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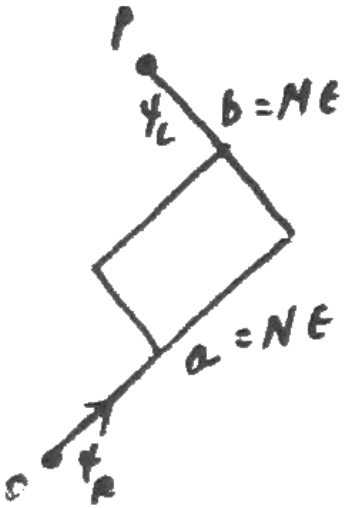
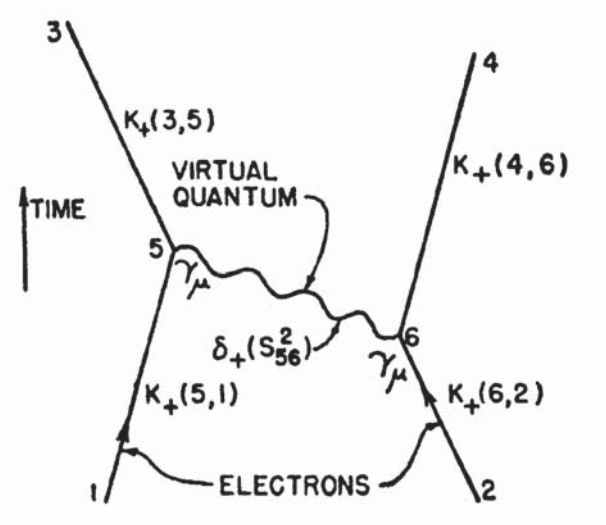
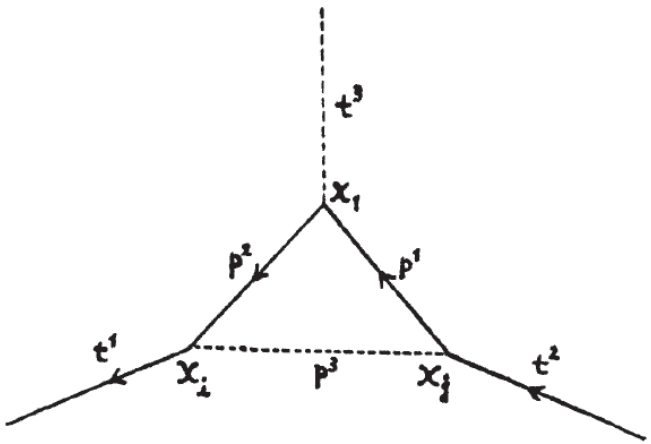
History and Philosophy of Feynman Diagrams







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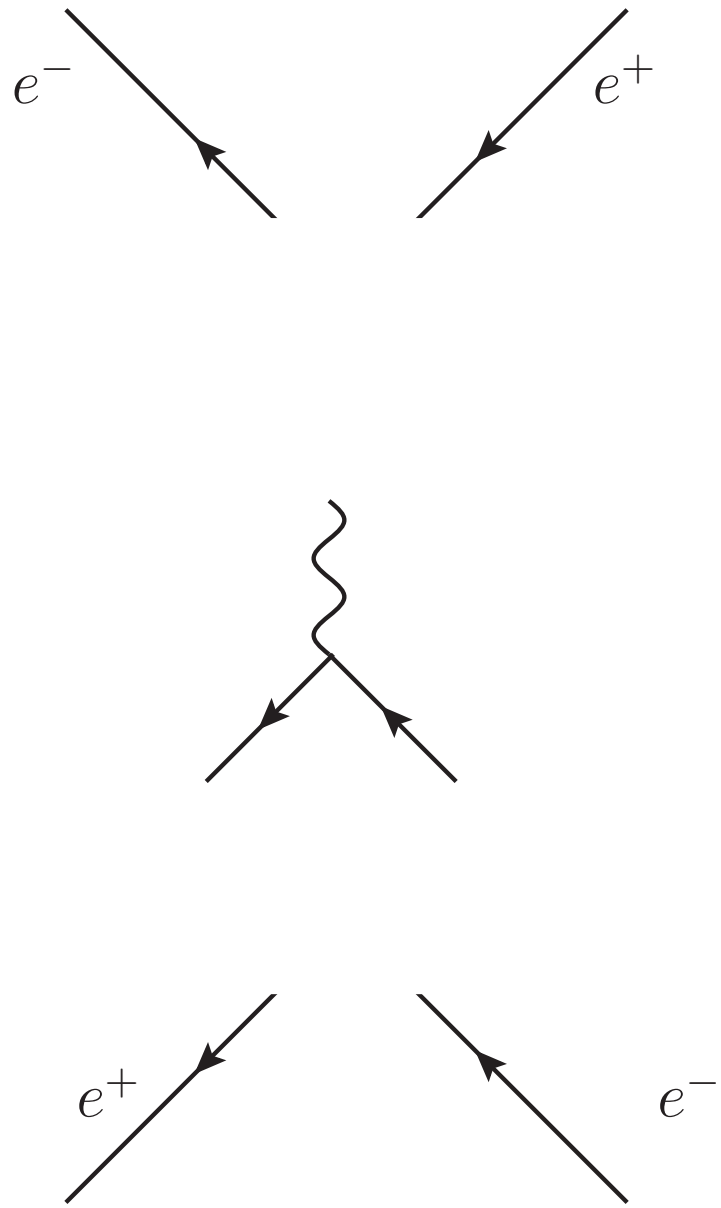
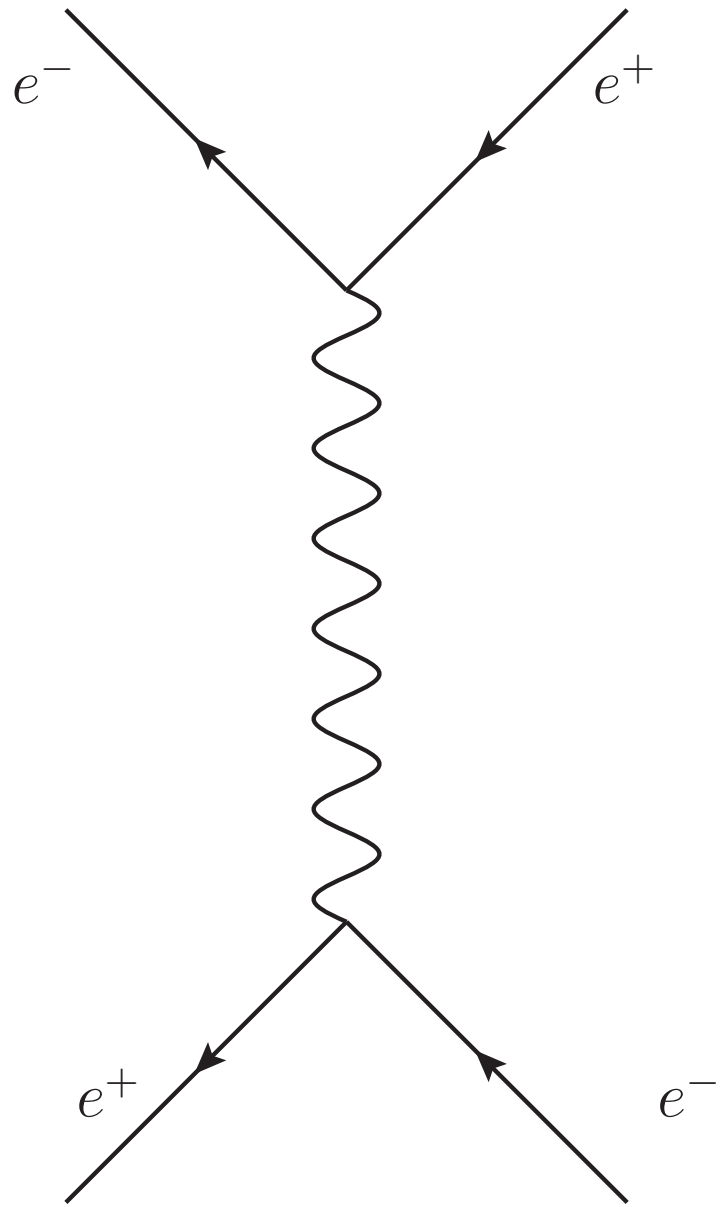
Genesis, modern application and interpretation of Feynman diagrams


e^-
e^+
e^+
e^-


e^-
e^+
e^+
e^-


e^-
e^+
e^+
e^-

Feynman rules

$$= \frac{i(\not{p} + m)}{p^2 - m^2 + i\epsilon}$$

$$= \frac{-ig_{\mu\nu}}{p^2 + i\epsilon}$$

$$= iQe\gamma^{\mu}$$

Peskin and Schroeder 1995, pp. 801–802

Not a representation of a physical process

We see the lines in the diagram; we do not visualize the physical process itself, nor any sort of abstract version of it.

