From Feynman’s Introduction

What I am going to tell you about is what we teach our physics students in the third or fourth year of graduate school …..

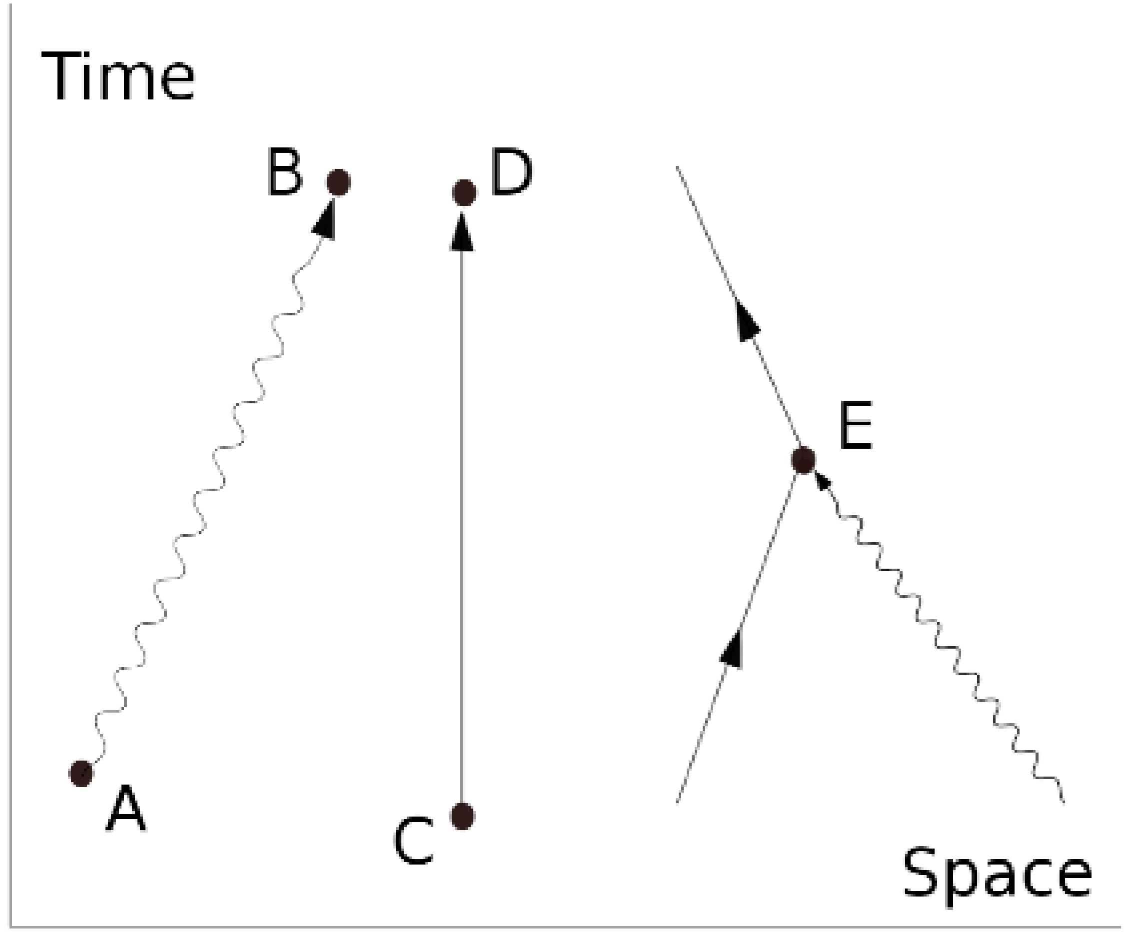
….. I’m going to explain to you what the physicists are *doing* when they are predicting how Nature will behave, but I’m not going to teach you any tricks so you can do it *efficiently*. You will discover that in order to make any reasonable predictions with this new scheme of quantum electrodynamics, you would need to make a awful lot of little arrows on a piece of paper. It takes seven years---four undergraduate and three graduate---to train our physics students to do that in a tricky, efficient way. That’s where we are going to skip seven years of education in physics: By explaining quantum electrodynamics to you in terms of what we are *really doing*, I hope you will be able to understand it better than do some of the students.

