Technische Universität Berlin

THE EPISTEMOLOGY OF THE LARGE HADRON COLLIDER (LHC)

Getting to know “the language of Dirac’s theory of radiation”

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Outline

1. Concepts, Representations, and Narratives

2. The introduction of the virtual transitions and the corresponding narrative

3. Two examples of the evaluation of the narrative

3.1 Igor Tamm and the light scattering by a pair of electrons

3.2 Bernhard Kockel and the “picture of subsequent transitions”

4. Conclusion

Concepts, Representations, and Narratives

Physical-mathematical concepts as context dependent tools

- concepts as embedded in historically situated epistemic constellations and practices
- fruitfulness and application depend on this wider epistemic constellation
- study through their verbal, diagrammatical, mathematical, etc. representations and the surrogate reasoning they allow for

Concepts, Representations, and Narratives

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Narratives (as explanations)

A widely applied storyline that integrates concepts, i.e. their representations, in an (often temporally) ordered fashion

Dirac (1926/27)

Basic (technical) ingredients for a new narrative

- time-dependent perturbation theory (Dirac 1926)
- Quantization of the transversal part of the electromagentic field (i.e. the radiation field) (Dirac 1927a,b)

$$a_m(t) \propto \sum_n \frac{v_{mn} v_{nm'}}{W_n - W_{m'}}$$

Dirac's conceptualization

"[...] radiation that has apparently been scattered can appear by a double process in which a third state, n say, with different proper energy from m [final state] and m' [initial state], plays a part. [...] a_n gets excited on account of transitions from state m' [...], and although it must itself always remain small, a calculation shows that it will cause a_m to grow continually with the time [...]. The scattered radiation thus appears as the result of the two processes $m' \to n$ and $n \to m$, one of which must be an absorption and the other an emission, in neither of which is the total proper energy even approximately conserved."

Dirac (1927, p. 712)

Dirac's conceptualization

"[...] each V_{mn} gives rise to transitions from state n to state m; *more accurately, it causes the eigenfunction representing state m to grow if that state n is already excited [...].*"

Dirac (1927b, p. 711) [emphasis added]

"a_n gets excited [scribbled out: at the expense of a_m; by transitions from m'] on account of the existence of $a_{m'}$ by an ..."

Notes on Draft of Dirac (1927b) (most probably March 1927). P. A. M. Dirac Papers. Florida State University.

Dirac's conceptualization

Dirac's research practice

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Working with the narrative

Dirac applied the verbal representation for the rederivation of the specific form of the Kramers-Heisenberg formula.

The Dirac Sea

- Relativistic description of the electron (Dirac 1928)

→ Inclusion of negative energy states

- Dirac (1930): fill up all the negative energy states with electrons (exclusion principle)

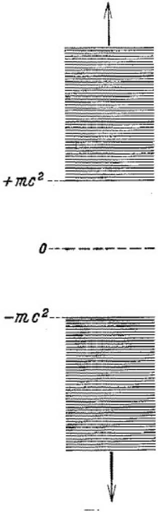

Figure taken from Weisskopf (1935b, p. 652)

Tamm and light-scattering by a pair of electrons

Igor Tamm's basic realizations

Dirac described

- a workaround for the Pauli exclusion principle
- scattering of light from a pair of electrons

Tamm and light-scattering by a pair of electrons

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Question: Under which restrictions is the scattering of light from a pair of electrons possible and what role plays the exclusion principle for the intermediate state?

Kockel and the “picture of subsequent transitions”

	1. Übergang	2. Übergang	3. Übergang
I	Paarerzeugung ($\mathfrak{p}_0^- \to \mathfrak{p}_1^+$)	Elektronensprung ($\mathfrak{p}_1^+ \to \mathfrak{p}_2^+$)	Elektronensprung ($\mathfrak{p}_2^+ \to \mathfrak{p}^+$)
II	„ ($\mathfrak{p}_1^- \to \mathfrak{p}_2^+$)	„ ($\mathfrak{p}_2^+ \to \mathfrak{p}^+$)	Positronensprung ($\mathfrak{p}_0^- \to \mathfrak{p}_1^-$)
III	„ ($\mathfrak{p}_1^- \to \mathfrak{p}_2^+$)	Positronensprung ($\mathfrak{p}_0^- \to \mathfrak{p}_1^-$)	Elektronensprung ($\mathfrak{p}_2^+ \to \mathfrak{p}^+$)
IV	„ ($\mathfrak{p}_2^- \to \mathfrak{p}^+$)	„ ($\mathfrak{p}_1^- \to \mathfrak{p}_2^-$)	Positronensprung ($\mathfrak{p}_0^- \to \mathfrak{p}_1^-$)
V	„ ($\mathfrak{p}_0^- \to \mathfrak{p}_1^+$)	Paarerzeugung ($\mathfrak{p}_2^- \to \mathfrak{p}^+$)	Paarvernichtung ($\mathfrak{p}_1^+ \to \mathfrak{p}_2^-$)
VI	„ ($\mathfrak{p}_2^- \to \mathfrak{p}^+$)	„ ($\mathfrak{p}_0^- \to \mathfrak{p}_1^+$)	„ ($\mathfrak{p}_1^+ \to \mathfrak{p}_2^-$)

