Feynman Diagrams by Wentzel (1938)

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1 Wentzel

In a 1938 review [1] of his earlier papers [2] on neutron decay according to the theory of Yukawa [3], Wentzel used several diagrams that are precursors of Feynman diagrams. In particular, his Fig. 7 shows the neutron decay $N \to Pe\nu$ via an intermediate boson Π (called a *Bose-Proton* by Wentzel, who used n rather than ν for a neutrino).

Fig. 7.

2 Stueckelberg

Stueckelberg is often credited with anticipating Feynman diagrams, on the basis of Fig. 1 of [4] (1941), although this perhaps echoes more the view of Wheeler (also 1941),[1] that positrons can be interpreted as electrons moving backwards in time, than Feynman diagrams themselves.

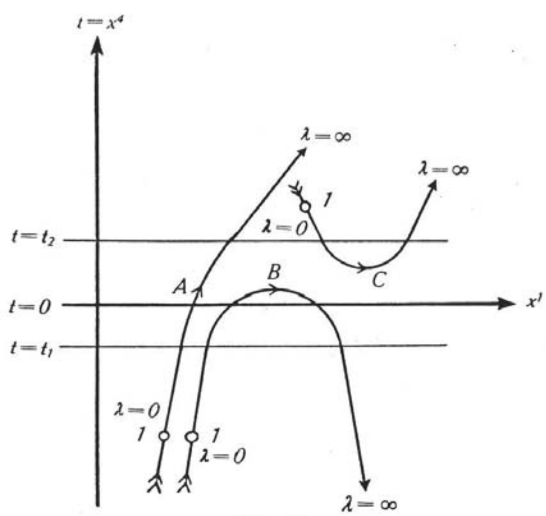

Fig. 1.

[1] As quoted by Feynman in https://www.nobelprize.org/prizes/physics/1965/feynman/lecture/. See also p. 944 of [5].

3 Feynman

Feynman first publicly discussed his diagrams at the Pocono Conference, Mar. 30-Apr. 3, 1948.[2] Later in 1948 he published a diagram, Fig. 1 of [5], in which a positron can be interpreted as an electron moving backwards in time, and attributed the idea for this to Wheeler (1941).

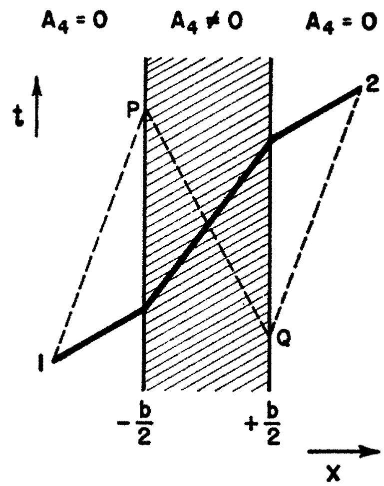

Fig. 1. If two points 1, 2 are separated by a high potential barrier, there are two paths which make action an extremum. One (solid line) represents passage of a fast electron. The other (dotted line) has a section reversed in time and is interpreted as the effective penetration of the barrier by a slow electron by means of a pair production at Q and annihilation at P, section PQ representing the motion of the positron.

In 1949, Feynman published another version of the above diagram, closer to that of Stueckelberg. Feynman mentioned that Stueckelberg also had the idea the positrons can be thought of as electrons moving backwards in time, but cited [7] which has no diagrams, rather than [4] which does.

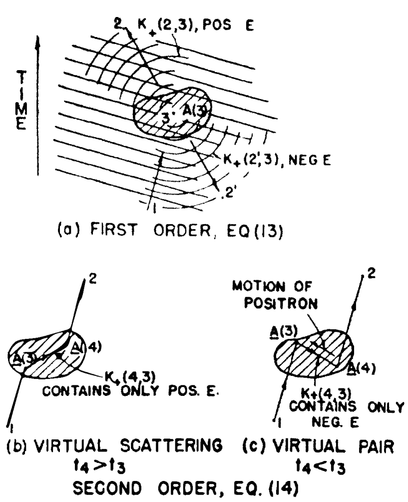

Fig. 2. The Dirac equation permits another solution $K_+(2,1)$ if one considers that waves scattered by the potential can proceed backwards in time as in Fig. 2 (a). This is interpreted in the second order processes (b), (c), by noting that there is now the possibility (c) of virtual pair production at 4, the positron going to 3 to be annihilated. This can be pictured as similar to ordinary scattering (b) except that the electron is scattered backwards in time from 3 to 4. The waves scattered from 3 to 2′ in (a) represent the possibility of a positron arriving at 3 from 2′ and annihilating the electron from 1. This view is proved equivalent to hole theory: electrons traveling backwards in time are recognized as positrons.

