And yet it moves: the momentum of static electromagnetic fields

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1 Momentum in "static" electromagnetic configurations

That a "static" electromagnetic field configuration can store non-zero momentum is today no longer a matter of discussion, with plenty of experimental evidence and theoretical analyses.[1] In the case of a "static" configuration the presence of non-zero momentum is still seen as counter-intuitive. Quoting Feynman:[2]

> Also, $\boldsymbol{E}$ and $\boldsymbol{B}$ are quite static. But the Poynting vector says that there is a flow of energy, because there is an $\boldsymbol{E} \times \boldsymbol{B}$ that is not zero. If you look at the energy flow, you find that it just circulates around and around. There isn't any change in the energy anywhere–everything which flows into one volume flows out again. It is like incompressible water flowing around. So there is a circulation of energy in this so-called static condition. How absurd it gets!

Or, more recently, Griffiths:[3]

> even purely *static* fields can store momentum. How can a system at rest carry momentum?

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[1] Page & Adams 1945; Feynman, Leighton, et al. 2010 Ch. 27; Romer 1966; Pugh & Pugh 1967; Furry 1969; Calkin 1971; Wallace & O'Connell 1980; Casserberg 1982; Sharma 1988; Romer 1995; Narayan 2021; Gralla & Lobo 2022; see also Poynting 1905; Page 1958 § 158; Jones & Richards 1954; Calkin 1966; Coleman & Van Vleck 1968; Scanio 1975; McDonald 2015; Allen & Jones 1990; Majcen, Haaland, et al. 2000; McDonald 2003; 2019; Harbola 2010; Griffiths 2012; Morris & Styer 2012; McDonald 2022a,b.
[2] Feynman, Leighton, et al. 2010 § 27-5 p. 27-15. [3] Griffiths 2012 § 1 p. 7.

Bibliography

("de X" is listed under D, "van X" under V, and so on, regardless of national conventions.)

Allen, J. E., Jones, T. V. (1990): *Relativistic recoil and the railgun*. J. Appl. Phys. **67**[1], 18–21. doi:10.1063/1.346056.

Calkin, M. G. (1966): *Linear momentum of quasistatic electromagnetic fields*. Am. J. Phys. **34**[10], 921–925. doi:10.1119/1.1972282.

Calkin, M. G. (1971): *Linear momentum of the source of a static electromagnetic field*. Am. J. Phys. **39**[5], 513–516. doi:10.1119/1.1986204.

Casserberg, B. R. (1982): *Electromagnetic momentum introduced simply*. Am. J. Phys. **50**[5], 415–416. doi:10.1119/1.12827.

Coleman, S., Van Vleck, J. H. (1968): *Origin of "hidden momentum forces" on magnets*. Phys. Rev. **171**[5], 1370–1375. doi:10.1103/PhysRev.171.1370.

Feynman, R. P., Leighton, R. B., Sands, M. (2010): *The Feynman Lectures on Physics. Vol. II: Mainly Electromagnetism and Matter*, new millennium ed. (Basic Books, New York). https://www.feynmanlectures.caltech.edu/. First publ. 1964.

Furry, W. H. (1969): *Examples of momentum distributions in the electromagnetic field and in matter*. Am. J. Phys. **37**[6], 621–636. doi:10.1119/1.1975729.

Gralla, S. E., Lobo, K. (2022): *Electromagnetic scoot*. Phys. Rev. D **105**[8], 084053. doi:10.1103/PhysRevD.105.084053. Updated version at arXiv doi:10.48550/arXiv.2112.01729.

Griffiths, D. J. (1989): *Note on "Field versus action-at-a-distance in a static situation"*. Am. J. Phys. **57**[6], 558. doi:10.1119/1.15976. See Sharma 1988.

Griffiths, D. J. (2012): *Resource letter EM-1: Electromagnetic momentum*. Am. J. Phys. **80**[1], 7–18. doi:10.1119/1.3641979.

Harbola, M. K. (2010): *Energy flow from a battery to other circuit elements: role of surface charges*. Am. J. Phys. **78**[11], 1203–1206. doi:10.1119/1.3456567.

Jones, R. V., Richards, J. C. S. (1954): *The pressure of radiation in a refracting medium*. Proc. R. Soc. Lond. A **221**[1147], 480–498.

Majcen, S., Haaland, R. K., Dudley, S. C. (2000): *The Poynting vector and power in a simple circuit*. Am. J. Phys. **68**[9], 857–859. doi:10.1119/1.1302733.

McDonald, K. T. (2003): *Hidden momentum in a coaxial cable*. arXiv doi:10.48550/arXiv.physics/0312028.

McDonald, K. T. (2015): *The force on an antenna array*. http://kirkmcd.princeton.edu/examples. First publ. 1979.

McDonald, K. T. (2019): *Four expressions for electromagnetic field momentum*. http://kirkmcd.princeton.edu/examples. First publ. 2006.

McDonald, K. T. (2022a): *Radiated energy and momentum for time-dependent dipoles*. Am. J. Phys. **90**[4], 247–248. doi:10.1119/5.0088991. Extended version at http://kirkmcd.princeton.edu/examples/narayan.pdf.

McDonald, K. T. (2022b): *Electromagnetic-field angular momentum of a classical charged particle in a uniform magnetic field*. http://kirkmcd.princeton.edu/examples/field_l.pdf.

Morris, N. A., Styer, D. F. (2012): *Visualizing poynting vector energy flow in electric circuits*. Am. J. Phys. **80**[6], 552–554. doi:10.1119/1.3679838.

Narayan, O. (2021): *Momentum conservation in the Biot-Savart law*. Am. J. Phys. **89**[11], 1033–1036. doi:10.1119/10.0005207.

Page, L. (1958): *Introduction to Theoretical Physics*, 3rd ed., 3rd pr. (Van Nostrand, Princeton, USA). First publ. 1928.

Page, L., Adams Jr., N. I. (1945): *Action and reaction between moving charges*. Am. J. Phys. **13**[3], 141–147.

Poynting, J. H. (1905): *Note on the tangential stress due to light incident obliquely on an absorbing surface*. Philos. Mag. **49**, 169–171. doi:10.1080/14786440509463267.

Pugh, E. M., Pugh, G. E. (1967): *Physical significance of the Poynting vector in static fields*. Am. J. Phys. **35**[2], 153–156. doi:10.1119/1.1973915.

Romer, R. H. (1966): *Angular momentum of static electromagnetic fields*. Am. J. Phys. **34**[9], 772–778. doi:10.1119/1.1973478.

Romer, R. H. (1995): *Question #26. Electromagnetic field momentum*. Am. J. Phys. **63**[9], 777–779. doi:10.1119/1.18075.

Scanio, J. J. G. (1975): *Conservation of momentum in electrodynamics – an example*. Am. J. Phys. **43**[3], 258–260.

Sharma, N. L. (1988): *Field versus action-at-a-distance in a static situation*. Am. J. Phys. **56**[5], 420–423. doi:10.1119/1.15592. See also Griffiths 1989.

Wallace, G. L., O'Connell, R. F. (1980): *Energy flow vector of the electromagnetic field*. Can. J. Phys. **58**[6], 744–745. doi:10.1139/p80-101.