Brown 1996, p. 267

Invention of a system of abbreviations

[Feynman] diagrams evolved as a shorthand to help Feynman translate his integral-over-path perturbative expansions into the expressions for transition matrix elements being calculated.

Schweber 1994, p. 434

No modifications to the content of the theory

Tomonaga, Schwinger, and Feynman rescued the theory without making any radical innovations. Their victory was a victory of conservatism. They kept the physical basis of the theory precisely as it had been laid down by Dirac, and only changed the mathematical superstructure.

Dyson 1965, p. 589

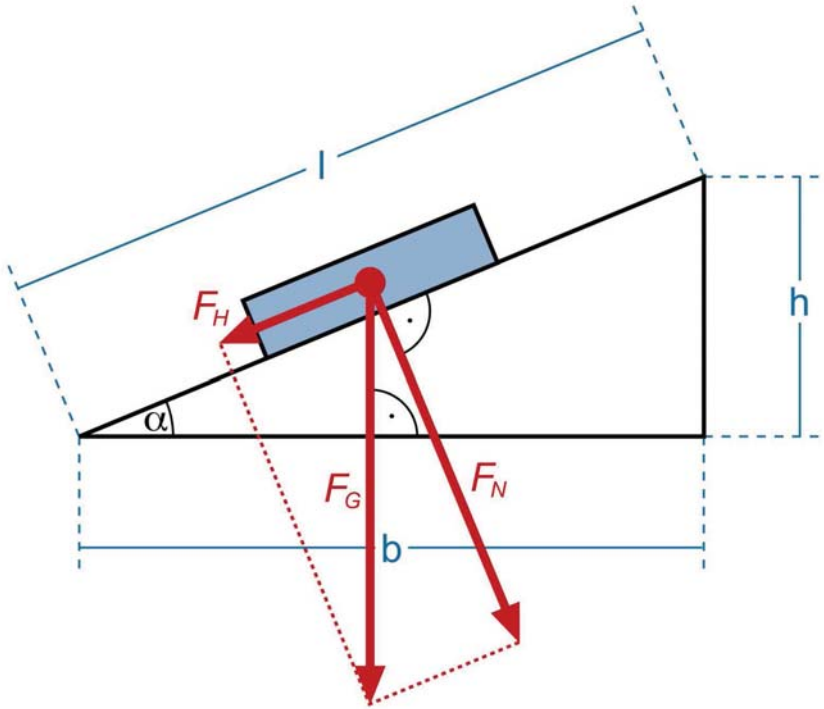
Received view

– Not a representation of a physical process

– Invention of a system of abbreviations

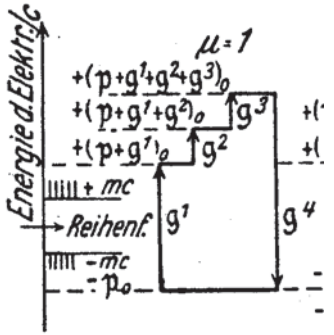
– No modifications to the content of the theory

Representing and calculating

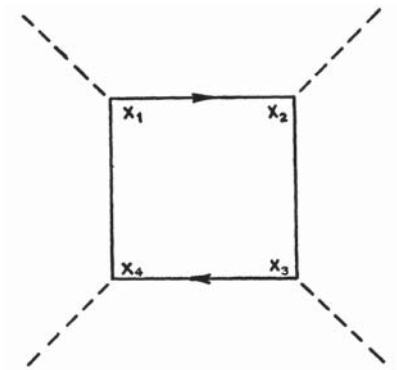


http://de.wikipedia.org/wiki/Kräfteparallelogramm (accessed January 22, 2009).

Light-by-light scattering

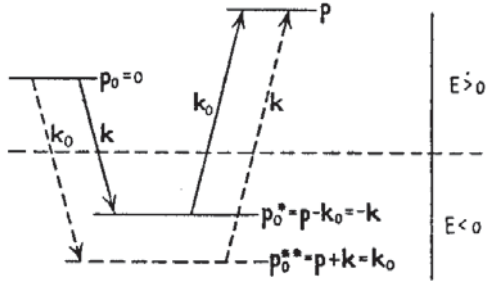


Euler 1936, p. 419

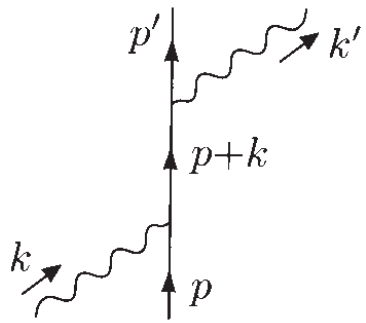


Karplus and Neuman 1950, p. 381

Compton scattering

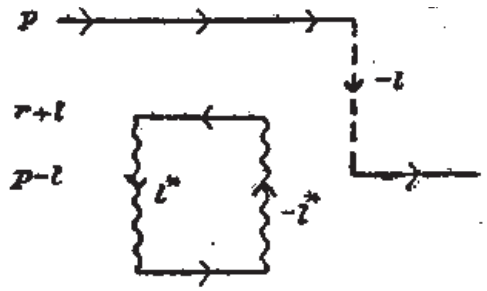


Heitler 1944, p. 190

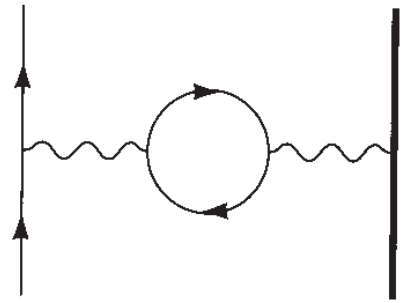


Peskin and Schroeder 1995, p. 158

Electron scattering off a potential



Koba and Takeda 1949, p. 69

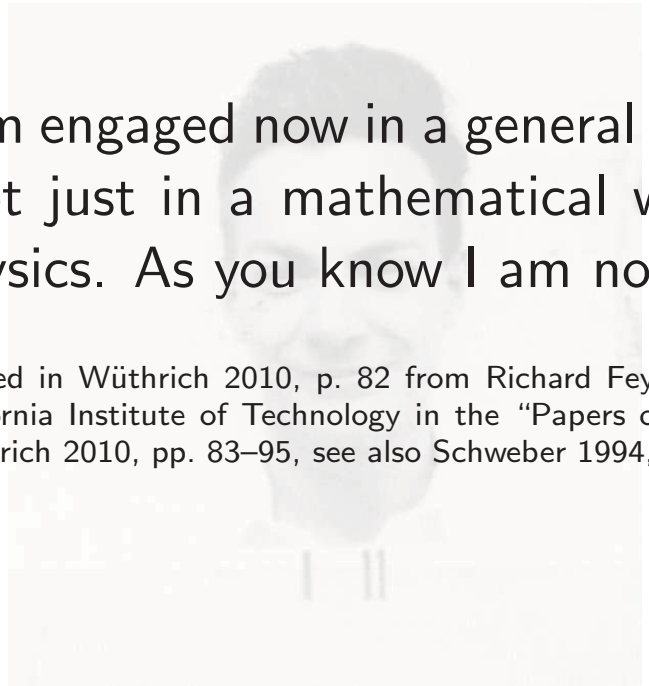


Peskin and Schroeder 1995, p. 244

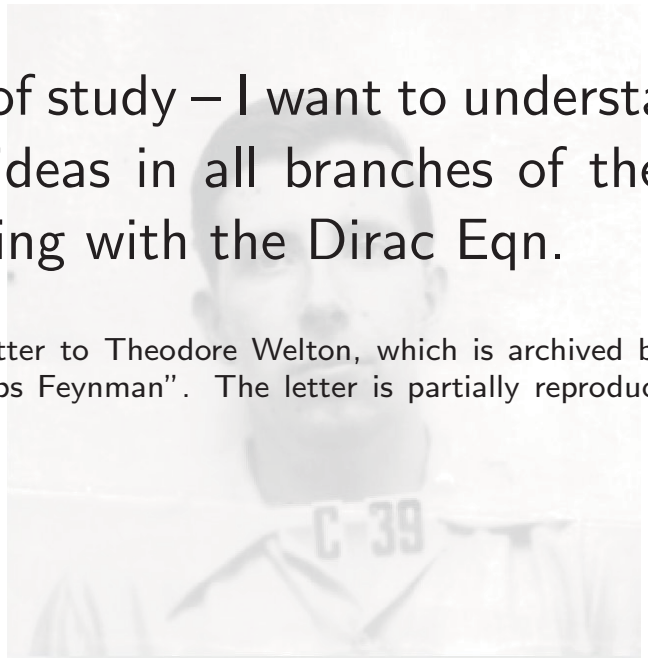
Feynman's struggle for a physical interpretation of the Dirac equation

Los Alamos badge photos from Welton 2007, p. 49

Feynman's programme



I am engaged now in a general program of study – I want to understand (not just in a mathematical way) the ideas in all branches of theor. physics. As you know I am now struggling with the Dirac Eqn.

