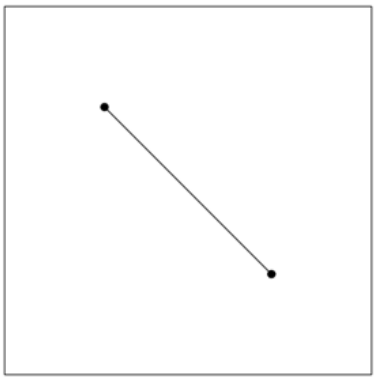
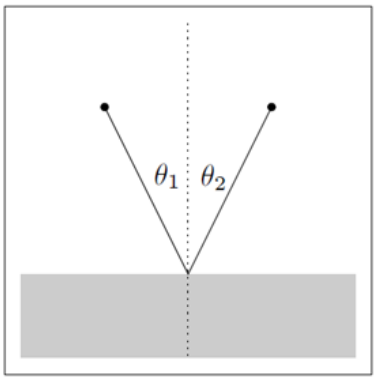
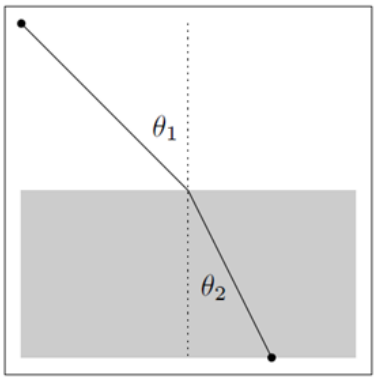
Quantum Optics and Least Action

Fermat's principle: the path a ray of light takes the least amount of time to travel



