Comment on "Experimental demonstration of electric power generation from Earth's rotation through its own magnetic field"

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(Received 28 March 2025; accepted 30 March 2026; published 2 June 2026)

In a recent paper, Chyba *et al.* [Phys. Rev. Res. **7**, 013285 (2025)] claim to be able to generate electrical power from Earth's rotation by a rigid device that is stationary on Earth's surface. The device is thus corotating with the surface of Earth and the generated power is claimed to originate from the motion of the device in Earth's magnetic field. Here, I show that such a device is *theoretically* impossible and demonstrate where precisely there are errors in the theory by Chyba *et al.* Also, I argue that they have not yet shown *experimentally* that the sub-pW power they obtained is produced by tapping the kinetic energy of Earth's rotation.

DOI: 10.1103/6qlw-cjr2

I. INTRODUCTION

Chyba, Hand, and Chyba [1] (I will refer to this work by CHC) claim to present experiments demonstrating the extraction of energy from Earth's rotation (thereby despinning Earth very slightly). This experiment is based on the earlier theory of Chyba and Hand [2] (I will refer to this work by CH). The experimental device is essentially a magnetically permeable tube (called "cylindrical shell" by CH) with attached wires connected to the load (in their experiment, a voltage or current meter). The whole device is static with respect to and comoving with the surface of Earth and thus moves through the axially symmetric component of Earth's magnetic field, which they claim does not rotate with Earth. CHC argue that the motion of this rigid device in the constant vector value $\mathbf{B}_{\text{Earth}}$ leads to an emf.

The ideas presented in CH were previously theoretically challenged by Jeener [3] and experimentally by Veltkamp and Wijngaarden [4]. Jeener analyzed the transformation of Earth's magnetic field to a reference system fixed on Earth's surface and found a zero emf in the latter frame. This finding was challenged by Chyba and Hand [5] by analyzing the axially symmetric component of Earth's magnetic field as opposed to the nonaxially symmetric component. In their experimental paper, Veltkamp and Wijngaarden demonstrated that the magnetic field of the tube of the proposed device does not enter in the Lorentz force on electrons in that tube and that hence the emf is zero.

In Sec. III, the latter argument will be made more precise. In the sections thereafter, concise criticisms of the theory in CH and CHC are formulated that pinpoint precisely where errors are made. In the last section, I discuss why CHC have not yet demonstrated that their device is indeed capable of harvesting electrical energy from Earth's rotation and what is minimally needed to substantiate such a claim.

II. THEORY BY CHYBA *et al.*

The emf $\mathcal{E}$ is given [Eq. (3) of CHC] by $\mathcal{E} = \oint_C (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot d\ell$, where the integrand derives from the Lorentz force law $\mathbf{F}_L = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$. This emf is thus calculated according to the prescription by Griffiths [6] and corresponds to "$\mathcal{E}_I$" as defined by Auchmann *et al.* [7]. The velocity $\mathbf{v}$ is the velocity of the (rigid) circuit C as observed in the frame where $\mathcal{E}$ is calculated.

By using Stokes' theorem and the Maxwell-Faraday equation, the emf is written as

$$\mathcal{E} = \iint [\nabla \times \mathbf{E} + \nabla \times (\mathbf{v} \times \mathbf{B})] \cdot \mathbf{dA} \tag{1a}$$

$$= \iint [-\partial \mathbf{B}/\partial t + \nabla \times (\mathbf{v} \times \mathbf{B})] \cdot \mathbf{dA}, \tag{1b}$$

where the second line is the second line of Eq. (3) of CHC. As CHC concede, normally in a tube like theirs, the $\mathbf{v} \times \mathbf{B}$ force component leads to an electrical polarization of the tube, which sets up an electrical field $\mathbf{E}_p = -\nabla V$ (hence $\nabla \times \mathbf{E}_p = \mathbf{0}$) such that $\mathbf{E} + \mathbf{v} \times \mathbf{B} = \mathbf{0}$ and zero emf results. However, CHC claim that due to the special magnetic configuration in their device it is possible to have $\nabla \times (\mathbf{v} \times \mathbf{B}) \neq 0$ [Eq. (3) of CHC], which would lead to the possibility of a nonzero emf. In the next section, I discuss whether indeed the emf is nonzero.