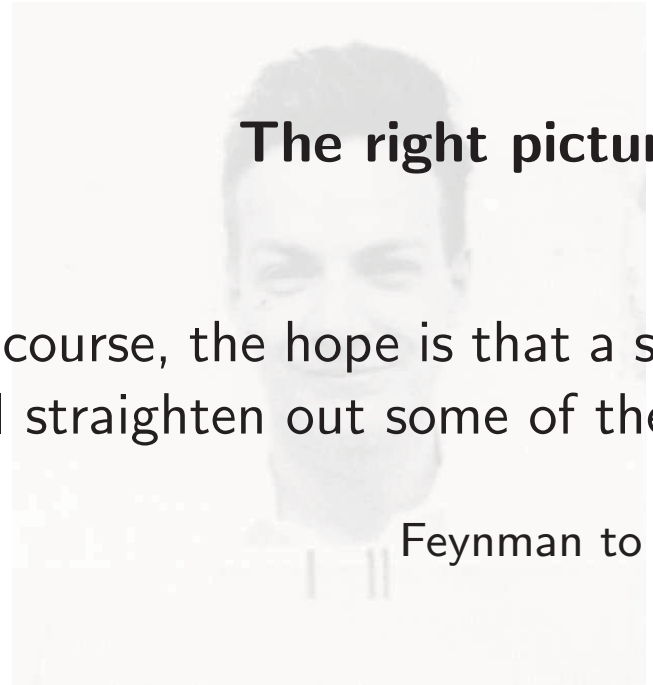


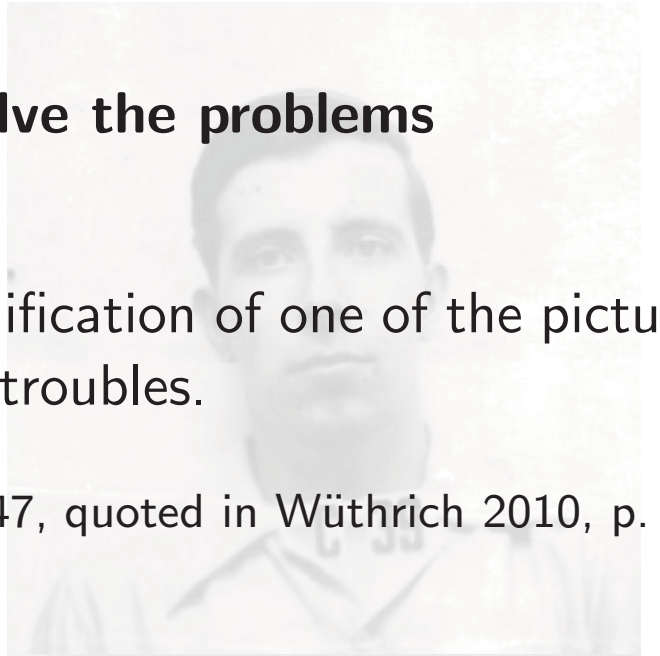
Quoted in Wüthrich 2010, p. 82 from Richard Feynman's 1947 letter to Theodore Welton, which is archived by the California Institute of Technology in the "Papers of Richard Phillips Feynman". The letter is partially reproduced in Wüthrich 2010, pp. 83–95, see also Schweber 1994, pp. 406–408.

Feynman's quest for pictures

I find physics is a wonderful subject. We know so very much and then subsume it into so very few equations that we can say we know very little (except these equations—Eg. Dirac, Maxwell, Schrod[inger]). Then we think we have *the* physical picture with which to interpret the equations. But there are so very few equations that I have found that many physical pictures can give the same equations. So I am spending my time in study—in seeing how many new viewpoints I can take of what is known.

Feynman to Welton 1947, quoted in Wüthrich 2010, p. 92.



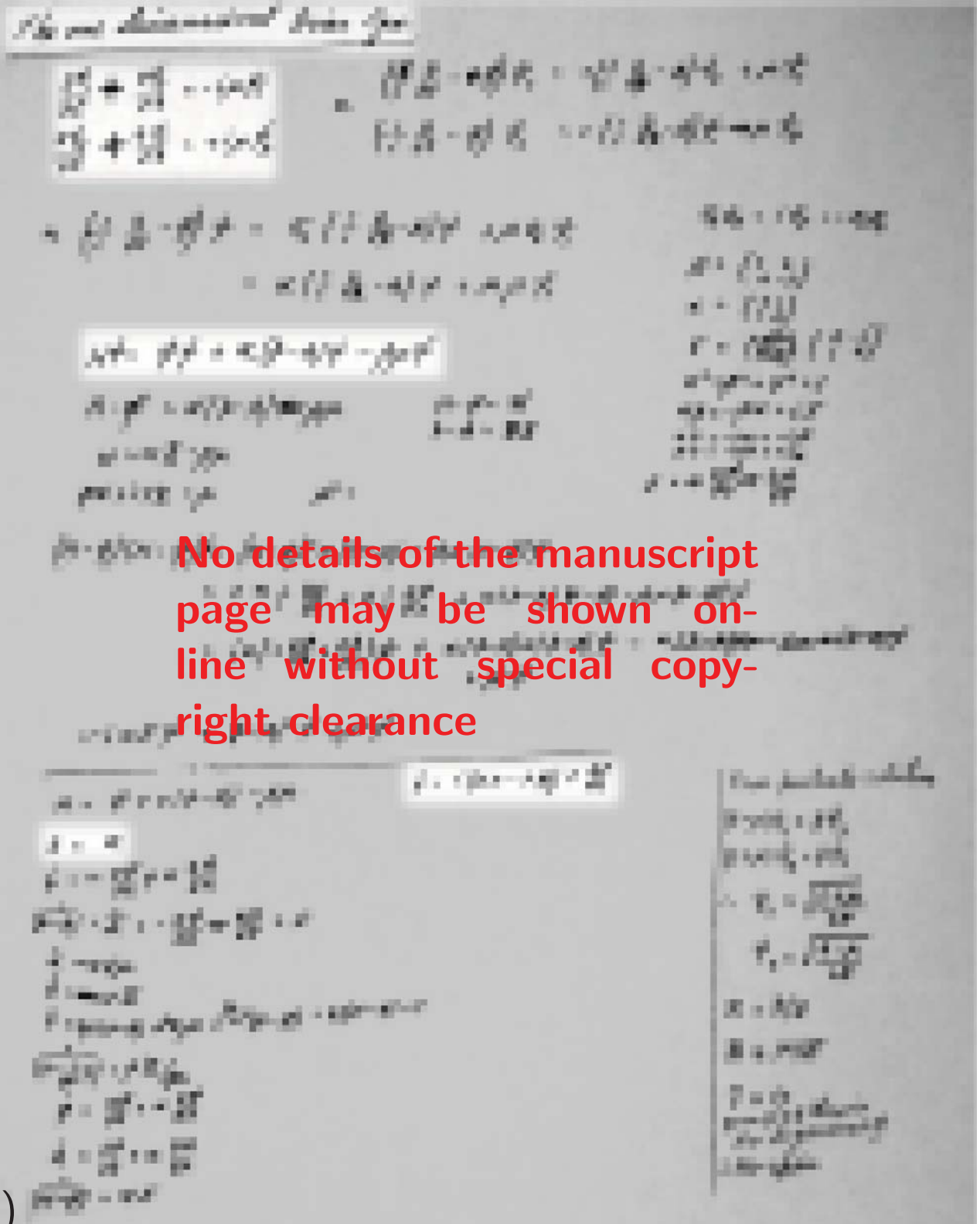


The right picture will solve the problems

Of course, the hope is that a slight modification of one of the pictures will straighten out some of the present troubles.

Feynman to Welton 1947, quoted in Wüthrich 2010, p. 92.