	1. Übergang	2. Übergang	3. Übergang
A	$\mathfrak{p}_0^- \to \mathfrak{p}_1^+$	$\mathfrak{p}_1^+ \to \mathfrak{p}_2^+$	$\mathfrak{p}_2^+ \to \mathfrak{p}^+$
B	$\mathfrak{p}_0^- \to \mathfrak{p}_1^+$	$\mathfrak{p}_1^+ \to \mathfrak{p}_2^-$	$\mathfrak{p}_2^- \to \mathfrak{p}^+$
C	$\mathfrak{p}_0^- \to \mathfrak{p}_1^-$	$\mathfrak{p}_1^- \to \mathfrak{p}_2^+$	$\mathfrak{p}_2^+ \to \mathfrak{p}^+$
D	$\mathfrak{p}_0^- \to \mathfrak{p}_1^-$	$\mathfrak{p}_1^- \to \mathfrak{p}_2^-$	$\mathfrak{p}_2^- \to \mathfrak{p}^+$

Figure 1: Taken from Kockel (1937, p. 167 and p. 168): Creation of a pair and a light quantum from two light quanta.

Kockel and the “picture of subsequent transitions”

	1. Übergang	2. Übergang	3. Übergang	Π_χ
I.₁	Paarerzeugung $(\mathfrak{p}_1 \to \mathfrak{p}_1 + \mathfrak{g}_1)$	Paarerzeugung $(\mathfrak{p}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2)$	Elektronensprung $(\mathfrak{p}_2 + \mathfrak{g}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2 + \mathfrak{g}_3)$	1
I.₂	Paarerzeugung $(\mathfrak{p}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2)$	Paarerzeugung $(\mathfrak{p}_1 \to \mathfrak{p}_1 + \mathfrak{g}_1)$	Elektronensprung $(\mathfrak{p}_2 + \mathfrak{g}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2 + \mathfrak{g}_3)$	1
I.₃	Paarerzeugung $(\mathfrak{p}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2)$	Elektronensprung $(\mathfrak{p}_2 + \mathfrak{g}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2 + \mathfrak{g}_3)$	Paarerzeugung $(\mathfrak{p}_1 \to \mathfrak{p}_1 + \mathfrak{g}_1)$	1
II.₁	Paarerzeugung $(\mathfrak{p}_1 \to \mathfrak{p}_1 + \mathfrak{g}_1)$	Paarerzeugung $(\mathfrak{p}_2 + \mathfrak{g}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2 + \mathfrak{g}_3)$	Positronensprung $(\mathfrak{p}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2)$	− 1
II.₂	Paarerzeugung $(\mathfrak{p}_2 + \mathfrak{g}_2 \to \mathfrak{p}_2 + \mathfrak{g}_3 + \mathfrak{g}_3)$	Paarerzeugung $(\mathfrak{p}_1 \to \mathfrak{p}_1 + \mathfrak{g}_1)$	Positronensprung $(\mathfrak{p}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2)$	− 1
II.₃	Paarerzeugung $(\mathfrak{p}_2 + \mathfrak{g}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2 + \mathfrak{g}_3)$	Positronensprung $(\mathfrak{p}_2 \to \mathfrak{p}_2 + \mathfrak{g}_2)$	Paarerzeugung $(\mathfrak{p}_1 \to \mathfrak{p}_1 + \mathfrak{g}_1)$	− 1

Figure 2: Taken from Kockel (1937, p. 176): Creation of two pairs from three light quanta.

Conclusion: Representations, Narratives and “False Predictions”

Dirac’s introduction

The explicit verbal, temporal description in terms of subsequent subprocesses was given by Dirac in 1927.

– high suggestiveness of mathematical apparatus and prior conceptualization

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- high suggestiveness of mathematical apparatus and prior conceptualization
- application of the verbal representation for the construction of mathematical formulas

Note: This function, the construction of the matrix elements to be calculated through (pseudo-)physical reasoning, was also in its reception a prime aspect connecting the narrative to theoretical practice.

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The evaluation of characteristics

Closely connected to a particular problem situation. The question was: which processes can take place at all and how can the calculational efforts be reduced?

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“False Predictions”

Such processes can no longer be conceived of in the representational format of Feynman diagrams. But, in this sense, the real processes conceivable differed in the conceptual schemes of QED in the 1930s and the later version of the 1940s.

Thank you for your attention!