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Comments on the paper

by A A Logunov, M A Mestvirishvili, and Yu V Chugreev "On incorrect formulations of the equivalence principle"

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At the very beginning of their paper, A A Logunov and co-workers [1] point out that the equivalence principle (EP) is typically formulated (in compliance with Einstein's early works [2, 3]) without reserve for its local character. Specifically, they refer to the EP formulation as proposed by one of the authors in Ref. [4]: "According to this principle, all physical phenomena proceed similarly in the inertial reference frame K_g having homogeneous gravitational field with acceleration of gravity ($\mathbf{g}$) and in the uniformly accelerated system K_a which moves with acceleration $-\mathbf{g}$ relative to an inertial system without gravitational field". A A Logunov et al [1] also cite a similar formulation from [5]. They emphasise that Refs [2–5] "do not even mention locality (small space-time domains)". But this is obviously nothing more than prejudiced fault-finding. Indeed, Ref. [4] did not concern the theory of relativity and pretended to be nothing else but notes on "The Emission and the Strength of Radiation Friction in the case of Uniform Acceleration of a Charge". For this reason, it was not our intention to accurately formulate EP in one place. At the same time, Ref. [4] states (p. 581): "To construct the general theory of relativity and as a corollary of general relativity, it is necessary and sufficient to observe EP 'in the little', that is locally, in a sufficiently small region of space-time when the gravitational field may be regarded as being steady and uniform".† Similarly, the authors of book [5] emphasise the local character of EP immediately after they have repeated the formulation of EP as given in [1].

When A Einstein started elaborating the general theory of relativity in 1907 [2], he was primarily concerned with the homogeneous gravitational field. However, in 1911, he noted as follows: "Certainly *any* field of gravity can not be substituted by the state of motion of a system without gravitational field just as all the points of an arbitrarily moving medium can not be made static by means of relativistic transformation". We take this note to mean that Einstein was perfectly aware of the fact that, in the case of an arbitrary field, EP is applicable only to regions where the field may be considered homogeneous. Afterwards, Einstein many times reaffirmed the local character of EP. Suffice it to mention of his booklet [7] which deals with 'a box' commonly referred to as 'Einstein's elevator'.

The theory of relativity has been extensively treated in the literature, and it would be presumptuous to assume that no one has ever suggested formulating EP as pertaining to an infinitely extended uniform gravitational field or a uniformly accelerated boundless reference frame. On the other hand, it is evident that neither an infinite homogeneous field nor an uniformly accelerated boundless reference frame can be physically realised. Therefore, it is impossible to verify (to confirm or disprove) what might occur under such conditions as lying beyond the scope of physics. Meanwhile, A A Logunov et al. [8] examine the electromagnetic field in a uniformly accelerated boundless reference frame. Moreover, these authors argue that EP is inapplicable to electrodynamics [1, 8].

However, there is no need to discuss these problems here since we are concerned with EP only in its straightforward local formulation proposed, for instance, by Pauli [9], later in [10] and, in part, in [1]. This formulation is not at all in conflict with reiterated Einstein's [11] and is favoured by A A Logunov et al [1, 8]. In fact, this formulation implies that an arbitrary gravitational field can be comprehensively described by metric tensor $g_{\mu\nu}$. This was also noted by Pauli (see [9], p. 202).

At the same time, application of EP to electrodynamics has given rise to a paradox of charge radiation in systems K_g and K_a. At first sight, a charge is certain to radiate in system K_g but is unlikely to do so in system K_a since it is not accelerated with respect to the inertial reference frame K. Therefore, systems K_g and K_a appear to be nonequivalent, and EP seems violated. The solution of this paradox in an attempt to show that 'everything is OK' and EP is fulfilled, has been sought by many authors [12–14]. In Ref. [4] we repeated relevant arguments and once again tried to demonstrate in Ref. [10], at greater length now, the validity of EP in electrodynamics, in view of the obvious failure to understand it shown by A A Logunov et al [8]. We still believe we have attained our object.‡ Arguments of A A Logunov et al [1] to the contrary are largely based on misunderstanding or rather the reluctance of these authors [1, 8] to understand what is meant by radiation in Refs [4, 10, 12 – 14].

It has been pointed out many times [4, 10, 12 – 14] that a charge may be considered to emit radiation if flow P of the Poynting vector across the surface surrounding the charge differs from zero. Such a definition, which is reasonable and justified, implies that a uniformly accelerated charge may radiate although there is no wave zone in this case, and one can not speak about the appearance of photons. Meanwhile, A A Logunov and co-workers understand by radiation only the field in the wave zone as it ensues from the following statement [1]: "There can be no wave zone in this problem, hence no radiation". Whether radiation is possible or not in the absence of the wave zone is the very core of the long-standing debate concerning the behaviour of a uniformly accelerated charge over the entire time interval (see [14] in particular). Assuming acceleration to occur within a certain finite interval immediately places everything in perspective (see for instance [4]).

In order to prove EP, it is necessary to demonstrate that values of flow P (or electrodynamic fields themselves) are the same in both systems, K_g and K_a. This has been done in Ref. [10]. The case being considered locally, i.e. in a small region, there was no reason to think of a wave zone, etc.

† Fock[6] was quite right when he stated: "The local character of EP should be understood in the spatial sense: the field of gravity in a sufficiently small volume (i.e. inside a satellite) can be compensated by acceleration for both small and large time intervals".

‡ Formula (57a) in [1] is valid, but in the small domain being examined, where $a\eta/c \ll 1$, it turns into the non-relativistic formula (23) from our paper [10]. Also, it needs to be borne in mind that field delay must be taken into consideration if formula (23) is to be derived from formula (20) in [10] (were it not done, there would be a two-fold error, in agreement with [1]). In other words, the value of P calculated in [1] conforms to the result obtained in [10].

We use this opportunity to note that Ref. [19] was omitted in [10]: (Belloni L, Reina Ch, in *Einsteinovsky sbornik 1984–1985*) (Collected papers on Einstein's Theory) (Moscow: Nauka, 1988) p. 201.

It should also be noted that A A Logunov et al. [1] believe our formulation of EP (see [9, 10]) to be incorrect on the assumption that one may think of situations (interactions) in which the curvature tensor can not be excluded by any transformation of coordinates even in an infinitely small region. This is true, and EP is actually invalid in such situations in that even an infinitely small inhomogeneity of gravitational field would inevitably interfere with the observed effects. But this emphasises once again that EP is a physical principle which it is possible to put to the test in order to confirm or refute. Such verification is exactly what physicists spare no efforts to do [15]. EP has been proven with a very high degree of accuracy. As far as classical electrodynamics is concerned, it has already been noted that the validity of EP with respect to electric charge behaviour in systems K_g and K_a can be proved by means of direct calculation [10]. Recently, this has been confirmed in [16].

To conclude, we agree with A A Logunov, M A Mestvirishvili, and Yu V Chugreev [1] that opinions have been expressed, and "it is up to the thoughtful reader to compare them and decide which is right and which is wrong". Indeed, we can not see any point in further discussion with A A Logunov.

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