Zitterbewegung



The one dimensional Dirac Eqn.

$$\frac{\partial \psi_1}{\partial t} + \frac{\partial \psi_3}{\partial z} = -i\mu\psi_1$$
$$\frac{\partial \psi_3}{\partial t} + \frac{\partial \psi_1}{\partial z} = +i\mu\psi_3$$

$$H\psi = \phi\psi + \alpha(p - A)\psi - \beta\mu\psi$$

$$\dot{F} = i(HF - FH) + \frac{\partial F}{\partial t}$$

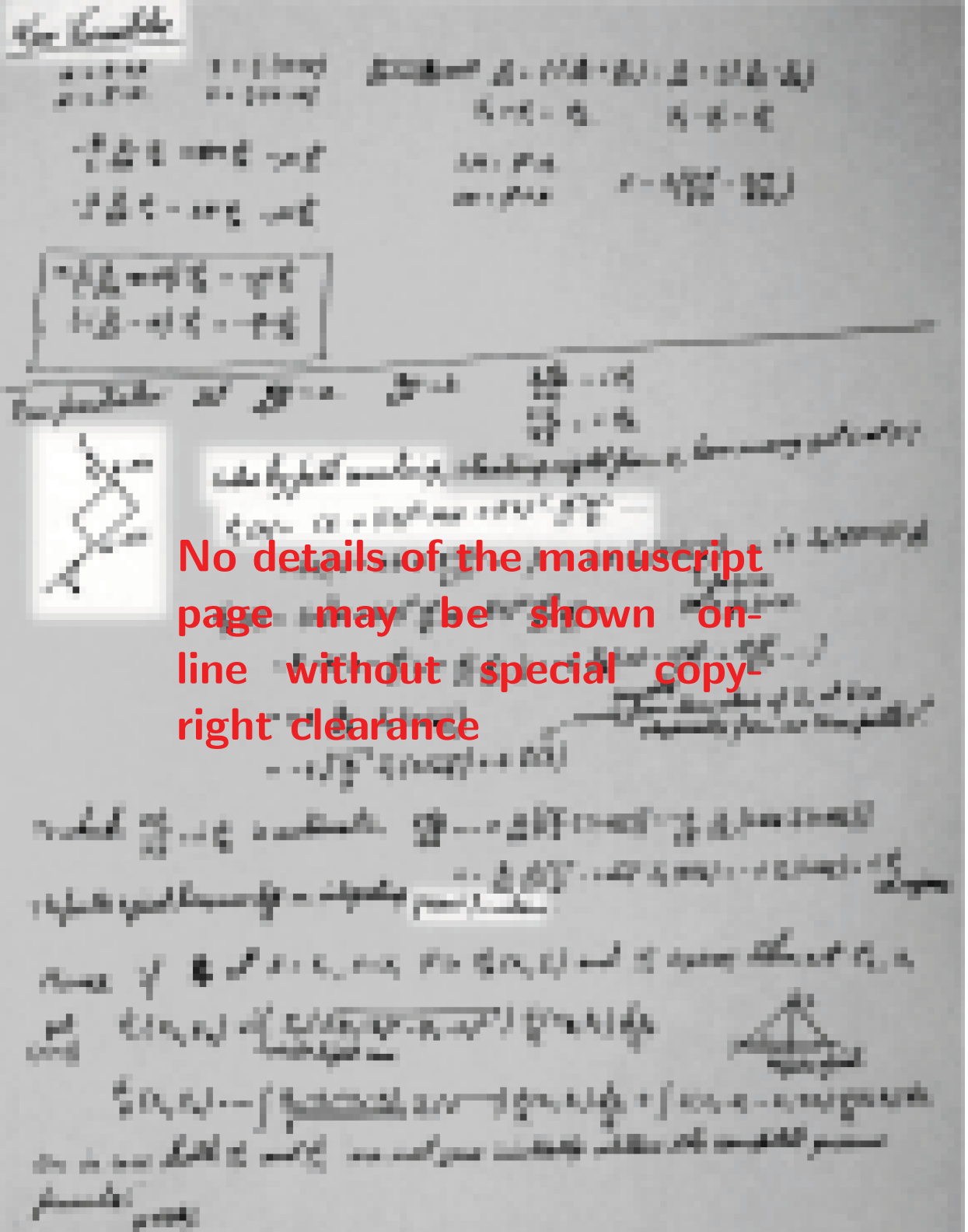
$$\dot{x} = \alpha$$

(For details and a facsimile of the manuscript page, see Wüthrich 2010, pp. 66–68. Cf. Breit 1928, Schrödinger 1930, Dirac 1933, Dirac 1935, p. 260)

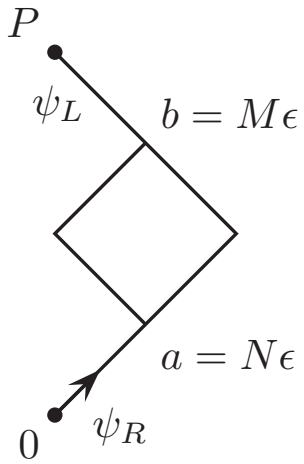
Unsatisfactory results in Feynman 1948

These results for spin and relativity are purely formal and add nothing to the understanding of these equations. There are other ways of obtaining the Dirac equation which offer some promise of giving a clearer physical interpretation to that important and beautiful equation.

Feynman 1948, p. 387



New Variables



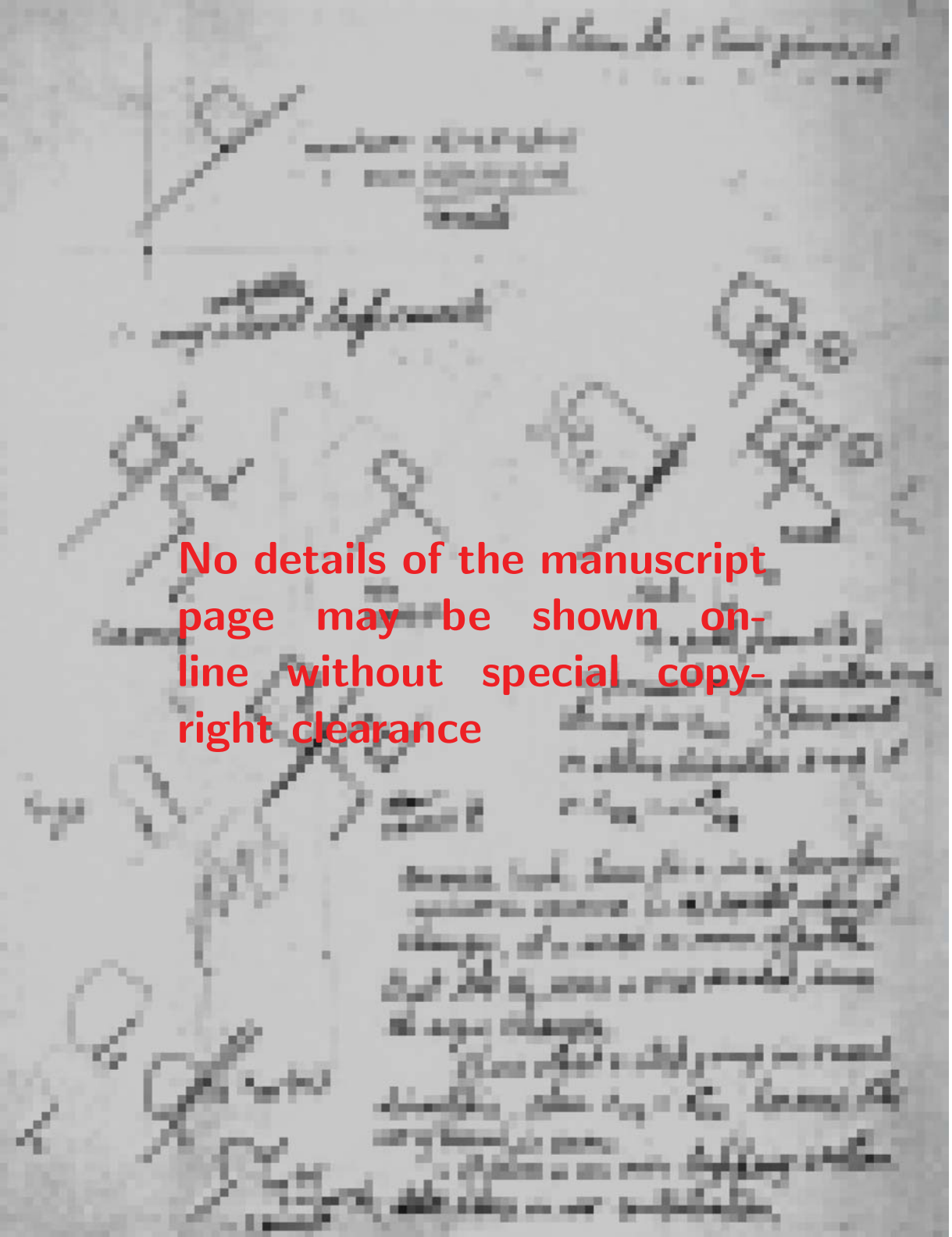
by path counting

$$\psi_L(P) = i\epsilon + (i\epsilon)^3 MN + (i\epsilon)^5 \frac{M^2}{2!}\frac{N^2}{2!} \cdots$$

Green's function

(For details and a facsimile of the manuscript page, see Wüthrich 2010, pp. 68–75.)

