Classical Fields: Are They Real?

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Outline

Paul Tipler

We think of the electric field as a condition in space set up by the system of point charges. [. . .] [T]he electric field is more than a calculational device. This concept enables us to avoid the problem of action at a distance [. . .] We thus think of the force exerted on a charge q_0 at point P as being exerted by the field at point P rather than by the charges, which are some distance away. Of course the field at point P is produced by the other charges, but not instantaneously. [11, 705-6]

Percy Bridgman 1927

The electromagnetic field itself is an invention and is never subject to direct observation. What we observe are material bodies with or without charges [...], their positions, motions, and the forces to which they are subject. [...] The electromagnetic field as such is not the final object of our calculations, but the calculation of it is only an intermediate auxiliary step, convenient to make because our mathematical formulation gives so simple a connection between electromagnetic field, charges, and mechanical action that the latter can be calculated at once in terms of the former. In fact the connection is so simple that in many cases we have come to regard our problem as solved if we can compute the electromagnetic field, overlooking the fact that the field has no immediate meaning in terms of experience. [3, 136–7]

David Griffiths

What exactly *is* an electric field? I have deliberately begun with what you might call the "minimal" interpretation of **E**, as an intermediate step in the calculation of electric forces. But I encourage you to think of the field as a "real" physical entity, filling the space around electric charges. Maxwell himself came to believe that electric and magnetic fields are stresses and strains in an invisible primordial jellylike "ether". Special relativity has forced us to abandon the notion of ether, and with it Maxwell's mechanical interpretation of electromagnetic fields. (It is even possible, though cumbersome, to formulate classical electrodynamics as an "action-at-a-distance" theory, and dispense with the field concept altogether.) I can't tell you, then, what a field *is*—only how to calculate it and what it can do for you once you've got it. [5, Sec. 2.1.3]

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general arguments against realism:

- underdetermination of theory by data,
- pessimistic induction.

Introduction

action-at-a-distance:

- instantaneous, or
- retarded.

locality vs. non-locality.

A Priori Counterarguments

instantaneous action-at-a-distance:
cause cannot act at a place where it is not present.
$\rightarrow$ field helpful?

retarded action-at-a-distance:
cause cannot act after it has ceased to exist.
$\rightarrow$ field helpful!

EPR-Locality

A physical theory is *EPR-local* iff according to the theory procedures carried out in one region do not immediately disturb the physical state of systems in sufficiently distant regions in any significant way. [7, 8]

examples:

1. attenuation of physical influence with distance (gravitation),
2. retardation of physical influence (electromagnetism).

Fields

What are they?

What are they used for?

What is there ontological status?

Is it possible to interpret the field as non-existent?

Is there an empirically equivalent theory without fields?

Spatiotemporal Locality

For any event E, any finite temporal interval $\tau > 0$ and for any finite distance $\delta > 0$, there is a complete set of causes of E such that for each event C in this set, there is a location at which it occurs that is separated by a distance no greater than δ from a location at which E occurs, *and* there is a moment at which C occurs *at the former location* that is separated by an interval no greater than τ from a moment at which E occurs *at the latter location*. [6, 15]

- gravitation not spatiotemporally local,
- electromagnetism only spatiotemporally local if the field exists.

Gravitation: The Dispositional View

spread of causal dispositions throughout space.

remarks:

- disposition existent without a test particle.
- support of counterfactuals.
- properties of points of space?
- field just distribution of dispositions?
- difference to action-at-a-distance?

George Berkeley: *De Motu*

difference between force and attraction?

causal explanation: yes.

how does the attraction work?

two senses of explanation:

1. traditional: involvement of the nature of mechanism,
2. weaker: lawlike succession.

Newton's Doubts

> That gravity should be innate, inherent and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else by which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers. [4, 302–3]

from the mathematical to the physical:

- movement by the Creator,
- material ether (discrete),
- immaterial spirit pervading all bodies (continuous).

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- matter constituted by the field.
- criteria for fields, e.g.
  - time for transmission,
  - changing direction of transmission.

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Maxwell (1864):

- electromagnetic theory,
- energy and momentum of fields, even in the absence of matter.

Main Features

Poisson equation,

instantaneous,

attachment to the sources (sources vanish $\Rightarrow$ field disappears),

reaches arbitrarily far,

no medium for transmission,

decreases with distance,

not spatiotemporally local,

EPR-local.

Main Features

Maxwell's equations,

reaches arbitrarily far,

decreases with distance,

radiation (detachment from the sources),

finite speed (retarded action),

no medium required for propagation,

energy, momentum, and angular momentum plus conservation,

radiation reaction,

infinite self-interaction.

Self-Interaction

usually neglect of self-field.

but radiation reaction.

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1. energy balance: Abraham-Lorentz equation.
2. mass renormalization: Lorentz-Dirac equation. [1]

Attempts for Action-at-a-Distance

different interpretation of Maxwell's theory [9]:
direct interaction along light-cones using only retarded potentials.

new theory:
Wheeler-Feynman electrodynamics.

Consequences of Action-at-a-Distance

standard arguments:

- no initial conditions as spacelike hypersurfaces.
- no energy-momentum conservation.

Metaphysical Theories

Humeanism,

primitivism about laws,

dispositionalism.

Status of Fields

stuff, substance,

property,

mathematical tool,

new category.

Status of Energy and Momentum

fundamental notions,

derived entities.

In Favor of Fields

a priori arguments against instantaneous and retarded action-at-a-distance.

radiation: retarded action.

carry energy, momentum, angular momentum, entropy.

conservation of energy.

initial value problem.

Against Fields

fields only introduced to account for the motion of particles.

fields not directly observable.

ontological status:

- stuff, substance?
- properties? of space-time points?
- new ontological category?

interpretation of the field as non-existent.

formulation of retarded distant action theory.

inconsistency: self-field.

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