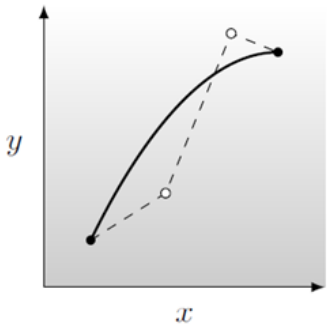


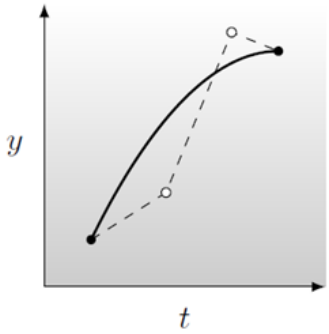


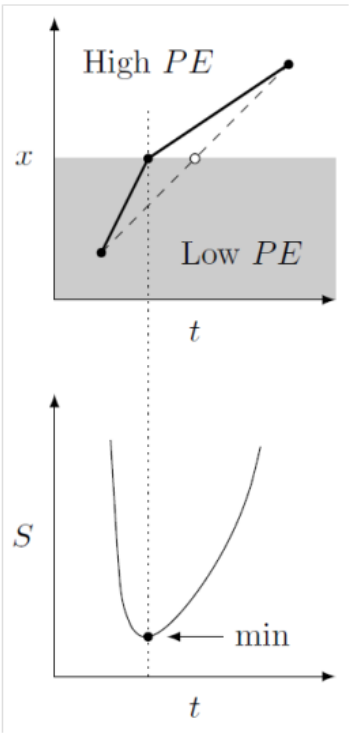
$$v = c/n$$

$$\ell = \sum n\Delta x$$

Hamilton's principle: the path a physical particle is the path of least action



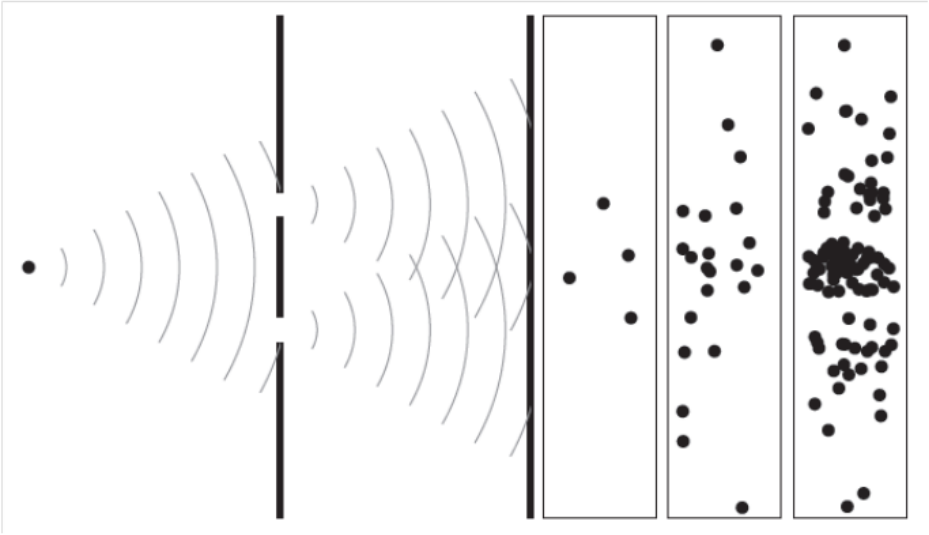




$$S_0 = \sum mv\Delta x \qquad S = \sum L\Delta t$$

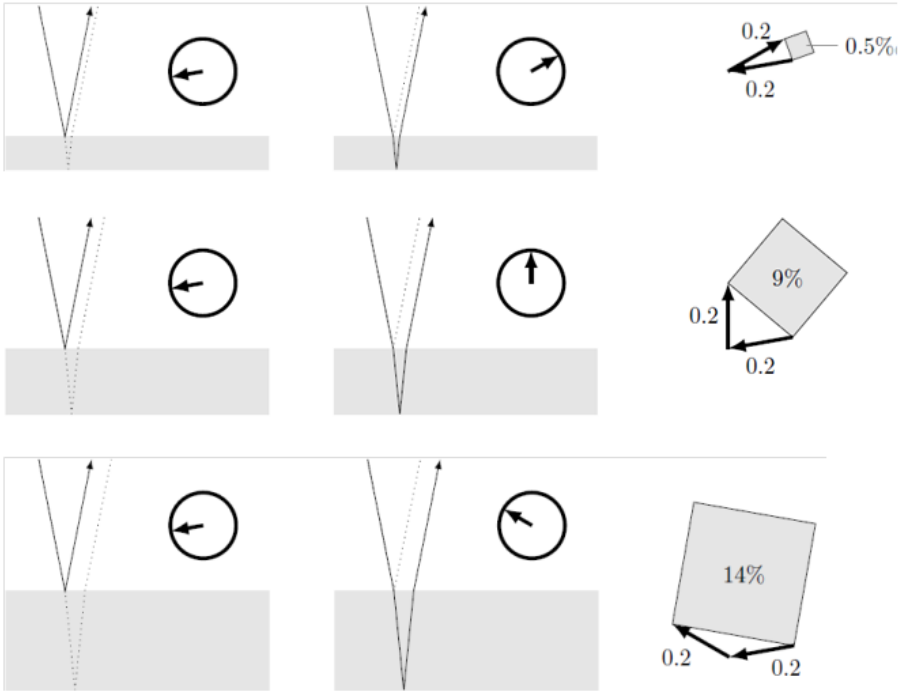
$$E_{\text{tot}} = \tfrac{1}{2}mv^2 + PE \qquad L = KE - PE$$