Positrons and interaction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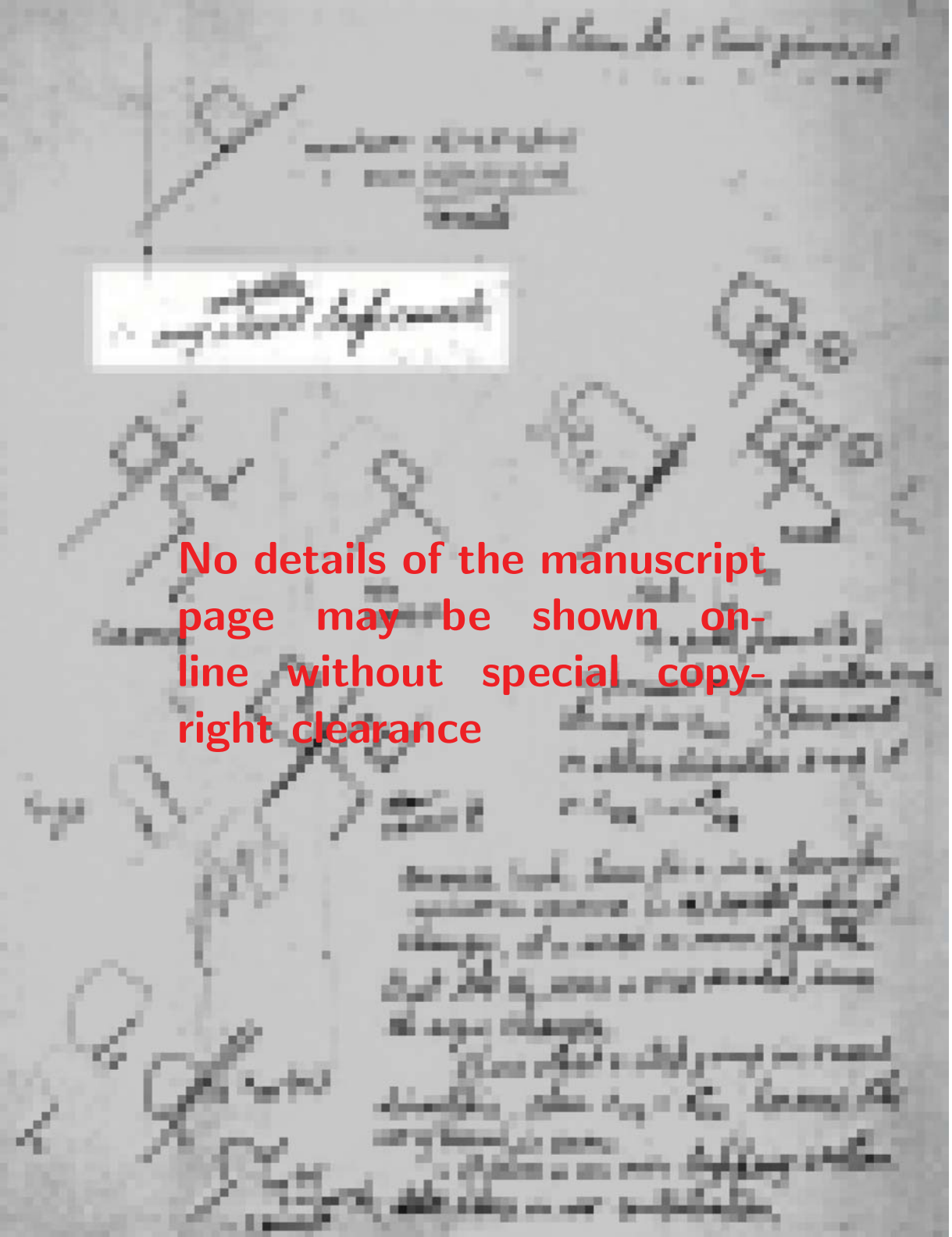
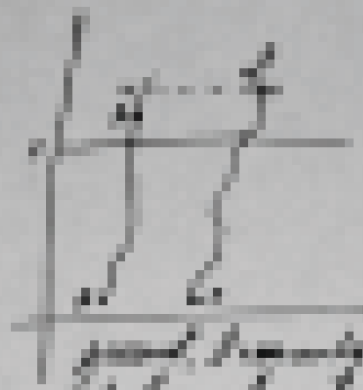


$\therefore$ any completely closed loop cancels

(For a facsimile of the page in question, see Wüthrich 2010, p. 97, and Schweber 1986, p. 482)



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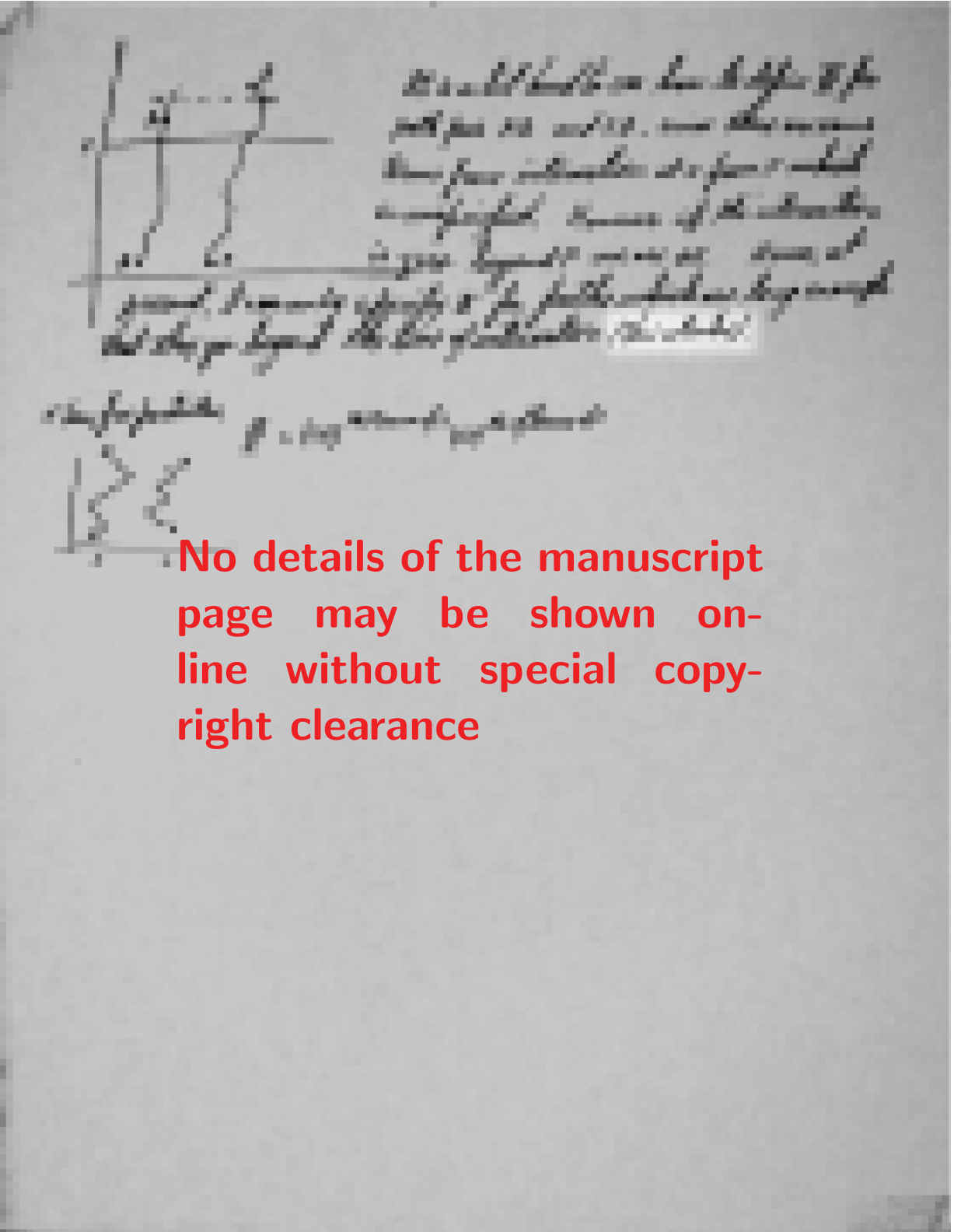

