The Metaphysics of Classical Electrodynamics and its Time Reversal Invariance

Valia Allori
Northern Illinois University

What is the issue?

Recent disagreement: Is Classical Electrodynamics (CED), as all physicists think, time reversal invariant?

- David Albert: NO
- Frank Arntzenius ,John Earman, Paul Horwich, David Malament (and others): YES

Where does this disagreement come from?

- I propose that these people disagree about what CED really is, therefore there is no true disagreement at all about the invariance properties of CED.
- Before answering whether CED is T-reversal invariant, we need to answer: What is the metaphysics of CED?

Instantaneous State and Dynamical Condition

Albert's definition of instantaneous state:

- a complete description of the world at a time such that:
  - It is genuinely instantaneous (no temporal dependence between the objects);
  - It is complete.
    - Es: instantaneous state in classical mechanics (CM)
      - The particles' positions;
      - But not (x,v) (it violates independence): it should be called (according to Albert) the dynamical condition at an instant.

Albert's distinction between instantaneous state and dynamical condition:

- The instantaneous state S represents what exists in the world at one instant.
- The dynamical condition D specifies what is needed at one time to determine the state of the system at another time.

Time Reversal Symmetry in CM

Albert's def. of time reversal invariance:

- A theory is time reversal invariant if and only if considering a possible temporal sequence of instantaneous states S_1; S_2;...;S_n, then the backward sequence of instantaneous states S_n; S_{n-1};...; S_1 is also a possible one.

T-reversal Invariance in CM

- T(x(t)) = x(t) so that S is unchanged under T.
- (In contrast D transforms as T(x, v) = (x,-v), since T(v) = T(dx(t)/dt)=- - dx/dt= - v).
- Since for any possible S_1; S_2;...;S_n, also S_n; S_{n-1};...; S_1 is possible, CM is T-reversal invariant.

T-reversal Invariance in CED:

- Albert's argument for the claim that CED is <u>not</u> T-reversal invariant:
  - 1) In CED, the instantaneous state is S=(x,E,B);
  - 2) We need that T(S)=S;
  - 3) There is no reason why T(B)=-B; so T(S)=S

    - 4) In order for CED to be T-reversal invariant we need T(E) = E and T(B) = -B; so that T(S) is not S;
    - Therefore, CED is not T- reversal invariant.
- Justification for 1): They are logically independent from the particles' positions (unlike v).
- Justification for 2): S represents what there is in the world, and T's action on S should not change that.
- Justification for 3): B is not like v (v is defined as the rate of change of position and so that it makes sense for it to flip sign under T): B is not the rate of change of anything, so it should NOT change sign under T.

Disagreement
Arntzenius , Earman, and Malament disagree: There are reasons for thinking that B flips sign under T .

Mathematical story on how A and B are defined: B is an axial vector, so that T(E) = E, and T(B) = -B, and CED is T-reversal nvariant.

Relation to Albert:

- Arntzenius – Earman- Malament: The transformation of B is understood using its intrinsic geometric definition as axial vector.
    - Malament &Earman: they do not explicitly say whether B belongs to S or not (but probably yes).
    - Arntzenius: he explicitly holds that B belong to S.
        - All claim CED is time reversal invariant.
    - Horwich: he claims that B belongs to S and T(S)=S (like Albert)
        - he claims CED is T-reversal invariant (like Earman, Malament and Arntzenius) → incoherent?

Open questions:

- Why people disagree?
- How do explain Horwich position's?

Why the disagreement?
Earman, Jill North, and Stephen Leeds:

- Albert and Malament use different notions of time reversal.

In contrast, I think that this situation can be better understood as a disagreement about how to interpret the formalism of CED:

- According to some (Albert+Arntzenius/Earman/Malament)the world is made of particles and fields, but they disagree about what fields are.
- According to others (Horwich), the world is just made of particles.

Formalism and its interpretation
Underdetermination:

- Any physical theory is expressed in terms of mathematical relations among different variables.
- In order to interpret a theory realistically, one needs to take at least some of these variables as representing physical objects.
- S captures the metaphysics of the theory; D instead contains also the variables needed to implement the dynamics for the stuff in S.

The Semicolon:

- Let us use the semicolon symbol " ;" in D to separate S from the rest of the variables. Let us put S on the left of the semicolon.
- Then the "most natural interpretation" of S will give us the metaphysics.
  - Ex. CM:
    - D (x; v): S is given by x, which naturally represents point-particles in three-dimensional space. This is what matter is made of.
- By moving the semicolon we can generate different "interpretations" of the same mathematical formalism. They are actually different theories.
  - Ex: different possible CM:
    - CMx = (x; v); CMxv = (x, v;); CMv = (v; x)
      - CMx is the "most natural":
        - in CMxv S is not really instantaneous,
        - CMv is not complete.

Symmetry Properties:

- If we wish the theory to be invariant under a given symmetry, the variables in D but not in S will have to transform in exactly the way that is required to ensure that both the original and the transformed histories are possible histories of the world.
  - Ex. CM (namely CMx) is Galilei invariant:
    - The original and the Galilei-transformed histories of the particles are both possible histories of the world.

Many CEDs

The different positions:

- Arntzenius (and possibly Malament&Earman): CEDx,E,B' = (x, E , B';):
  - The world is made of particles and fields;
  - Fields are represented by the antisymmetric tensor.
  - Time reversal invariant.
- Albert: CEDx,E,B = (x, E, B;)
  - The world is made of particles and fields;
  - Fields are represented by functions.
  - Not time reversal invariant.

Moving the Semicolon ...

- Malament's definition of B and T-reversal invariant CED: CEDx = (x; E, B)
  - The world is made of particles;
  - There are field, according to Malament's definition for the fields, but they do not describe matter.
  - Time reversal invariant.
    - Isn't this Horwich?

Three Metaphysics

All proposals provide possible metaphysics for CED. Accordingly, they have different symmetry properties:

- Albert, considering CED to be CEDx,E,B, judges it to break time reversal invariance;
- Earman, Malament and Arntzenius, considering CED to be CEDx,E,B', conclude the contrary;
- Horwich, arguably considering CED to be CEDx, considers it to be time reversal invariant but for a different reason.

Bottom line: they are talking past each other!

Which is the "Natural Interpretation"? (A: Albert; Arntzenus/Earman/Malament:A/E/M; H: Horwich)

- In CEDx,E,B' (A/E/M) S changes under T, in CEDx,E,B (A) and in CEDx (H) it does not.
- CEDx,E,B (A) needs a standard absolute rest and an objective temporal orientation, while CEDx,E,B' (A/E/M) and CEDx (H) do not.
- CEDx,E,B' (A/E/M) and CEDx (H) have symmetries, CEDx,E,B (A) does not .
- CEDx (H) explains the nature of fields, while CEDxEB' (A/E/M) does not.
- Reasons to reject CEDx (H):
  - It is incomplete.
    - Response: The fields should be understood as describing "properties of objects" rather than objects themselves.
  - There are no free fields.
    - Response: If the fields are not physical, then the solutions of Maxwell's equations have never any physical meaning, including free Maxwell's equations.
- Another reason to like CEDx (H):
  - Ockham's razor: Do not enlarge the ontology if not needed.
    - Objection: Introducing the fields as part of the furniture of the world, we can explain why there is energy associated to them. If we do not, how do we account for that?