There are only three basic actions:

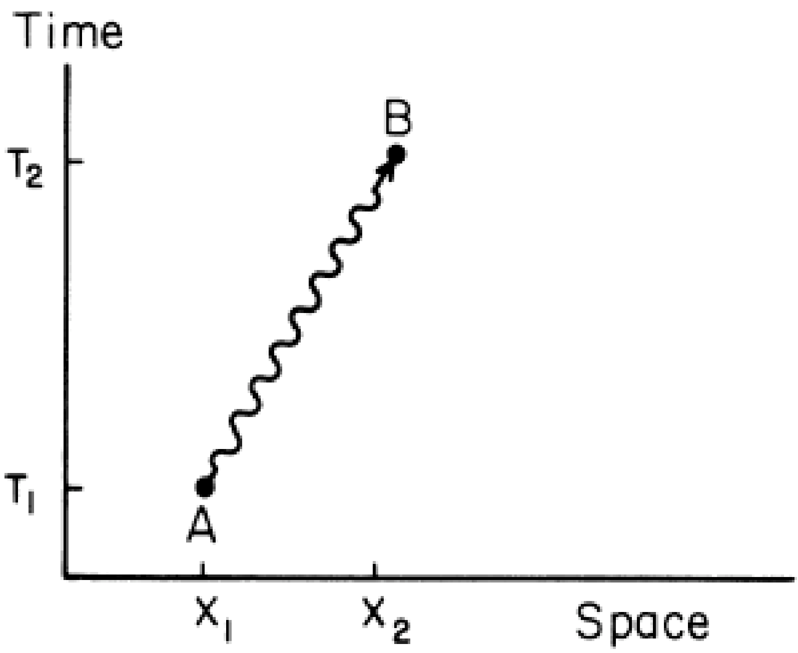
A photon goes from one place and time to another place and time.

An electron goes from one place and time to another place and time.

An electron emits or absorbs a photon at a certain place and time.