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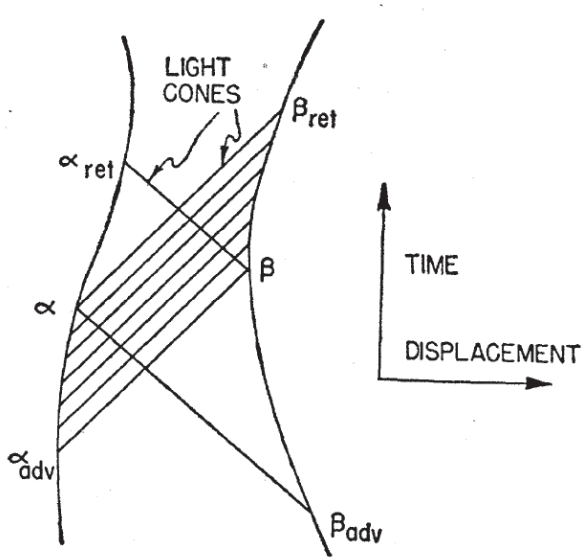
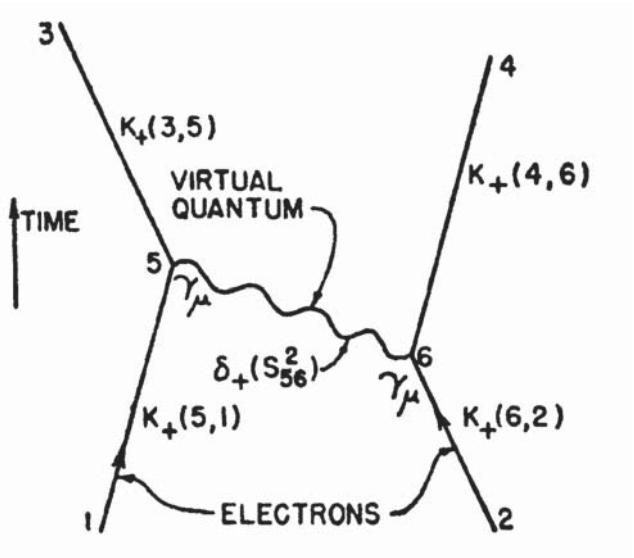
this stinks

(For a facsimile, see Wüthrich 2010, p. 110)

Abandoning the microscopic model



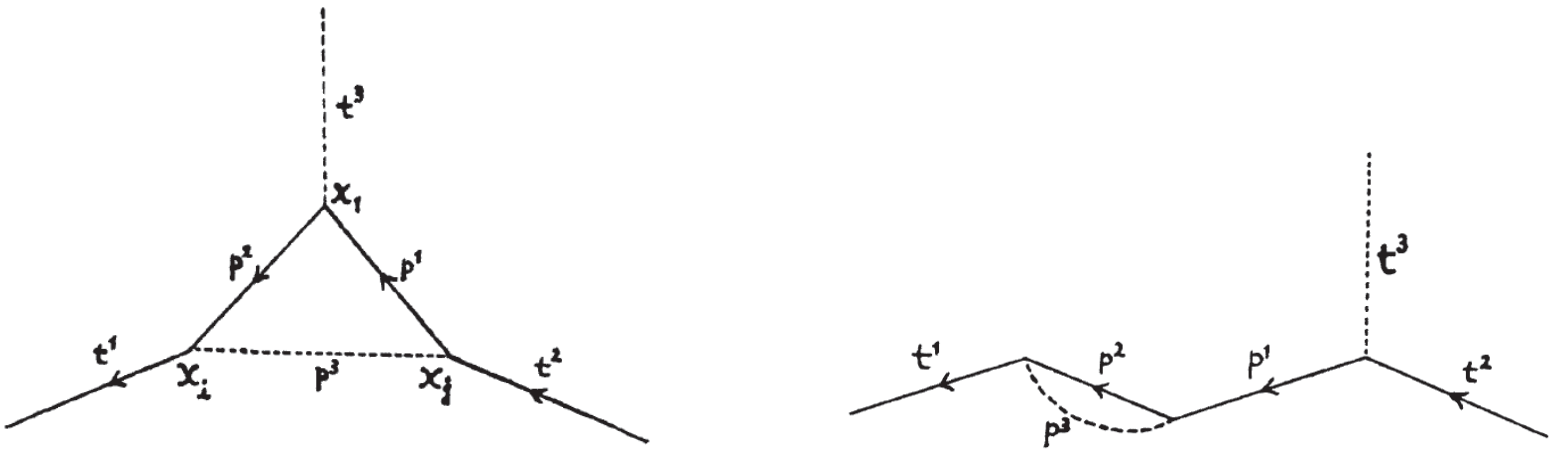
Wheeler and Feynman 1949, p. 431



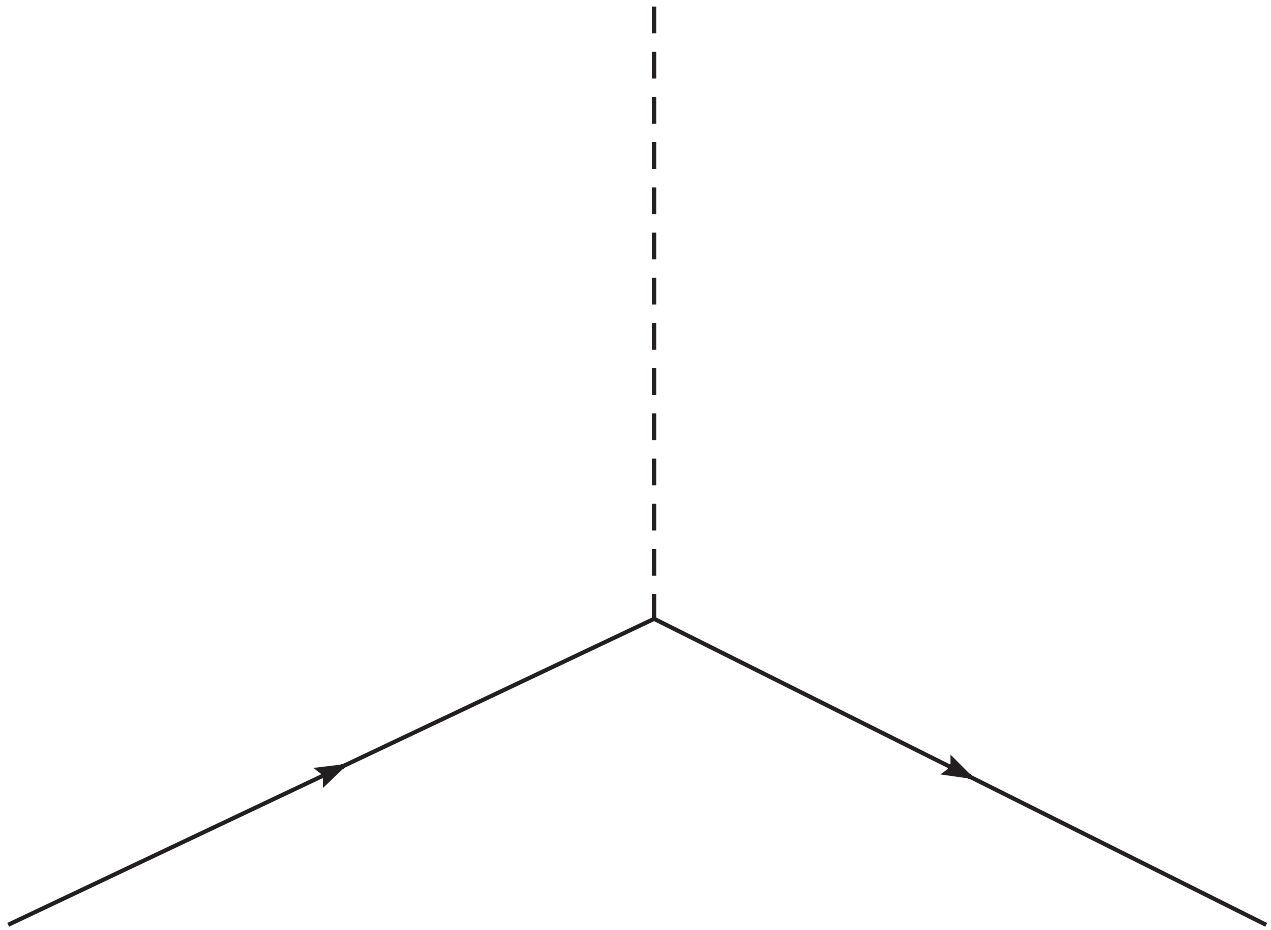
"Space-Time Approach to QED"
(Feynman 1949, p. 772)

