The "Aarau Question" and the de Broglie Wave

G. Galeczki

Institute of Physics, University of Cologne
Zülpicher Str. 77, D-50937 Cologne, Germany

The analogy between Einstein's "Aarau Question" of riding on a light-wave and—nevertheless—"seeing" the light-wave running away with velocity "c" and Mugur-Schächter's proposal to associate with every particle having non-zero proper mass a progressive plane wave moving with invariant velocity "V" with respect to the particle, is shown not to solve any difficulties in fundamental physics. The spinning ring model of charged particles, however, provides an "internal clock" with a frequency independent of the relative motion of possible "observers".

Introduction

A strange similarity between the embryonic ideas from which special theory of relativity theory (STR) and wave mechanics (WM) originated might have escaped general attention. The similarity concerns the fuzzy and hitherto unexplained picture of some periodic phenomenon seen by an imaginary observer "riding" on a photon and on an electron, respectively.

We begin by considering the "Aarau Question" posed by Einstein when he was a young man (Einstein 1956, 1949):

> During that year (sometime between October 1895 and the early fall of 1896) in Aarau the question came to me: If one runs after a light wave with (a velocity equal to the) light velocity, then one would encounter a time-independent wavefield. However, something like that does not seem to exist! This was the first juvenile thought experiment which has to do with the special theory of relativity.

Further, in his more extensive autobiographical notes, published in 1949, Einstein remarked that "after ten years of reflection, such a principle (special relativity) resulted from (this) paradox upon which I had already hit at the age of sixteen". As is well known, ten years after "the Aarau Vision" special relativity was born; yet it took the mature Einstein another decade to confess to Pauli "*Für den Rest meines Lebens will ich darüber nachdenken, was das Licht ist!*" (in translation: "For the rest of my life I shall reflect on what light is!")

Indeed, for the rest of his life Einstein voiced his discontent with the photon concept (the very idea for which he was awarded the Nobel prize) and continued to hope that the discreteness of matter and energy would follow naturally from a comprehensive, continuous field theory based on a geometry with, possibly, more than four dimensions. One of Einstein's most loyal disciples (Sachs 1971) even goes so far as to reject the photon as a bona-fide particle at all: this amounts to the rejection of free (from the source) electromagnetic fields as solutions of the homogeneous Maxwell equations!

Light and kinematics

What kind of "wavefield" could the young Einstein have had in mind between the fall of 1895 and the fall of 1896? He was most probably thinking of waves in aether, without which the propagation of light was thought to be impossible. However, he "felt" that these waves would exhibit anomalous behaviour with respect to a hypothetical observer. His "Aarau Question" relies upon a far-fetched Gedankenexperiment which, in contrast to the usual type, does not operate with phenomena of known behaviour. A usual Gedankenexperiment is sometimes given preference over a laboratory experiment only because of technical difficulties, the concepts involved being well known and the expected phenomena predictable. We could imagine ourselves "riding on a Moonbeam", but nothing provides us with any hint that the co-moving wavefield will be time dependent! On the contrary, our familiarity with wave-motion would support the "frozen-in wave" alternative.

The kinematics of STR, through its hyperbolic velocity addition formula (in one spatial dimension):

$$v = v_1 \oplus v_2 = \frac{v_1 + v_2}{1 + (v_1 v_2/c^2)} \qquad (1)$$

accounts for the Aarau Gedankenexperiment result $c \oplus v = c$, where v denotes the velocity of the observer. Here we must, however, bear in mind that application of the hyperbolic composition law is restricted to radar-velocities, which are, unfortunately, never measured (Galeczki 1993).

It is appropriate to recall here that "special" relativity requires its two famous principles, and at least the following conventions:

1) Validity of the second principle for the one-way velocity of light

2) Definition of distant synchronicity for two observers A and B at rest in an inertial frame of reference

$$t_B = 0.5(t_{A1} + t_{A3}) \qquad (2)$$

3) Definition of "the time of a distant event":

$$t_E = 0.5(t_{A1} + t_{A3}) \qquad (3)$$

4) Definition of "the distance of an event":

$$r_E = 0.5c(t_{A3} - t_{A1}) \qquad (4)$$

5) Definition of "the velocity of a distant object":

$$v_E \equiv \frac{\Delta r_E}{\Delta t_E} \qquad (5)$$

where r_E and v_E are denoted the radar-distance and radar-velocity, respectively. The radar-velocity, contrary to the time-of-flight velocity, is operationally upper bounded, since otherwise the measuring electromagnetic signal will not catch the moving object. The unique feature of "special" relativity is that the radar-velocity of high-energy particles has never been measured; therefore, the (radar) velocity-dependence of the mass has never been confirmed.

