Adherence to internationally agreed nomenclature in service courses for engineering majors

Colm O'Sullivan

Department of Physics, University College Cork, Cork, Ireland. Email: ctosull@ucc.ie

Abstract

During the past half century most physicists, chemists, engineers and others have readily adopted the recommendations for symbols and nomenclature agreed by intergovernmental organizations and national and international authorities (such as CGPM, BIPM),IUPAP,IUPAC,NIST,ISO, etc). Such standardization in the form of internationally agreed conventions has greatly enhanced commercial, technical and scientific communication and, in education, has made it easier for students to read different texts and to proceed smoothly to more advanced level courses. There remain, however, anomalies where agreed nomenclature is not yet universally accepted. Difficulties that this presents for undergraduate learners are the subject of this contribution.

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1. Introduction

Most introductory textbooks in physics, chemistry and engineering readily adopt the recommendations for symbols and nomenclature agreed by intergovernmental organizations and national and international authorities such as Conférence Générale des Poids et Mesure (CGPM), Bureau International des Poids et Mesures (BIPM), the International Union of Pure and Applied Physics (IUPAP), the International Union of Pure and Applied Chemistry (IUPAC), the US National Institute of Standards and Technology (NIST) and the International Organization for Standardization (ISO). Such standardization of internationally agreed conventions makes it easier for students to read other texts and to proceed to more advanced level courses. There remains, however, one very obvious exception where agreed nomenclature is not universal and which is the subject of this contribution.

IUPAP/IUPAC definition: The quantity *electric flux* is defined by IUPAP (Cohen and Giacomo [1] – the SUNAMCO 'Red Book') and by IUPAC (Cohen *et al* [2] – the IUPAC 'Green Book') such that the total electric flux through a surface *S* is given by

$$\Psi_{\mathrm{E}} = \iint_{S} \boldsymbol{D}.d\boldsymbol{S} \qquad (1)$$

where ***D*** is the electric displacement at each point on the surface. While official documents from BIPM and NIST on nomenclature generally avoid the use of the term 'electric flux', such documents define ***D*** as the *electric flux density*, thus indicating conformity with the IUPAP/IUPAC norm. This nomenclature is commonly used in textbooks aimed at electrical engineering students. A trawl of the holdings of the Cambridge University Library showed that the overwhelming majority of titles in engineering electromagnetics directed at undergraduate engineering students adopted this internationally agreed definition. Gauss' law in such texts is a transparent consequence of the flux model and is normally written as

$$\oiint_S \boldsymbol{D}.d\boldsymbol{S} = Q \qquad (2)$$

where Q is the net (free) electric charge within the (closed) surface S.

Common physics textbook definition: By contrast, the great majority of textbooks aimed at students taking introductory physics courses in university or at the upper level in high school use a different definition for the quantity 'electric flux' [3], namely

$$\Psi'_{\mathrm{E}} = \iint_S \boldsymbol{E}.d\boldsymbol{S} \qquad (3)$$

where $\boldsymbol{E}$ is the electric field strength (intensity) at each point on the surface. This definition is also used in a majority of textbooks aimed at intermediate or advanced electromagnetism for physics students. From this viewpoint, $\boldsymbol{E}$ is the 'electric flux density', at variance with the IUPAP/IUPAC definition. [4]

While either of these definitions can be used as a starting point for the formulation of electromagnetism, they conceal two somewhat distinct approaches to the interpretative formalism involved.

2. Laws of electromagnetism in linear isotropic homogeneous media

There is no corresponding issue concerning the definition of magnetic flux which all authors and authorities agree is defined as

$$\Psi_{\mathrm{M}} = \iint_S \boldsymbol{B}.d\boldsymbol{S} \qquad (4)$$

where $\boldsymbol{B}$ is the magnetic flux density or magnetic induction.

The treatment of electromagnetism in a medium requires all four vector fields together with appropriate constitutive equations (e.g., $\boldsymbol{D} = \varepsilon\boldsymbol{E}$, $\boldsymbol{B}=\mu\boldsymbol{H}$ in a linear isotropic homogeneous medium — vacuum being a special case of such a medium with $\varepsilon = \varepsilon_0$ and $\mu = \mu_0$). The fundamental laws of electromagnetism in this case are Maxwell's equations for a medium; in integral form these are

Ampere-Maxwell law:

$$\oint_C \boldsymbol{H}.d\boldsymbol{l} = I + \frac{d}{dt}\iint_S \boldsymbol{D}.d\boldsymbol{S} \qquad (5a)$$

Gauss' law for magnetism:

$$\oiint_S \boldsymbol{B}.d\boldsymbol{S} = 0 \qquad (5b)$$

Gauss' law for electrostatics:

$$\oiint_S \boldsymbol{D}.d\boldsymbol{S} = \sum_i q_i \qquad (5c)$$

Faraday's law:

$$\oint_C \boldsymbol{E}.d\boldsymbol{l} = -\frac{d}{dt}\iint_S \boldsymbol{B}.d\boldsymbol{S} \qquad (5d)$$

Inspection of these equations shows a marked symmetry between $\boldsymbol{D}$ and $\boldsymbol{B}$ and between $\boldsymbol{E}$ and $\boldsymbol{H}$. Furthermore, an obvious implication from the equations is that if $\iint_S \boldsymbol{B}.d\boldsymbol{S}$ is to be seen as *magnetic flux* then, for consistency, $\iint_S \boldsymbol{D}.d\boldsymbol{S}$ should be interpreted as *electric flux* in conformity with the consensus of IUPAP, IUPAC, BIPM, NIST and electrical engineering texts.