Feynman's rebuilds optics via least action and particles of light (photons)



$$\psi = \exp(iS/\hbar)$$

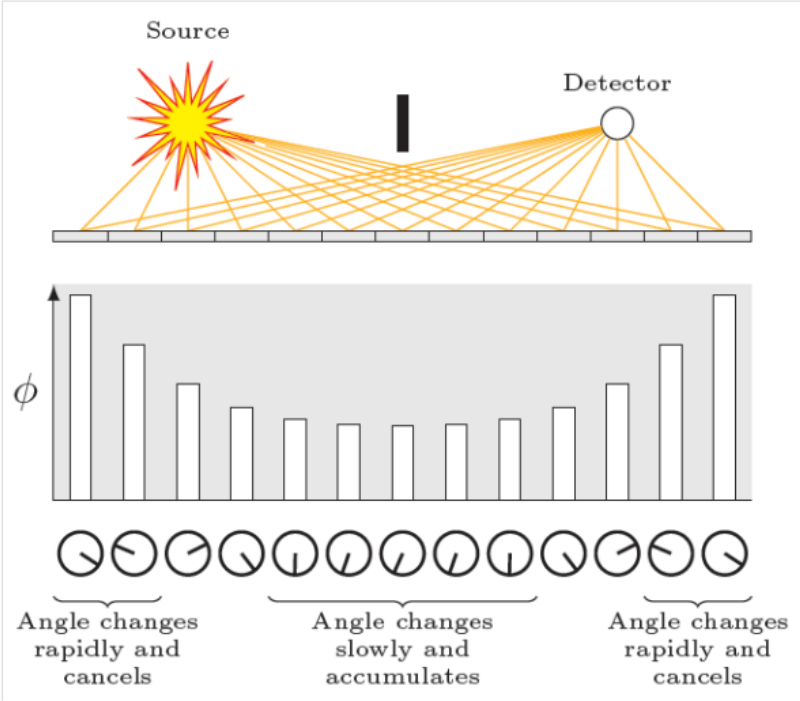
The "grand principle" of QED: phasors characterize the probability of the action