Since "special" relativity actually introduces a new kinematics, the real tests of the theory have to be kinematic. However, the outcome of Fresnel's aether drag experiment (i.e., the measurement of the velocity of light in flowing liquids)—one of the very few kinematic tests—is better accounted for by the "fixed time delay theory" of light propagation in material media (Marinov 1977; Kosowski 1978). According to this theory, the actual velocity of light is not at all affected by the velocity of the medium. In particular, the true propagation in a material medium must be precisely the same as in free space. Since the apparent velocity of light in a stationary medium is less than the vacuum velocity c, this can only mean that light is delayed by the molecules in the medium. A photon passing through a stationary material medium becomes attached to a molecule for a fixed time τ after which it reradiates, as in free space, with velocity c to the next molecule at a distance L (the mean free path of the photon) where it again becomes attached for a fixed time τ_o to the next molecule, etc. This theory appears to account for the experiments of Fresnel, Fizeau, Airy (telescope filled with water to detect Bradley aberration), Hoek (1868!) as well as other experiments.

Summing up, the kinematics fitting the Aarau Gedanken-experiment remains illusory and untestable, just like the time dependent wavefield seen by an observer riding on the crest of a light wave.

Moving clocks and kinematics

The problem of "moving clocks" is more realistic than the "Aarau question", since we know much more about clocks than about the nature of light (and surely more than Einstein knew in 1905; however, Einstein's honesty regarding his ignorance about light commands respect!). The statements: "Moving clocks go slow(er)", or: "Time stops for observers moving with the velocity of light in vacuum", are no less illusory than the observations reported by the moon-beam rider in the Aarau Gedankenexperiment. The speeding-up or the slowing-down of a clock has nothing to do with the transformation connecting the parameters $(x; y; z; t)$ and $(x'; y'; z'; t')$ used by stationary (with respect to the clock) and moving observers, respectively, for the purpose of formulating a physical law. In Einsteinian relativity, a clock shows different "times" to different observers at the same instant, depending on their respective (relative) velocity: $t' = t(1 - v^2/c^2)^{-1/2}$. For a distant clock ($x \neq 0$), one has: $t' = (1 - v^2/c^2)^{-1/2}(t - xv/c^2)$. According to healthy common sense, however, *any clock, has to be a public clock*. A public clock, having necessarily a built-in periodic, cyclic

process, an integrating mechanism and a dial (or a digital display, if you wish), shows any observer—no matter what his state of motion is—the same hand positions. This latter might likewise be called clock time.

It is customary in the "special" relativistic literature to consider muons as clocks. The muon—sometimes seen as a "massive electron"—is a charged particle with intrinsic spin $\hbar/2$. It is unstable and decays, "at rest", into an electron and two neutrinos in approximately 2.2 μsec. The decay obeys the statistical, exponential law of radioactive disintegration:

$$N = N_o \exp\left(-\frac{t}{\tau_o}\right) \qquad (6)$$

This law pertains to a system consisting of a large number of independent mesons. It is neither invariant, nor covariant under Lorentz transformations! The experiments with mesons accelerated to velocities close to c indicate increased half-lives, obeying roughly the same v-dependence as mass and energy:

$$\tau = \gamma\tau_o \qquad (7)$$

This phenomenon is proclaimed by orthodox "special" relativists as a genuine manifestation of "time dilation". This claim is, however, completely false, since:

1. "Time dilation" should affect the time parameter t:

$$t = \gamma t_o \qquad (8)$$

rather than the half-life of a statistical ensemble,

2. According to de Broglie's widely accepted "special" relativistic recipe to derive his famous de Broglie "wave" from the "periodic element" (12) by Lorentz transforming the time parameter t from the "proper frame" of the particle, in comparing the half-lives of "stationary" and "moving" mesons, respectively, one ought to apply the Lorentz transformation to the parameter t_o in (6):

$$t_o = \gamma\left(t + \frac{vx}{c^2}\right) \qquad (9)$$

which should cause a smearing out of the "delta-localized" spatial distribution (6):

$$N(x,t) = N_o \exp\left[-\frac{\gamma(t + xv/c^2)}{\tau_o}\right] \qquad (10)$$

Of course, there would be no smearing if one closed the path of the mesons, but this is known to introduce huge accelerations (some 18 orders of magnitude stronger than the acceleration of gravity in the vicinity of earth).

3. The life-time of an individual meson is considered an "ill defined" concept in orthodox quantum mechanics, since the time-dependent wave function pertaining to the internal dynamics of the meson is unknown. The individual life-time of an unstable meson is not the analogue of an atomic characteristic time $T_o = 1/\nu_o$ relating to an internal electronic transition with $h\nu_o = E_2 - E_1$. Thus, the unstable meson is, from the very outset, completely unfit to play the rôle of a clock: it lacks a cyclic time evolution, it has no "integrating mechanism" and it has no "display" (in the most liberal sense of the term). The observed velocity dependence of the

half-life of a meson population moving with velocity v is a *statistical mechanical* effect.

