The Metaphysics of Classical Electrodynamics and its Time Reversal Invariance

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What is the issue?

- Recent disagreement:
- Is Classical Electrodynamics (CED), as all physicists think, time reversal invariant?
- Or is it not?
  - David Albert [Albert 2000] argues that it is not
  - Everybody else disagrees:
    - for instance John Earman [Earman 2002], David Malament [Malament 2004] and Frank Arntzenius [Arntzenius 2004];
    - Paul Horwich [Horwich 1987] argues for an intermediate position.

Where does this disagreement come from?

- 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 the couple of positions and velocities, since it violates independence:
    - (x,v) should be called the dynamical condition at an instant.

Instantaneous State and Dynamical Condition

- Albert's distinction between instantaneous state and dynamical condition:
  - (x,v) should be called the dynamical condition at an instant.
  - 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:
  - The time reversal operator T has to leave S untouched.
    - In CM:
      - The transformation of the positions: $T(x(t)) = x(t)$.
        - S is unchanged.
      - The transformation of the velocities $T(v) = T(dx(t)/dt) = - - dx/dt = - v$
        - D transforms as $T(x, v) = (x,-v)$.

Time Reversal invariance

- 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.
    - Movie analogy.

Time Reversal Symmetry in CED

- Albert's argument for the claim that CED is not T-reversal invariant:
  - 1) In CED, the instantaneous state is S=(x,E,B);
  - 2) For a theory to be T-reversal invariant 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 time reversal invariant.

Time Reversal Symmetry in CED

- Justification for 1): Why does Albert think that E and B should be in S?
  - They are logically independent from the particles' positions (unlike v).
- Justification for 2): Why does Albert think that S should be left untouched by T?
  - S represents what there is in the world, and T's action on S should not change that;

Time Reversal Symmetry in CED

- Justification for 3): Why does Albert think that B should not flip sign under T?
  - 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

- Earman, Arntzenius and Malament disagree:
  - There are reasons for thinking that B flips sign under T .
  - They provide similar analyses.
- We'll focus on Malament's results now, and Arntzenius' later.....

Malament's story

- In relativistic space-time the world-line of a particle is a smooth curve.
- The electromagnetic force is map from the tangent line to the curve to force vectors,
- To choose a temporal direction, we take a direction of the 4-velocity, and T flips this direction.
- In requiring that the map describing the force has the desired properties, we get that it has to be an antisymmetric tensor.
- From the properties of the antisymmetric tensor and specifying additional structure, we obtain E and B.
- It turns out that T(E) = E, and T(B) = -B, so that CED is invariant under T.

Relation to Albert

- **Malament/Earman:**
  - The transformation of B is understood using its intrinsic geometric definition.
  - Does B belongs to S? He does not say, but probably yes.
  - He claims CED is time reversal invariant.
- **Arntzenius:**
  - He provides an analysis similar to Malament's;
  - He explicitly holds that B belong to S.

Why the disagreement?

- Earman, North [North 2008], and Leeds [Leeds 2006]:
  - The controversy has its source in the fact that 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 (A+E/M/A)the world is made of particles and fields,
    - But they disagree about what fields are.
  - According to others (H), 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 is 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.

The Semicolon and the Nature of Reality

- By moving the semicolon we can generate different “interpretations" of the same mathematical formalism.
  - They are actually different theories.
  - Ex: different possible CM:
    - CM_x = (x; v); CM_{xv} = (x, v;); CM_v = (v; x)
- CM_x is the “most natural”:
  - in CM_{xv} S is not really instantaneous,
  - CM_v 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.
  - Ex. CM is Galilei invariant:
    - Tthe original and the Galilei-transformed histories of the particles are both possible histories of the world.

Many CEDs

- The different positions:
  - $CED'_{x,E,B} = (x, E , B';)$:
    - The world is made of particles and fields,
    - Fields are represented by the antisymmetric tensor.
    - Time reversal invariant.
      - Arntzenius (and possibly Malament).
  - $CED_{x,E,B} = (x, E, B;)$:
    - The world is made of particles and fields
    - Fields are represented by functions.
    - Not time reversal invariant.
      - Albert.

Moving the Semicolon ...

- Malament's definition of B and T-reversal invariant CED:
  - $CED_x = (x; E, B)$:
    - 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.
      - Horwich.

Many CEDs

- Another position:
  - $CED_{E,B}$ = (E , B ; x):
    - The world is made of fields,
    - The particles are “singularities” in the fields.
      - Einstein.

Three Metaphysics

- All proposals provide possible metaphysics for CED.
- Accordingly, they have different symmetry properties:
  - Albert, considering CED to be $CED_{x,E,B}$, judges it to break time reversal invariance;
  - Earman, Malament and Arntzenius, considering CED to be $CED'_{x,E,B}$, conclude the contrary;
  - Horwich, arguably considering CED to be CED_{x}, considers it to be time reversal invariant but for a different reason.
- Bottom line: **they are all correct!!!**

The “Natural Interpretation” is...???

- $CED_{x,E,B}$ (Albert) is better than $CED'_{x,E,B}$ (M/A):
  - In $CED'_{x,E,B}$ S changes under T:
- $CED'_{x,E,B}$ is better than $CED_{x,E,B}$:
  - Ockham's razor [Arntzenius and Greaves 2009]:
    - $CED_{x,E,B}$ needs a standard absolute rest and an objective temporal orientation, while $CED'_{x,E,B}$ does not.
  - $CED'_{x,E,B}$ (M/A) and CED_{x} (H) have symmetries, $CED_{x,E,B}$ (Alert) does not .

The “Natural Interpretation” is...???

- One reason to like CED_x over CED'_{XEB} (M/A): CED_x explains the nature of fields, while CED'_{XEB} does not.
  - CED_x:
    - Symmetry properties are dictated by the intrinsic definition of the fields.
    - They have such a definition because they were introduced to implement the dynamics for the particles.
  - CED'_{xEB}:
    - Symmetry properties are dictated by the intrinsic definition of the fields.

The “Natural Interpretation” is...???

- Reasons to reject CED_x :
- It is incomplete..
  - Response:
    - The fields should be understood as describing properties rather than physical objects.
- There are no free fields..
  - Response:
    - If the fields are not physical then the solutions of Maxwell's equations have never any physical meaning.

The “Natural Interpretation” is...???

- Another reason to like CED_x:
- Ockham's razor:
  - Do not enlarge the ontology if not needed.
  - Objection:
    - Introducing the fields as part of the furniture of the world, we explain why there is energy associated to them.

Conclusion

- The discussion is far from being settled.
- In any case, the aim of this paper was to provide a different point of view on the disagreement about T-reversal invariance of CED:
  - different people disagree because when they think of CED they think of different theories.
- If this is correct, we need to settle first which is the most natural take on CED, otherwise we will not be able to solve the disagreement about the symmetry properties of the theory.