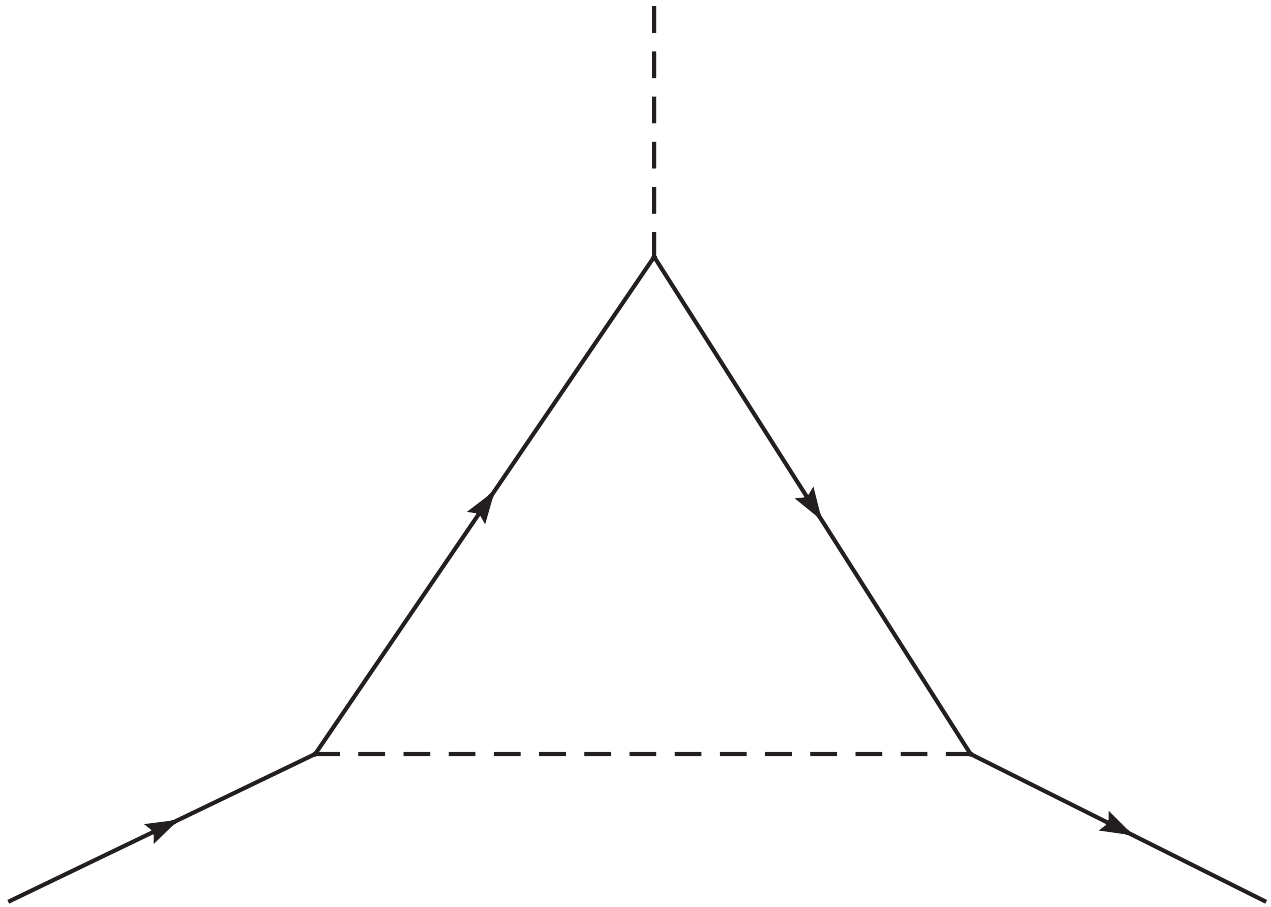
Dyson's systematization and theoretical update

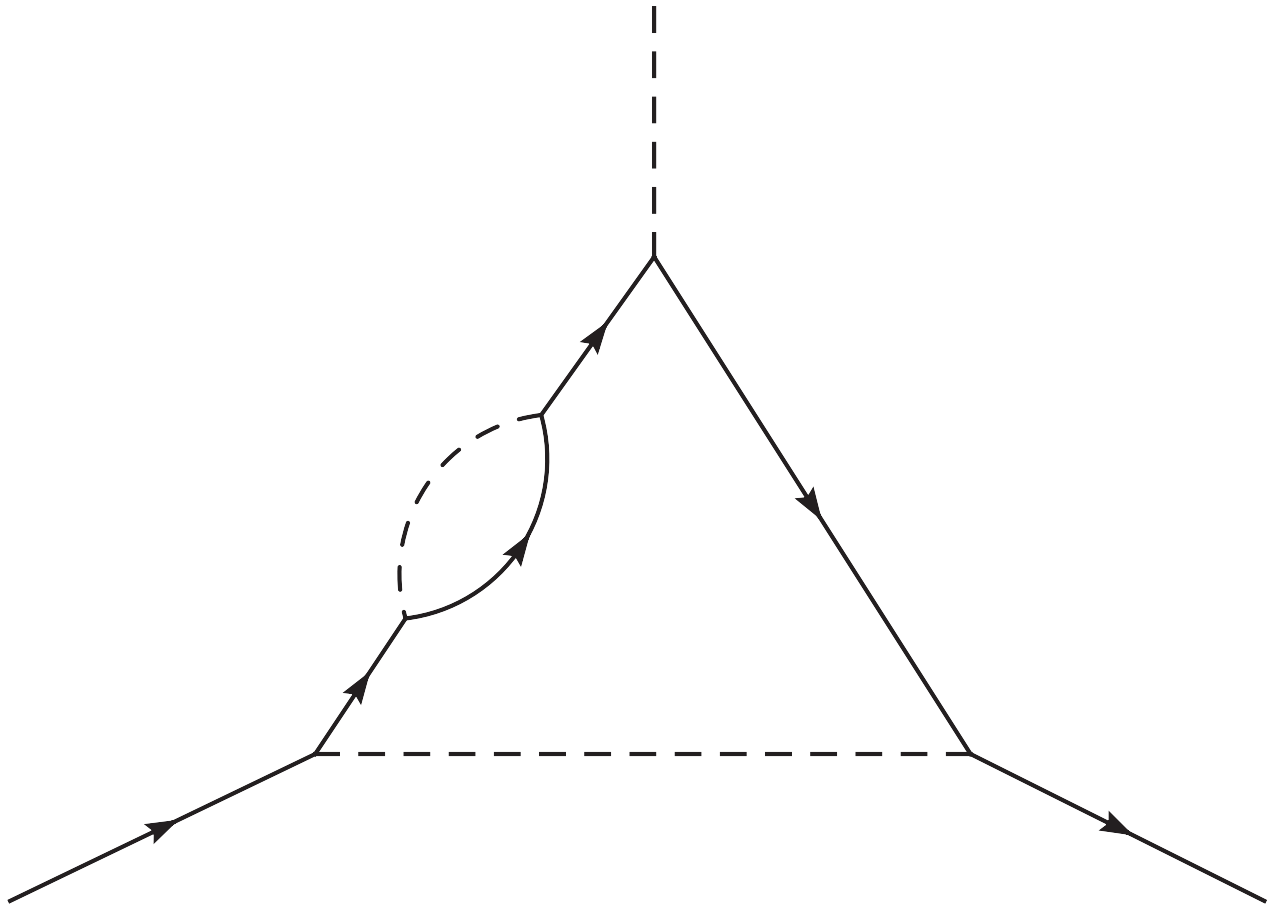
Freeman Dyson at Princeton, 1972. From www.nytimes.com