III. IS THE EMF NONZERO?

To answer the question whether a nonzero emf is expected, I first subject the Lorentz force in the tube to closer scrutiny. In fact, $\mathbf{B}$ is the sum of Earth's magnetic field and the magnetic field due to the magnetically permeable tube. Both sources of magnetic field produce in their respective

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rest frames a magnetic field only, but—due to the Lorentz transformations—will have also an electric field $\mathbf{E} = \mathbf{v} \times \mathbf{B}$ in frames that move at a velocity $\mathbf{v}$ with respect to those respective rest frames. With CHC, I will work in the limit $v \ll c$. Also with CHC, I approximate the motion of the circuit due to Earth's rotation by a linear motion at velocity $\mathbf{v}_E$ (shorthand for $\mathbf{v}_{\text{Earth}}$). In this approximation, the total magnetic field in the rest frame K of Earth's field (not corotating with Earth) is $\mathbf{B}_{\text{K}} = \mathbf{B}_{\text{Earth}} + \mathbf{B}_{\text{tube}}$ and the electric field is $\mathbf{E}_{\text{K}} = -\mathbf{v}_E \times \mathbf{B}_{\text{tube}}$. In the "laboratory" frame K′ that is comoving with the circuit and the surface of Earth, $\mathbf{B}_{\text{K}'} = \mathbf{B}_{\text{Earth}} + \mathbf{B}_{\text{tube}}$ and $\mathbf{E}_{\text{K}'} = \mathbf{v}_E \times \mathbf{B}_{\text{Earth}}$. Of course, to both $\mathbf{E}_{\text{K}}$ and $\mathbf{E}_{\text{K}'}$ a polarization field $\mathbf{E}_p$ as introduced by CHC should be added. However, the field $\mathbf{E}_p$ is due to a static charge distribution and will not contribute to the emf, as mentioned above.

The Lorentz force on a charge q comoving with the tube in frame K is thus

$$\mathbf{F}_{\text{K}} = q[(-\mathbf{v}_E \times \mathbf{B}_{\text{tube}} + \mathbf{E}_p) + \mathbf{v}_E \times (\mathbf{B}_{\text{Earth}} + \mathbf{B}_{\text{tube}})] \quad (2a)$$

$$= q(\mathbf{E}_p + \mathbf{v}_E \times \mathbf{B}_{\text{Earth}}). \quad (2b)$$

This demonstrates for frame K that there is no contribution to the Lorentz force containing $\mathbf{B}_{\text{tube}}$ because the contributions of $\mathbf{B}_{\text{tube}}$ to $\mathbf{E}$ and $\mathbf{v} \times \mathbf{B}$ cancel. As a consequence, the magnetization of the tube is irrelevant for the emf.

From Eqs. (2b) and (1a), the emf is evaluated as

$$\mathcal{E} = \iint [\nabla \times \mathbf{F}_{\text{K}}/q] \cdot \mathbf{dA} = \iint \nabla \times (\mathbf{v}_E \times \mathbf{B}_{\text{Earth}}) \cdot \mathbf{dA} = 0 \quad (3)$$

because $\nabla \times \mathbf{E}_p = 0$ (as mentioned above), and because $\mathbf{v}_E$ and $\mathbf{B}_{\text{Earth}}$ both are constant in space (and time). Thus, contrary to CHC, I find in K that $\mathcal{E} = 0$ irrespective of any special magnetization state $\mathbf{B}_{\text{tube}}$ and hence the device of CHC cannot work as claimed.

Note that I have *not* used $\mathbf{v}_E \times \mathbf{B}_{\text{Earth}} = -\mathbf{E}_p$ [Eq. (12) of CHC] in the argument above, which is the equality they want to violate with Eq. (13) of CHC. In addition, it should be stressed that Eq. (3) yields zero emf because $\nabla \times (\mathbf{v}_E \times \mathbf{B}_{\text{Earth}}) = 0$, while CHC argue that $\nabla \times (\mathbf{v} \times \mathbf{B}) \neq 0$ with $\mathbf{B} = \mathbf{B}_{\text{Earth}} + \mathbf{B}_{\text{tube}}$, which thus does not contradict Eq. (3). I will return in Sec. VII to the question whether CHC have indeed shown that $\nabla \times (\mathbf{v} \times \mathbf{B}) \neq 0$.