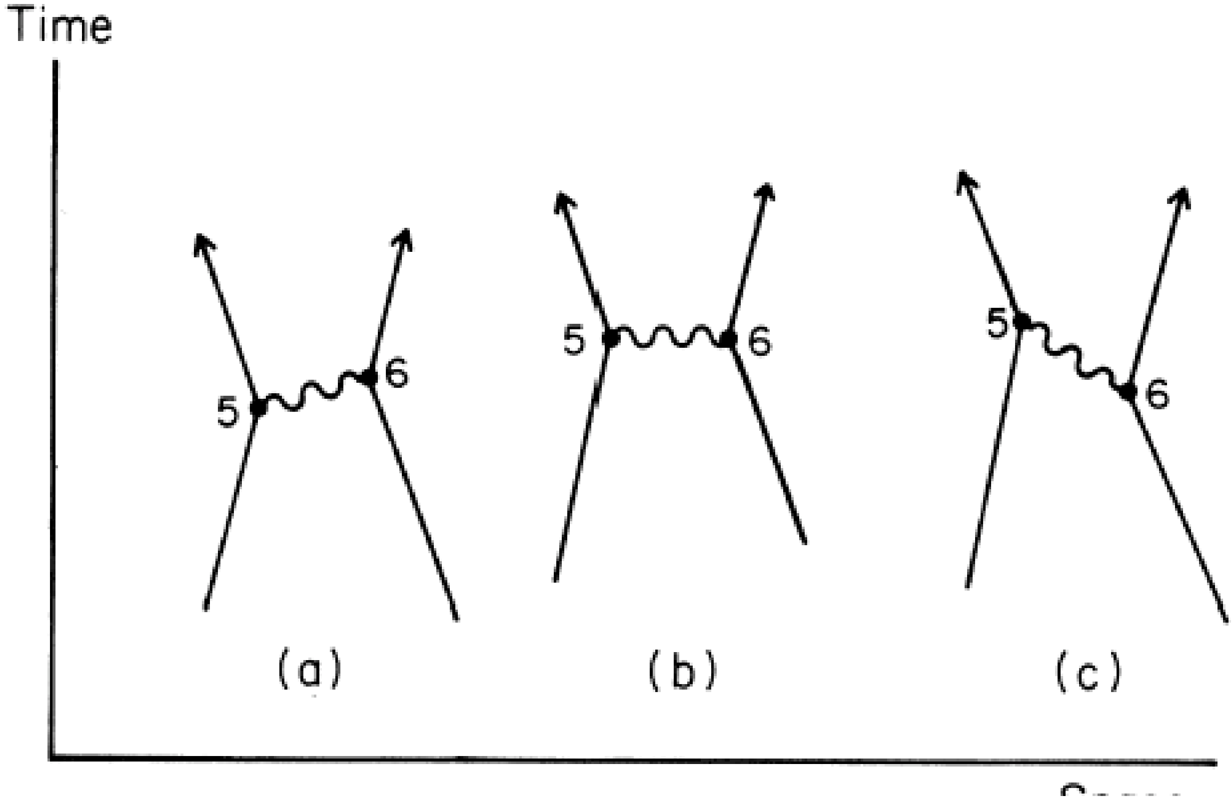


Photons Travel From Place to Place

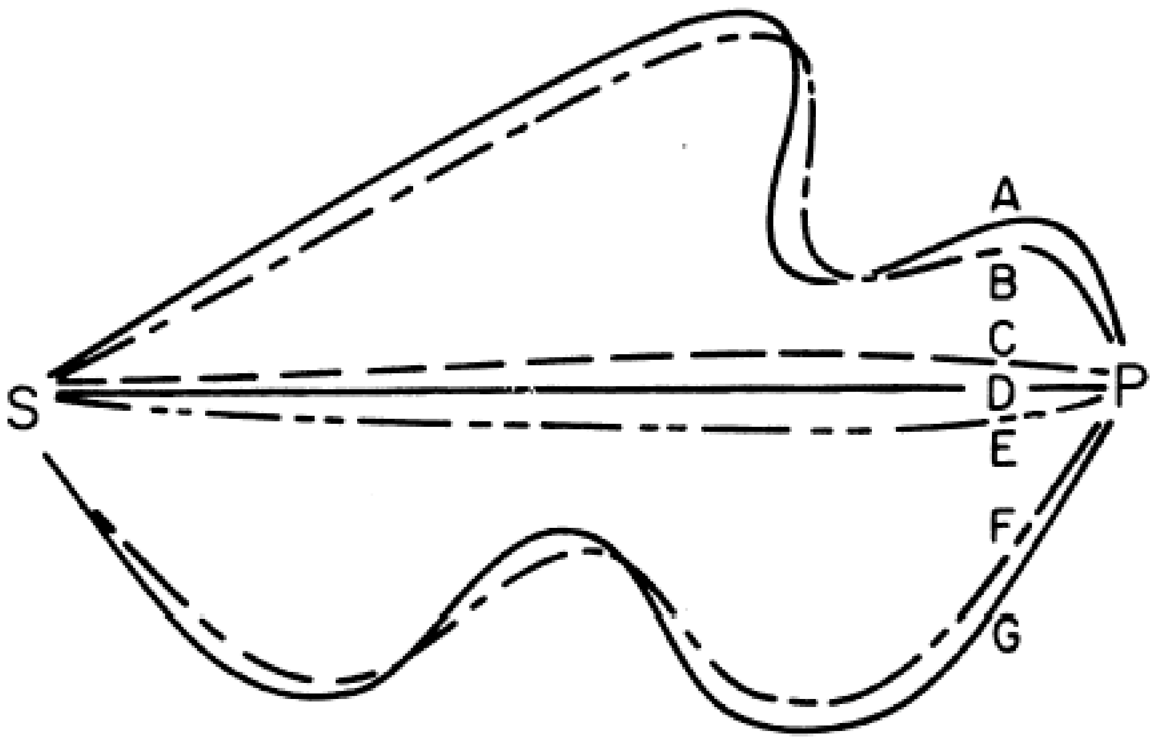


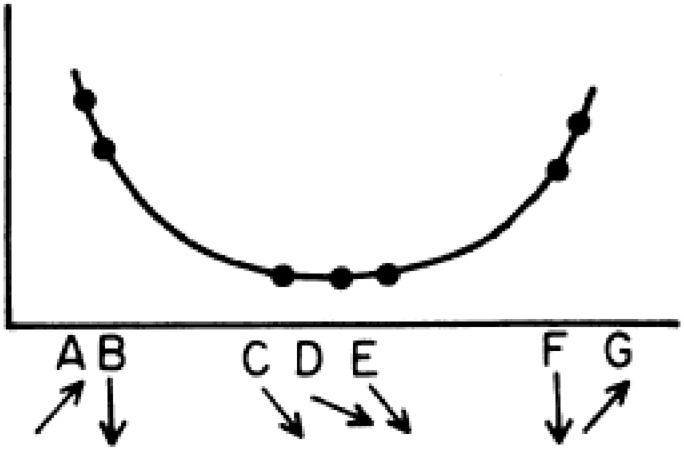
All Photons Are Travelling Forward, Backward and Without Time!

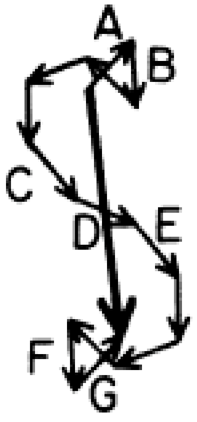
With $v>c$, $v=c$, and $v<c$!



Q: Why does light go in a straight line?