3. The physics approach

The perspective embodied in definition (3) above appears to have its origin in the reforms introduced by the Physical Science Study Committee (PSSC) [5] in the late 1950s which followed the initial PSSC meeting in MIT on 10-12 December 1956. [6] The Committee believed that it would be to the benefit of physics teaching 'if the presentation of the subject matter were focused towards one goal, and that goal ought to be *the atomic picture of the universe*' (italics original). [7]

An indirect consequence of this appears to have been a strong emphasis on the fact that the $\boldsymbol{E}$ and $\boldsymbol{B}$ fields are more fundamental than $\boldsymbol{D}$ and $\boldsymbol{H}$, as indeed they can be considered from a physicist's perspective. For example, from a relativistic point of view the $\boldsymbol{E}$ and $\boldsymbol{B}$ fields transform into one another by a simple change of reference frame, independent of the medium involved. Furthermore, the force on a charge in an electromagnetic fields depends only on these two fields as given by the Lorentz force equation, that is $\boldsymbol{F} = q\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}$, again independent of the medium in which the charge is embedded. Stress on this issue led to a general downgrading of the $\boldsymbol{D}$ and $\boldsymbol{H}$ fields to the extent that they are often not even mentioned in some introductory physics texts.

This primary emphasis on the $\boldsymbol{E}$ field leads to a somewhat complicated treatment of polarizable media. The usual approach taken is described very clearly, for example, in Panofsky and Phillips [8]: the electric field strength at a point in such a medium is considered to arise in two parts, viz. (a) true, free, movable charges and (b) bound, zero-net, polarization charges. In this approach, the $\boldsymbol{D}$ field is introduced in terms of the polarization vector $\boldsymbol{P}$ such that $\boldsymbol{D} = \varepsilon_0\boldsymbol{E} + \boldsymbol{P}$ which turns out to depend only on the 'true' or 'free' charges.

4. The engineering approach

The presentation of electromagnetics in engineering education usually starts from a more constructivist perspective with a greater emphasis on experimental observations, benchtop experiments and associated laboratory activities. A central motivation for this approach is the observation that, in the treatment of electric fields in dielectric media, the quantity $\boldsymbol{D}$ is *independent of the medium and depends only on the sources*, 'free' charges being the only sources of flux in this context. This means that, under the definition (1) above, the electric flux through any arbitrary surface is also independent of the medium. This leads to an altogether more simple formulation of introductory electrostatics than normally encountered in most introductory physics texts; for example, it completely avoids the need to introduce more complex concepts such as 'free' and 'bound' charges. In this approach, the only charges envisaged when these equations are first introduced are 'free'; the idea of 'bound charges' may be mentioned later, if desired, in the context of an explanation of linear, isotropic, homogeneous media from a microscopic perspective.

The treatment of phenomena associated with boundaries between dielectric media is also simpler in this approach. Whereas the direction of the electric field may be different on either side of the interface, the fact that the total flux through any arbitrary areas of the interface be continuous requires that the component of $\boldsymbol{D}$ perpendicular to the interface be the same on each side of the interface, again transparent in any flux model. The same considerations apply, of course, in the 'physics approach' if and when the quantity $\boldsymbol{D}$ has been introduced.

5. Conclusions

Starting the development of electromagnetism from the viewpoint of ‘electromagnetism in a medium’ has distinct advantages, namely,

- It is consistent with the IUPAP/IUPAC/ISO definition of electric flux.
- Introducing material initially in the context of macroscopic systems before interpreting it in terms of microscopic models is more in line with the usual treatment of other branches of introductory physics and engineering with which students are familiar (for example, thermal physics).
- Highlighting the symmetries that arise when the flux model is applied to electric and magnetic (and even, if desired, gravitational) sources – see Table below – should make life easier for both instructors and learners and enable students to master the material earlier.
- The approach leads to a simpler, more straight-forward and self-consistent presentation of electromagnetism than often encountered in introductory physics courses. This approach may be particularly useful for engineering majors and for other cohorts of students who do not subsequently undertake study in relativity, quantum mechanics, etc.

Thus, there would appear to be a strong case to be made that those interested in engineering education should insist that their physics colleagues adhere rigorously to internationally agreed conventions when teaching electromagnetism to engineering majors.