IV. ANALYSIS IN THE LABORATORY FRAME—PART 1

I will now calculate the Lorentz force $\mathbf{F}_{K'}$ in the comoving frame K′, where $\mathbf{E}_{\text{K}'} = \mathbf{v}_E \times \mathbf{B}_{\text{Earth}}$, as found in Sec. III. Since the tube is static in K′, and hence $\mathbf{v} = \mathbf{0}$ in the Lorentz force equation, I obtain

$$\mathbf{F}_{\text{K}'} = q[(\mathbf{E}_p + \mathbf{v}_E \times \mathbf{B}_{\text{Earth}}) + \mathbf{0} \times (\mathbf{B}_{\text{Earth}} + \mathbf{B}_{\text{tube}})] \quad (4a)$$

$$= q(\mathbf{E}_p + \mathbf{v}_E \times \mathbf{B}_{\text{Earth}}), \quad (4b)$$

which is the same force as given by Eq. (2b) as should be in the approximation used, i.e., $v \ll c$. Thus, I obtain analogously to Eq. (3) also for frame K′ that $\mathcal{E} = 0$. This implies that the device of CHC cannot work as claimed. Apart from $\mathbf{E}_p$ (which does not contribute to the emf), Eq. (4b) is identical to Eq. (6) of CHC. However, Eq. (4) applies to the complete device of CHC, including the effect of $\mathbf{B}_{\text{tube}}$ and thus indeed $\mathcal{E} = 0$ for their complete device.

V. INTRODUCTORY REMARKS ABOUT $\partial\mathbf{B}/\partial t$

CHC argue in the last paragraph of their Sec. I B that translating objects with nonuniform fields (such as $\mathbf{B}_{\text{tube}}$) may give rise to a nonzero $\partial\mathbf{B}/\partial t$. Indeed, an observer in K may observe a nonzero $\partial\mathbf{B}/\partial t$ at a fixed point in space due to the motion of the tube. However, since the tube and circuit are always comoving with the field of the tube, $\partial\mathbf{B}_{\text{tube}}/\partial t = 0$ at each charge q in the tube or circuit. In addition, $\mathbf{B}_{\text{Earth}}$ is constant in space and time and thus $\partial\mathbf{B}_{\text{Earth}}/\partial t = 0$ (both in K and in K′). Adding both contributions yields $\partial\mathbf{B}/\partial t = 0$ at the (comoving) location of each q. Hence, I expect that although indeed $\partial\mathbf{B}/\partial t \neq 0$ at fixed points in K, this will not be of consequence to the emf. In the next section, this will be investigated more precisely in the comoving frame K′, which also enables a brief discussion of Sec. XI of CH.

VI. ANALYSIS IN THE LABORATORY FRAME—PART 2

In K′, the tube is static and hence $\mathbf{v} = \mathbf{0}$ in the Lorentz force equation. This simplifies Eq. (1b) to

$$\mathcal{E} = \iint -\partial\mathbf{B}/\partial t' \cdot \mathbf{dA}, \quad (5)$$

where I have copied the prime on the time coordinate from CH [cf. left-hand side (LHS) of Eq. (65) of CH]. Since the tube is moving in a magnetic field, in principle there could be a nonzero $\partial\mathbf{B}/\partial t'$ at the tube, which then would lead to an emf. CH write correctly [Eq. (67) of CH] $\partial\mathbf{B}/\partial t' = (\partial\mathbf{B}/\partial y)(\partial y/\partial t') = v\partial\mathbf{B}/\partial y$, and argue subsequently that $v\partial\mathbf{B}/\partial y \neq 0$ and that in view of the nonzero $\partial\mathbf{B}/\partial y$, the emf would be nonzero.

However, $\mathbf{B} = \mathbf{B}_{\text{Earth}} + \mathbf{B}_{\text{tube}}$ and while the tube moves through the constant field $\mathbf{B}_{\text{Earth}}$ (with $\partial\mathbf{B}_{\text{Earth}}/\partial y = 0$), it is stationary with respect to its own field $\mathbf{B}_{\text{tube}}$. Thus, more precisely $\partial\mathbf{B}/\partial t' = v_E\partial\mathbf{B}_{\text{Earth}}/\partial y + v_{\text{tube}}\partial\mathbf{B}_{\text{tube}}/\partial y = v_E 0 + 0\partial\mathbf{B}_{\text{tube}}/\partial y = 0$. Subsitution in Eq. (5) yields $\mathcal{E} = 0$ in agreement with Sec. III, but contrary to CH. The error in CH is that the tube was assumed to be moving with respect to its own field, which is—of course—not the case.

In conclusion, I find that in both frames K and K′, a correct theory predicts zero emf in contrast to the claims in CHC and CH.

As an aside, I note that there is an independent *reductio ad absurdum* argument that proves that a nonzero $\partial\mathbf{B}_{\text{tube}}/\partial t$ cannot create a dc emf. Suppose with CHC that the emf $\mathcal{E}$ is a nonzero constant and that this emf is only due to $\partial\mathbf{B}_{\text{tube}}/\partial t$ (since $\partial\mathbf{B}_{\text{Earth}}/\partial y = 0$). Then, $\mathcal{E} \propto \partial\mathbf{B}_{\text{tube}}/\partial t$ and $\mathbf{B}_{\text{tube}} \propto \mathcal{E}t$. Thus, for a nonzero emf, $\mathbf{B}_{\text{tube}}$ and hence the magnetization of the tube needs to increase indefinitely with time. This is, of course, not possible because all magnetically permeable materials have a finite saturation magnetization.

