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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. In Griffiths's words:[2]

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

Singal[3] appealed to the equivalence between total momentum and total energy flux, a consequence of the symmetry of the total energy-momentum tensor which is also connected to the balance of boost momentum[4] and of angular momentum. Even in a "static" field configuration there can an energy flow; thus something – energy – is moving. This is an eminent explanation. But the energy flow itself may still be seen as counter-intuitive. Quoting Feynman, in his discussion of the space around a small charge and magnet:[5]

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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] Griffiths 2012 § 1 p. 7. [3] **singal2016**. [4] **<empty citation>**. [5] Feynman, Leighton, et al. 2010 § 27-5 p. 27-15.

> 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:[6]

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

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

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[6] Griffiths 2012 § 1 p. 7.

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