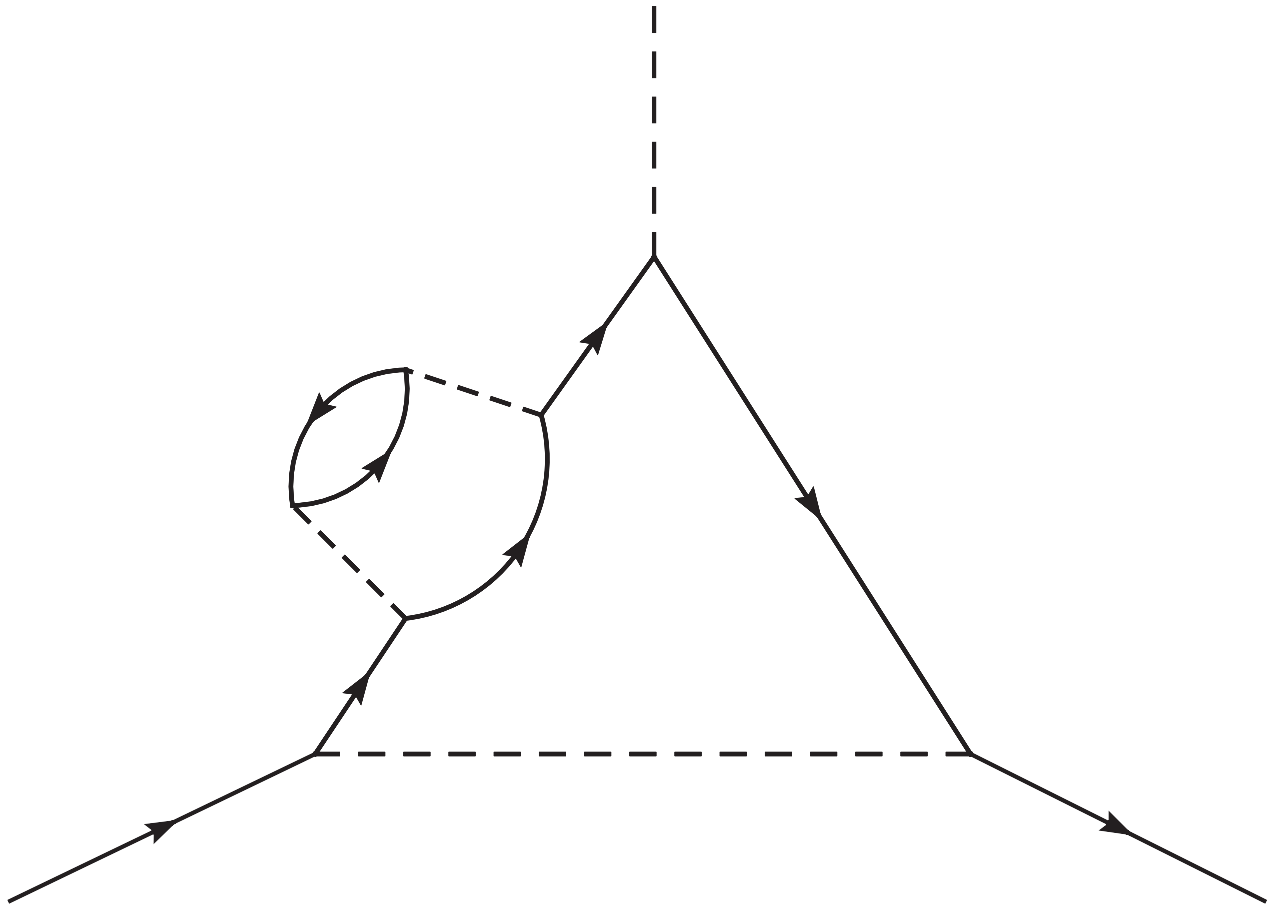


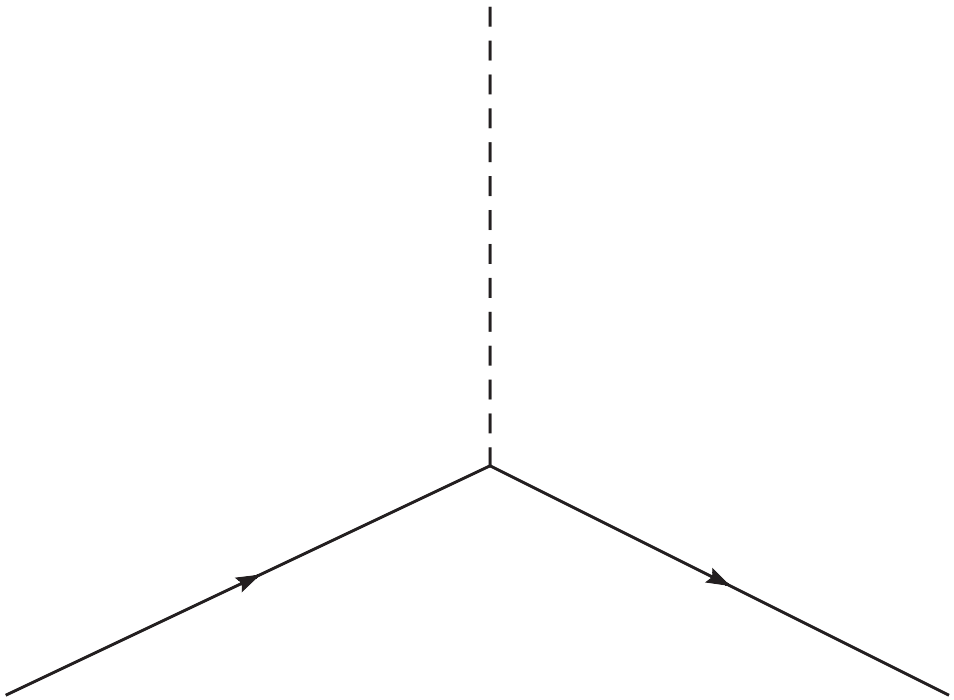
"The S Matrix in QED" (Dyson 1949, pp. 1741–1742)







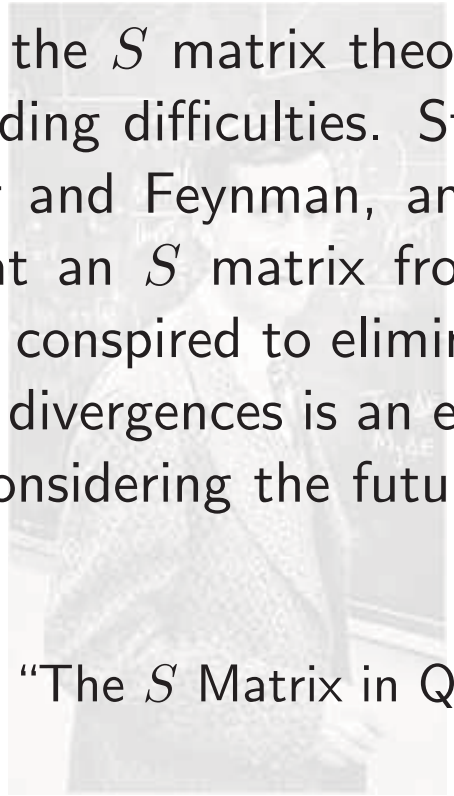




$$
\begin{aligned}
S_F &\rightarrow S'_F = Z_2 \; S'_{F1}(e_1) \\
D_F &\rightarrow D'_F = Z_3 \; D'_{F1}(e_1) \\
\gamma_\mu &\rightarrow \Gamma_\mu = Z_1^{-1} \, \Gamma_{\mu 1}(e_1)
\end{aligned}
$$

Renormalization

Removal of divergences through appropriate representation



The surprising feature of the S matrix theory, as outlined in this paper, is its success in avoiding difficulties. Starting from the methods of Tomonaga, Schwinger and Feynman, and using no new ideas or techniques, one arrives at an S matrix from which the well-known divergences seem to have conspired to eliminate themselves. This automatic disappearance of divergences is an empirical fact, which must be given due weight in considering the future prospects of electrodynamics.

"The S Matrix in QED" (Dyson 1949, p. 1754)

Appropriate representation of an adequate model

- Feynman diagrams are powerful tools for calculation; but not only.
- Feynman diagrams represent, in an abstract way, relevant features of quantum electrodynamic processes.
- Feynman diagrams are (visual representations of) models for the electrodynamic processes.
- The change from one visual representation to another does not only amount to a change in calculation techniques, but also
- to a change in how the processes are modeled and conceptualized.
- Theoretical problems (such as the uninterpretable infinities) can be solved by finding the appropriate representation of an adequate model.
- Once the adequate model and its appropriate representation has been adopted, the solution appears to be a fortunate coincidence (Dyson's surprise).
- The adequateness of the model and the appropriateness of the representation explain the coincidence.

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