[2] Wentzel also attended this conference, https://en.wikipedia.org/wiki/Pocono_Conference, but apparently did not remark on the similarity of his past diagrams to Feynman's new ones.

Also in 1949, Feynman published [8] the first Feynman diagrams as we now know them, as a mnemonic for computation of scattering amplitudes.

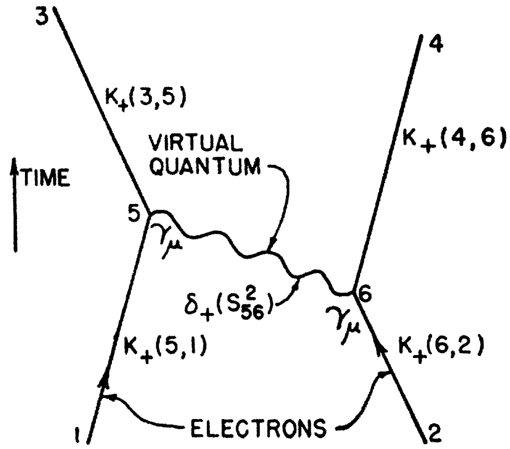

Fig. 1. The fundamental interaction Eq. (4). Exchange of one quantum between two electrons.

References

[1] G. Wentzel, *Schwere Elektronen und Theorien der Kernvorgänge*, Naturw. **26**, 273 (1938), http://kirkmcd.princeton.edu/examples/EP/wentzel_naturw_26_273_38.pdf

[2] G. Wentzel, *Zur Theorie der β-Umwandlung und der Kernkräfte. I*, Z. Phys. **104**, 34 (1937), http://kirkmcd.princeton.edu/examples/EP/wentzel_zp_104_34_37.pdf
Zur Theorie der β-Umwandlung und der Kernkräfte. II, Z. Phys. **104**, 34 (1937), http://kirkmcd.princeton.edu/examples/EP/wentzel_zp_105_738_37.pdf

[3] H. Yukawa, *On the Interactions of Elementary Particles. I*, Proc. Phys.-Math. Soc. Japan. **17**, 48 (1935), http://kirkmcd.princeton.edu/examples/EP/yukawa_ppmsj_17_48_35.pdf
H. Yukawa and S. Sakata, *On the Interactions of Elementary Particles. II*, Proc. Phys.-Math. Soc. Japan. **19**, 1083 (1937), http://kirkmcd.princeton.edu/examples/EP/yukawa_ppmsj_19_1083_37.pdf
H. Yukawa, S. Sakata and M. Taketani, *On the Interactions of Elementary Particles. III*, Proc. Phys.-Math. Soc. Japan. **20**, 319 (1938), http://kirkmcd.princeton.edu/examples/EP/yukawa_ppmsj_20_319_38.pdf

[4] E.C.G. Stueckelberg, *Remarque à propos de la création de paires de particules en théorie de relativité*, Helv. Phys. Acta **14**, 588 (1941), http://kirkmcd.princeton.edu/examples/QED/stueckelberg_hpa_14_588_41.pdf

[5] R.P. Feynman, *A Relativistic Cut-Off for Classical Electrodynamics*, Phys. Rev. **74**, 939 (1948), http://kirkmcd.princeton.edu/examples/QED/feynman_pr_74_939_48.pdf

[6] R.P. Feynman, *The Theory of Positrons*, Phys. Rev. **76**, 749 (1949), http://kirkmcd.princeton.edu/examples/QED/feynman_pr_76_749_49.pdf

[7] E.C.G. Stueckelberg, *La mécanique du point matériel en théorie de relativité et en théorie des quanta*, Helv. Phys. Acta **15**, 23 (1942),
http://kirkmcd.princeton.edu/examples/QED/stueckelberg_hpa_15_23_42.pdf

[8] R.P. Feynman, *Space-Time Approach to Quantum Electrodynamics*, Phys. Rev. **76**, 769 (1949), http://kirkmcd.princeton.edu/examples/QED/feynman_pr_76_769_49.pdf