VII. THE ADVECTION-DIFFUSION EQUATION FOR B

CHC calculate the precise value of the emf using the advection-diffusion equation for $\mathbf{B}$. This equation takes into

account that a local emf in a conductor will lead to a current in proportion to its conductivity σ [Eq. (14) of CHC; also Eq. (7) of CH]:

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = \mathbf{J}/\sigma = \eta \nabla \times \mathbf{B}, \tag{6}$$

where the first equality holds because of the generalized Ohm's law and the second equality because of the Ampère-Maxwell law $\mathbf{J} = (1/\mu)\nabla \times \mathbf{B}_\mathbf{J}$, while $\eta = (\sigma\mu)^{-1}$. Taking the curl of Eq. (6) gives the advection-diffusion equation [Eq. (15) of CHC] for $\mathbf{B}$:

$$-\frac{\partial \mathbf{B}}{\partial t} + \nabla \times (\mathbf{v} \times \mathbf{B}) = -\eta \nabla^2 \mathbf{B}. \tag{7}$$

In CH, this equation is written in terms of the vector potential $\mathbf{A}$ [Eqs. (6) and (23) of CH] and subsequently solved. The solution, of course, satisfies Eq. (6). The integral of the lhs of this equation is the emf and hence so is the integral of the right-hand side. Indeed, the emf is calculated [Eq. (21) of CHC] as $\mathcal{E} = \eta \oint \nabla \times \mathbf{B} \cdot \mathbf{d}\ell$. This emf is found to be nonzero for certain material properties and the calculated magnetization state; i.e., a nonzero emf is found despite my arguments above. This is, however, not a proof at all for a nonzero emf for the following reasons.

First, $\mathbf{E} + \mathbf{v} \times \mathbf{B}$ in Eq. (6) is the Lorentz force per charge q, which was found to be zero in Secs. III and IV. No contradiction will be found if we also put $\mathbf{J}/\sigma = \eta \nabla \times \mathbf{B} = \mathbf{0}$ in Eq. (6): Zero emf yields zero current. The origin of the error in Eq. (14) of CHC is now clear: $\mathbf{E} + \mathbf{v} \times \mathbf{B}$ was used for calculating the emf while ignoring the canceling of terms containing $\mathbf{B}_{\text{tube}}$ in Eq. (2b).

Second, in writing $\mathbf{J}$ (and hence $\eta \nabla \times \mathbf{B}$) in Eq. (6) and by their subsequent derivation, it was implicitly *assumed* by CH that the emf was nonzero and thus that a nonzero current was present. The magnetization of the tube $\mathbf{B}_{\text{tube}}$ was then calculated *demanding* that $\mathbf{B}_{\text{tube}}$ satisfies Eq. (6), i.e., demanding that $\mathbf{B}_{\text{tube}}$ is consistent with a current flowing through the loop. Thus, of course, $(1/\mu)\nabla \times \mathbf{B} = \mathbf{J}$ is found, which only proves that no calculational error was made. If the correct assumption $\mathbf{J} = \mathbf{0}$ had been used from the outset, then—of course—the solution of the modified equation (6) would have given $\nabla \times \mathbf{B} = \mathbf{0}$ and thus zero emf.

I stress that Eq. (13) of CHC, i.e., $\nabla \times (\mathbf{v} \times \mathbf{B}) \neq 0$, is found as a consequence of the assumption of $\mathbf{J} \neq \mathbf{0}$ (i.e., a nonzero emf) and thus cannot be used as an *a priori* agument for the same nonzero emf.

In conclusion, the non-zero emf found from the solution of the advection-diffusion equation in CHC is not a proof at all that the emf is really nonzero. To the contrary, I have shown in the preceeding sections that the emf is zero.

VIII. SIMILAR DEVICES WILL ALSO NOT WORK

Here, I argue that no device that consists of a rigid loop with a fixed orientation in a constant external magnetic field can generate an emf; i.e., modifying the device of CHC cannot fix its shortcomings.