4. The whole scenario of the impressive CERN experiment has nothing "relativistic" in it! The dynamics of the mesons is controlled by huge electromagnets resting in the laboratory, which can be by no means assimilated with the "non-interacting observers" of the theory of (very) "special" relativity.

Einstein, a Swiss citizen, considered it superfluous to specify the internal structure and the working principle of his clocks; the slowing-down was supposed to be (and is still considered to be) a universal kinematic mechanism affecting all clocks in the same way. There is no problem to calibrate the time parameter t of a stationary observer against this clock-time. Contradictions (not paradoxes) arise if one fails (like in Einsteinian STR) to distinguish between the clock-time of a moving clock and the time parameter t' used by an observer moving relative to the clock. Lorentz, Poincaré and Ives always considered "active transformations", which amounts to viewing "clock-slowing-down" and "length contraction" as real physical effects caused by absolute motion relative to the aether background. Alternatively, in the so called "passive interpretation" of the Lorentz transformation championed by Sachs (1971), the abstract space and time (language) parameters have to be scrambled if we want to write physical laws in covariant form, while the clock (time) is not influenced by the uniform relative motion between the clock and the observer. However, the insensitivity of clocks to uniform motion harmonizes better with Galilean relativity, for which $t = t'$ too. We could still use Maxwell's equations, provided we refer all charge velocities to the local field, rather than to the observer (Beckmann 1987). Even better, we can use Weber-Wesley electrodynamics (Wesley 1990).

According to Beckmann (1987), the two recognizable velocities in electrodynamics are: the velocity of a charge in a magnetic field, which occurs in the Lorentz force, and the velocity of charges forming a current, which occurs in the current density $\mathbf{j} = \rho\mathbf{v}$ involved in the second Maxwell equation. These velocities do not produce physical effects simply by virtue of their definition with respect to an "observer", just as a windmill will not start to rotate because an observer starts running with velocity v relative to the mill...

Weber-Wesley electrodynamics (Wesley 1990), meanwhile, is an extension of the Weber electrodynamics (1848) based on the (relative) velocity dependent potential:

$$U = \frac{qq'}{R}\left[1 - \frac{(dR/dt)^2}{c^2}\right]; \quad R = |\mathbf{r} - \mathbf{r}'| \quad (11)$$

In order to account for radiation, Wesley (1990) too has rewritten Weber's electrodynamics in terms of fields and introduced retardation via the substitution $t \rightarrow t - (R/c)$, where c stands for the isotropic one-way velocity of energy propagation of light in the fundamental frame of reference.

When the relative motion is accelerated, the influence of acceleration must be determined with reference to laws of dynamics and the internal structure of the clock in ques-

tion. Gedankenexperiments employing observers who ride on light-waves provide no alternative to the detailed description of physical processes in terms of dynamic laws supported by a consistent kinematics.

Problems with de Broglie's wave

I began the present discussion by pointing out the stimulating rôle of the co-moving (with a photon and a massive particle, respectively) observer in the development of both special relativity and wave mechanics. With regard to special relativity, I concluded that this rôle amounted to a far-fetched Gedankenexperiment, while the outcome was a kinematics which is not testable.

The start of de Broglie's wave mechanics was the assumption that in the co-moving frame of reference of a particle there is some "periodic element":

$$\psi_o = \varphi_o \exp(2\pi i\nu_o t_o) \quad (12)$$

which has the form of the complex representation of a stationary wave, the frequency being defined through:

$$h\nu_o = m_o c^2 \quad (13)$$

the "analog of Einstein's relation for photons" (de Broglie 1925). The first remark which comes to mind is that (12) represents a simple, harmonic oscillation, rather than a stationary wave. This "small inaccuracy" had far reaching consequences for de Broglie's mechanics, where the next step was to use the Lorentz transformation for time only, in order to obtain the periodic phenomenon seen by a "stationary observer":

$$\psi = \varphi_o \exp\left[2\pi i\nu\left(t - \frac{x}{v_f}\right)\right] \quad (14)$$

where $\nu = \nu_o(1 - v^2/c^2)^{-1/2}$ and $v_f \equiv c^2/v$ defines the phase velocity of de Broglie's wave. This velocity is a most strange one: on the one hand, it is associated with the particle, but on the other, it runs away from it! The slower the particle moves, the higher the phase velocity of the accompanying wave, such that for a co-moving observer the phase-velocity becomes infinite.