Table 1. Summary of the symmetries apparent when electric, magnetic and gravitational fields in a medium are described in terms of flux models.

	electric quantities	magnetic quantities	gravitational quantities
source	q	p	m
field	$\boldsymbol{E}$	$\boldsymbol{H}$	$\boldsymbol{g}$
force on source	$\boldsymbol{F} = q\boldsymbol{E}$	$\boldsymbol{F} = p\boldsymbol{H}$	$\boldsymbol{F} = m\boldsymbol{g}$
flux density	$\boldsymbol{D}$	$\boldsymbol{B}$	$\boldsymbol{\Gamma}$
flux	$\Psi_{\mathrm{E}} = \iint_S \boldsymbol{D}.d\boldsymbol{S} = \varepsilon \iint_S \boldsymbol{E}.d\boldsymbol{S}$	$\Psi_{\mathrm{M}} = \iint_S \boldsymbol{B}.d\boldsymbol{S} = \mu \iint_S \boldsymbol{H}.d\boldsymbol{S}$	$\Psi_{\mathrm{G}} = \iint_S \boldsymbol{\Gamma}.d\boldsymbol{S} = \frac{1}{4\pi G} \iint_S \boldsymbol{g}.d\boldsymbol{S}$
Gauss’ law	$\oiint_S \boldsymbol{D}.d\boldsymbol{S} = \sum_i q_i$	$\oiint_S \boldsymbol{B}.d\boldsymbol{S} = \sum_i p_i = 0$	$\oiint_S \boldsymbol{\Gamma}.d\boldsymbol{S} = \sum_i m_i$
flux density due to point source	$\boldsymbol{D} = \frac{q}{4\pi\varepsilon r^2}\hat{\boldsymbol{r}}$	$\boldsymbol{B} = \frac{p}{4\pi\mu r^2}\hat{\boldsymbol{r}}$	$\boldsymbol{\Gamma} = G\frac{m}{r^2}\hat{\boldsymbol{r}}$
force between point sources	$\boldsymbol{F} = \frac{q_1 q_2}{4\pi\varepsilon r^2}\hat{\boldsymbol{r}}$	$\boldsymbol{F} = \frac{p_1 p_2}{4\pi\mu r^2}\hat{\boldsymbol{r}}$	$\boldsymbol{F} = G\frac{m_1 m_2}{r^2}\hat{\boldsymbol{r}}$

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References

[1] E. R. Cohen and P. Giacomo, *Symbols, Units, Nomenclature and Fundamental Constants in Physics*, IUPAP-25; SUNAMCO 87-1, 1987.

[2] E.R. Cohen et al, *Quantities, Units and Symbols in Physical Chemistry*, IUPAC Green Book, 3rd Edition, 2nd Printing, IUPAC & RSC Publishing, Cambridge, 2008.

[3] Some authors call this the 'electric field flux', presumably to indicate the distinction between the two definitions. Others prefer to discuss 'lines of force' or 'field lines' instead of flux but the same issues arise in this case. Very occasionally (in English language texts) an author may also use a term such as 'electric displacement flux' for the flux defined by Equation (1).

[4] There have been very few exceptions to this approach in introductory physics texts but see, for example, J. S. Marshall, E. D. Pounder and R. W. Stewart, *Physics* (Addison-Wesley 1976) or M. Mansfield and C O'Sullivan, *Understanding Physics* (J Wiley & Sons 2011). Early editions of Sears and Zemansky's *College Physics* (Addison-Wesley 1960) also indicate a similar approach but later editions follow the approach now found in most such texts.

[5] G. C. Finlay, "Secondary School Physics: The Physical Science Study Committee", Am. J. Phys. **28**, pp. 286-293, 1960.

[6] For a brief summary of these developments see the PSSC textbook *Physics*, D. C. Heath and Company, Boston 1960, Appendix 3, pp. 641-643.

[7] "The Physical Science Study Committee – A Planning Conference Report", Physics Today, pp. 28-29, March 1957. Indeed, in the early PSSC approach, the treatment of electromagnetism was integrated with that of Atomic Physics (see endnote 6).

[8] W. K. H. Panofsky and M. Phillips, *Classical Electricity and Magnetism*, 2nd Edition, Addison-Wesley, 1978.

Author

Principal author: Colm Thomas O'Sullivan graduated in physics from the National University of Ireland with BSc (1961) and MSc (1963). He obtained a PhD in Astrophysics from The Catholic University of America in 1970. His primary research area has been in cosmic ray astrophysics but he has also contributed to research efforts in physics education including the teaching physics to engineering students. He retired as Associate Professor in Physics at the National University of Ireland Cork (University College Cork) in 2005. He is a member of the European Physical Society, GIREP (Groupe International de Recherche sur l'Enseignment de la Physique), the Irish Mathematical Society and a Fellow of the Institute of Physics.