First, Cullwick has demonstrated both theoretically [8] and—for a special configuration—experimentally [9] that the emf in a wire that moves in a magnetic field is independent upon the magnetization of that wire [in agreement with the canceling of $\mathbf{B}_{\text{tube}}$ in Eq. (2a)]. In other words, the emf in a magnetic wire is the same as in a copper wire. Applied to the device of CHC, this implies that the presence of a special magnetic material (and even a tube) in their device is irrelevant and that their emf should be the same as for a similar device made completely of copper, of which CHC concede that the emf would be zero. Thus, based on Cullwick's demonstrations I conclude that the device of CHC cannot work, nor similar ones. Veltkamp and Wijngaarden [4] have in their experimental paper also given a theoretical argument that is consistent with that of Cullwick [8].

Second, for a rigid loop, $\mathcal{E} = -d\Phi/dt$, and thus, there is only a nonzero emf if the magnetic flux Φ through the device is changing in time. Since CH claim that their device produces a constant DC voltage, $d\Phi/dt$ must be constant and $|\Phi|$ should increase linearly with time indefinitely. Since the size of the loop does not change, a constantly increasing $|\Phi|$ implies a constantly increasing magnetic field $\mathbf{B} = \mathbf{B}_{\text{Earth}} + \mathbf{B}_{\text{tube}}$. Here, $\mathbf{B}_{\text{Earth}}$ is constant and thus $\mathbf{B}_{\text{tube}}$ and the magnetization of the tube should increase indefinitly with time. However, since all magnetically permeable materials have a saturation magnetization, this is not possible. Thus, I am again led to the conclusion that their device cannot work.

IX. THE EXPERIMENT

The authors of CHC went to great length to verify a number of predictions from their theory in spite of huge difficulties such as a signal of about 18 μV in the presence of thermovoltages of 417 $\mu\text{V K}^{-1}$. Their observation of voltages in a rigid circuit that is stationary in the laboratory is certainly intriguing.

The important question, however, is whether it has been demonstrated by CHC that indeed with their device energy can be obtained from Earth's rotation. In my view, the evidence is not at all convincing for the following reasons: (1) A precise comparison between theory and experiment is not possible due to the unknown current path in the tube. (2) In view of the errors noted above in the theory, there is presently no theory at all that explains the experiments, let alone supports the idea that the observed voltages stem from Earth's rotation. (3) The claim of voltage generation crucially depends on a correct and consistent determination of the zero in the voltage and thermal gradient measurements. Although the authors went to great length in that respect, a reproduction of results with larger signals and thus less relative uncertainty in the zeros is imperative. (4) The dependence of the observed signal on the orientation of the device is certainly intriguing. However, it is not a proof that the signal is caused by motion through Earth's field. Such a dependence might be caused by the thermovoltage being magnetization dependent. (5) If the observed voltages are indeed a consequence of one of the many special properties [e.g., large Seebeck coefficient, rectification of high frequency (HF) radiation] of the used ferrite, then it is no surprise that zero emf is observed in a MuMetal tube.

Again, in my opinion and in view of the issues raised above, it has not been demonstrated yet that the observed voltages are related to motion of the device through Earth's field. There are, however, several modifications to the experiment that could be done to substantiate this extraordinary claim.

First, the experiment could be repeated at different latitudes thus using the different surface velocities of Earth. Of course, the change in surface magnetic field must be taken into account, but this would be a test for a correct velocity dependence of the signal.

Second, experiments could be made in laboratory-created magnetic fields and velocities, in the spirit of the experiment by Cullwick [9].

Third, I note that the laboratory frame K′ is simply an inertial frame where an external magnetic field $\mathbf{B}_{\mathrm{K}'} = \mathbf{B}_{\mathrm{Earth}}$ and (as noted above) an external electric field $\mathbf{E}_{\mathrm{K}'} = \mathbf{v}_E \times \mathbf{B}_{\mathrm{Earth}}$ are present. Thus, the experiments should be reproduced in a shielded room with artificially created $\mathbf{B}, \mathbf{E}$ fields and a stationary tube. Such experiments allow the variation of the external fields $\mathbf{B}, \mathbf{E}$ at will and a full exploration of the consistency of the observed emf's as a function of the field values.

Until such experiments are performed, it is not warranted to claim that the present device extracts energy from Earth's rotation.

Should future experiments be able to prove that the present device is indeed capable of extracting energy from Earth's rotation, then my detailed theoretical objections in Secs. III, IV, VI, and VII will still hold. Thus, also new experiments cannot be used by themselves as refutation of my objections. Rather, also in that case the present theoretical flaws must be fixed or a completely new theory should be formulated.

ACKNOWLEDGMENT

I am very grateful to Christopher Chyba for many interesting discussions during a period of many years.

DATA AVAILABILITY

There are no publicly available research data or software supporting this manuscript. Requests for further information or data should be sent to the authors.

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