M. Mugur-Schächter tried recently (1989) to bring wave mechanics into agreement with special relativity. Her approach involved replacing de Broglie's "periodic element" (12) with "a progressive plane wave associated with the quantum of energy $m_o c^2$ in the proper frame of reference of a particle with proper mass m_o:

$$\psi_o(x_o, t_o) = \varphi_o \exp\left[2\pi i\nu_o\left(t_o - \frac{x_o}{V_o}\right)\right] \quad (15)$$

so that, when passing to the "stationary observer" both x_o and t_o have to be (Lorentz) transformed. The analogy with the Aarau question is striking: even if the observer catches the particle, the clever progressive plane wave will still run away from him with the invariant velocity V_o! In a way, the velocity V_o plays for the particle with proper mass m_o the same rôle as c for the wave-field of the Aarau "experiment".

The question whether the invariant velocity V_o depends on the proper mass of the particle was not raised by Mugur-Schächter. One could speculate that the existence of a second universal constant with the dimensions of a velocity would imply a more general kinematics, with the Lorentz transformation as a limit situation corresponding to $V_o = \infty$. But enough speculation!

Extended particle models with an intrinsic frequency

Returning to de Broglie's idea of a periodic element associated with the proper frame of the particle, I shall first dissociate it from the kinematics of special relativity and second, I shall point out the existence of a successful extended particle model which implements this remarkable idea.

Progress in wave mechanics has been hindered by the prevalent tendency in quantum mechanics to conceptualize particles as point-like entities endowed with mass, charge and magnetic moment and to discourage further inquiries into specifics of the shape and topology of particle structures. Such attempts have been (and are still) seen as retrograde, naively classical, or even superfluous. For example, the attempt by Lorentz in 1925 to explain the electron spin as a consequence of the rotation of a sphere of radius $r_o = e^2/m_o c^2$ with an angular momentum $\hbar/2$ has, until now, been treated with contempt—the fact that it would imply a surface velocity about ten times c not being the only reason. Strangely, the older spinning ring or torus model of the electron has generally been overlooked, although it has now attained sufficient maturity to account for all the known properties of the electron, including the anomalous magnetic moment (Bergmann and Wesley 1990). Most important, the meaning of de Broglie's "periodic element" is, in this model, unambiguously defined: it is just the angular frequency of the rotating ring. Like the time indicated by public clocks, *this intrinsic frequency of the particle undergoes no Lorentz transformation*. Moreover, the proper mass of the electron (directly related to the intrinsic frequency) is accounted for by the purely classical electromagnetic energy of the charged spinning ring.

An attempt to describe particles and their mass-spectrum by means of "rotating strings" with a constant surface-to-mass ratio has been made by Henrik Broberg (1991). More recently, Donald Reed (1994) argued that the "chiral Beltrami vortex morphology" may be universal in microscopic quantum phenomena as well as at macroscopic plasma levels. Unlike fluid turbulence, where vortices have always been seen as "dynamic instabilities", vorticity seems to be a *natural topological property of matter at every level of organization*.

Conclusions

(1) Classical relativity, on the one hand, and de Broglie's wavelength associated with every particle having non-zero proper mass, on the other, retain their significance in present day physics.

(2) Attempts by Einstein and by Mugur-Schächter to amend the above theories by postulating wave-like phenomena which propagate with invariant velocities "c" and "V_o" in the proper frames of reference of photons and particles, respectively, are a source of more serious difficulties than the original ones.

(3) The spinning ring or torus model of the electron (and other charged particles) implements in a quantitatively successful way de Broglie's idea of an internal "periodic element" associated with any particle with non-zero proper mass. The internal, rotational frequency is observer independent. A similar independence of motion relative to a non-interacting observer must be a characteristic of any clock, with the consequence that any clock has to be a public clock.

References

Beckmann, P., 1987. *Einstein Plus Two*, Golem Press, Boulder, p. 88.

Bergman, D.L. and Wesley, J.P., 1990. *Galilean Electrodynamics* 1:63.

Broberg, H., 1991. *Apeiron* 9–10:62.

de Broglie, L., 1925. *Annales de Physique*, 10e Série, Tome III.

Einstein, A., 1949. in: *Albert Einstein: Philosopher-Scientist*, P.A. Schilpp, Editor, Tudor, New York.

Einstein, A., 1956. in: *Helle Zeiten, Dunkle Zeiten*, Europa Verlag, Zürich.

Galeczki, G., 1993. *Physics Essays* 6:86.

Kosowski, S., 1978. *Il Nuovo Cimento* 46B:98.

Marinov, S., 1977. *Eppur Si Muove*, C.B.D.S., Bruxelles, pp. 74–81 and 143–146.

Mugur-Schächter, M., 1989. *Found. Phys. Lett.* 2:261.

Pauli, W., 1961. in: *Aufsätze und Vorträge über Physik und Erkenntnistheorie*, Friedr. Vieweg & Sohn, Braunschweig, p. 88.

Reed, D., 1994. *Spec. Sci. Technol.* 17:205.

Sachs, M., 1971. *Int. J. Theor. Phys.* 4:453.

Wesley, J.P., 1990. *Found. Phys. Lett.* 3:443.