_v^2 - 2\,\lambda_{pe}\,\lambda_v \cos\alpha)^{1/2}$$

and:

$$\cos\beta = (\lambda_{ep} \cos\alpha - \lambda_v) / \lambda_e$$

it makes the event independent of any future events and the manner it is communicated. It describes the effect solely on the basis of what happened at a given moment in a given place. However, this requires the adoption of a superposition of the system with respect to the dominant system, i.e. the environment. For the experiment performed (I-S), such a system was the Earth and the speed of the ion relative to it. The same experiment, conducted on a fast moving medium, such as an airplane, will produce different results, dominated by the Earth. Then, the direction of flight (east or west) and the mass of the measuring system and the carrier. In principle, one should return to the concept of the ether, discarded a century ago, but understood not as a homogeneous medium in which light moves. Such an ether should be understood as the total field of all potentials existing in this location: gravitational and electromagnetic potentials, weak and strong interactions, and all others, including those we have not yet learned. A space in which every participant, be it a particle, a photon, or a planet, is both influenced by this field and creates it itself.

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