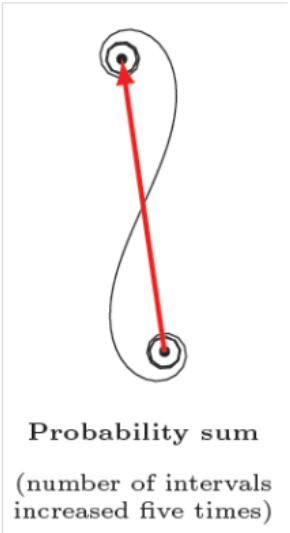


$$S = hf\Delta t$$

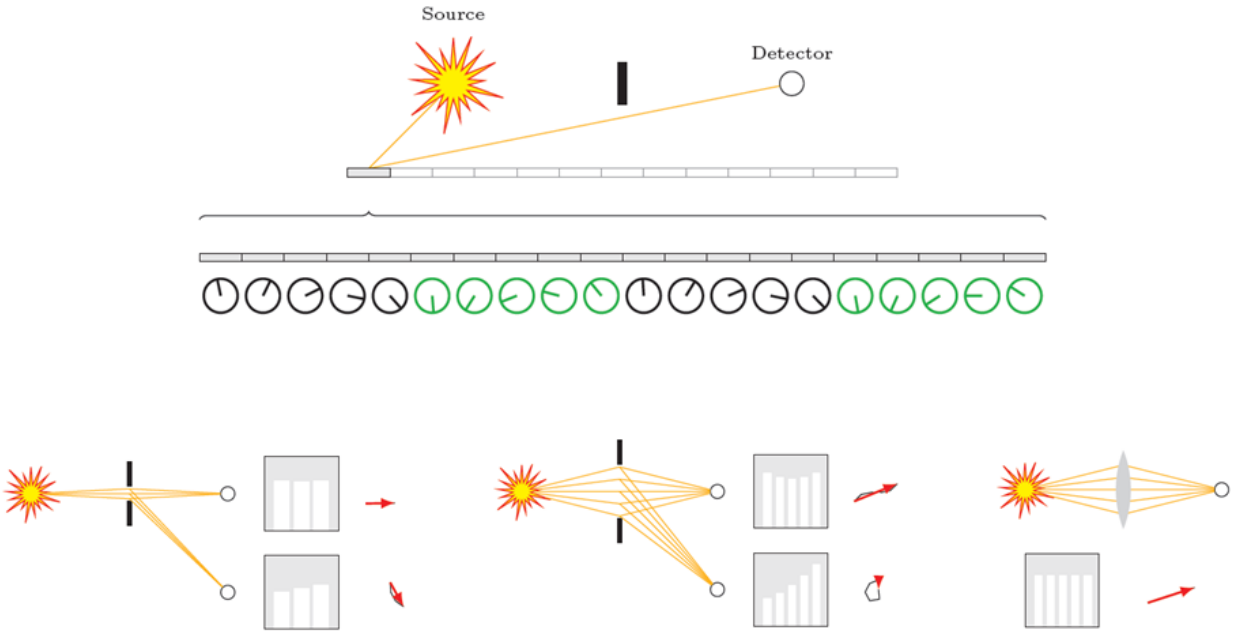
$$\phi = S/h = f\Delta t$$

The "general rule" of QED: the true path is the phasor sum of all possible paths

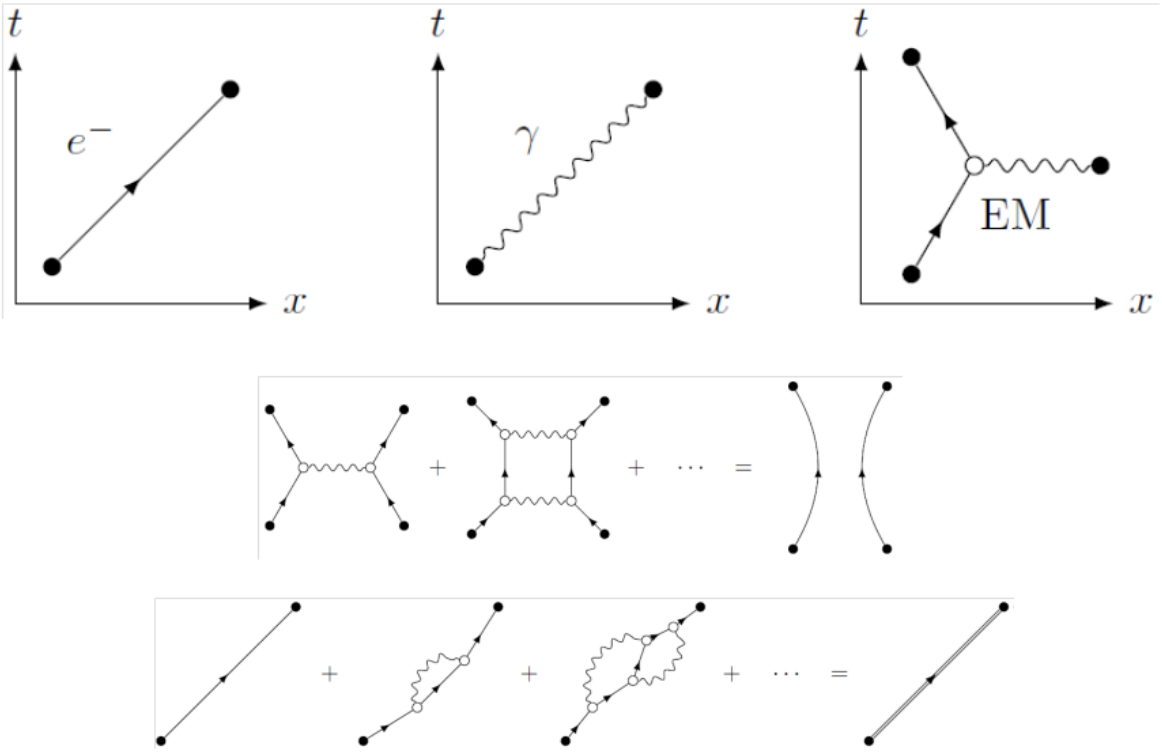




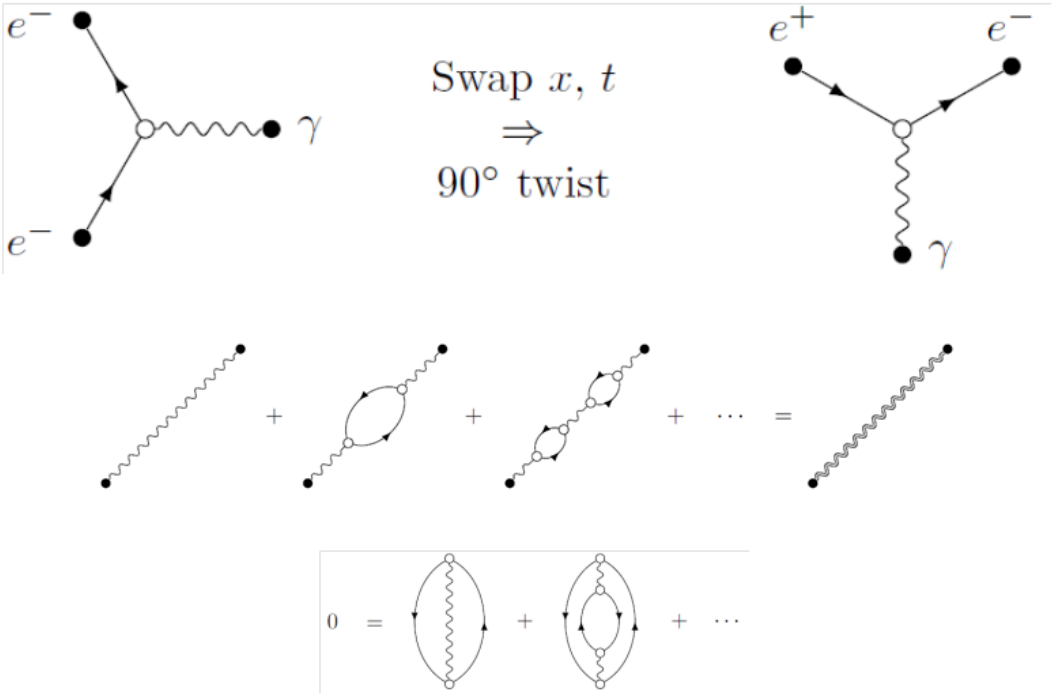
Incredibly, these ideas explain all of optics and quantum mechanics



Electromagnetism comes from charged particles exchanging photons of light



What's new: anti-matter annihilates matter in a burst of light and vice versa



- With Feynman diagrams, truly anything goes. Including moving backward in time.
- As one plays around with these diagrams, one gets used to imagining them in a malleable way because each of these internal changes are indistinguishable.
- QED is also relativistically valid and in relativity time and space are joined in space-time. Understanding this, Feynman asked the question: what happens if we rotate these diagrams 90°? Essentially this swaps the role of space and time. The two diagrams are no longer equivalent, but it does beg the question what is it?
- In particular, our basic interaction diagram: an electron absorbs a photon. On its side, this diagram starts with just a photon and ends with two electrons, one moving up in time (normal) and another moving backward in time.
- Feynman recognized this process as the creation of anti-matter. Energy goes in (as a photon) and is converted into an electron (the normal one) and its anti-matter twin the positron (an electron with positive charge).
- In this way the theory provides a simple explanation for the existence of anti-matter and why every particle must have an anti-particle twin.
- Whether or not we interpret anti-matter as time-reversed matter, the fact is that a photon can dissolve into matter/anti-matter pairs and vice versa. This means that we must consider so-called **bubble diagrams** as possible contributions to our overall sum over history.
- And it is precisely these bubble diagrams that explain the slight deviations from classical field theory such as the gyromagnetic moment of the electron to astonishing accuracy.
- We can even draw a self-contained bubble diagram without any incoming or outgoing particles. The vacuum is a sea full of virtual matter-antimatter pairs. In QED even the vacuum is a many-body problem!