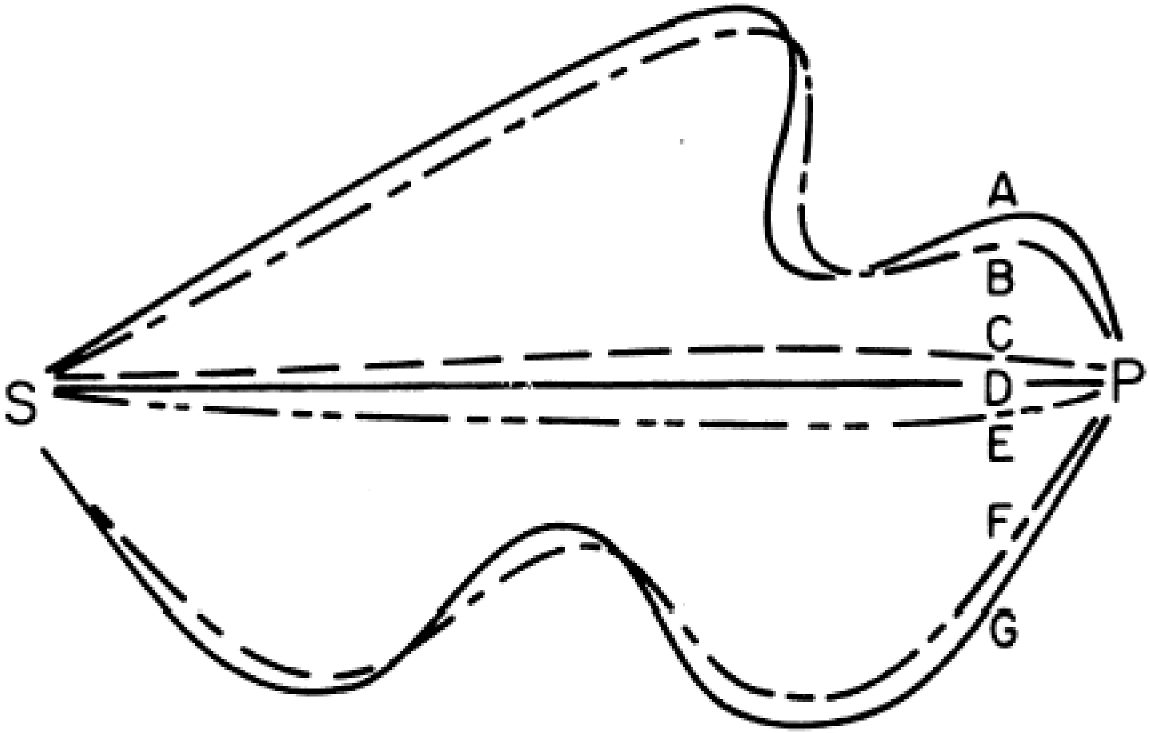


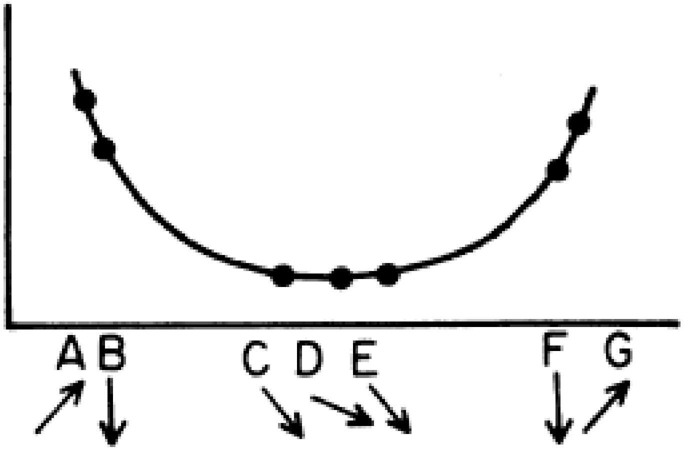


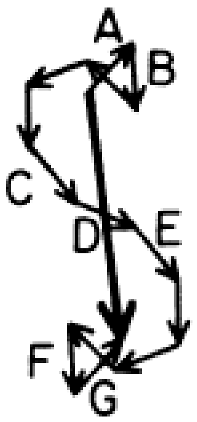


A: It doesn’t---it only appears to!

Q: Why does light propagate with v=c?

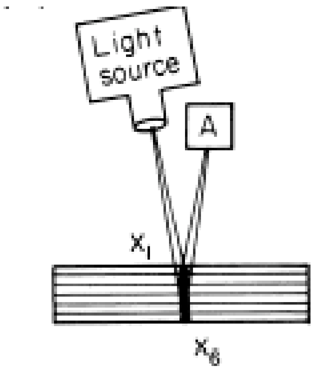


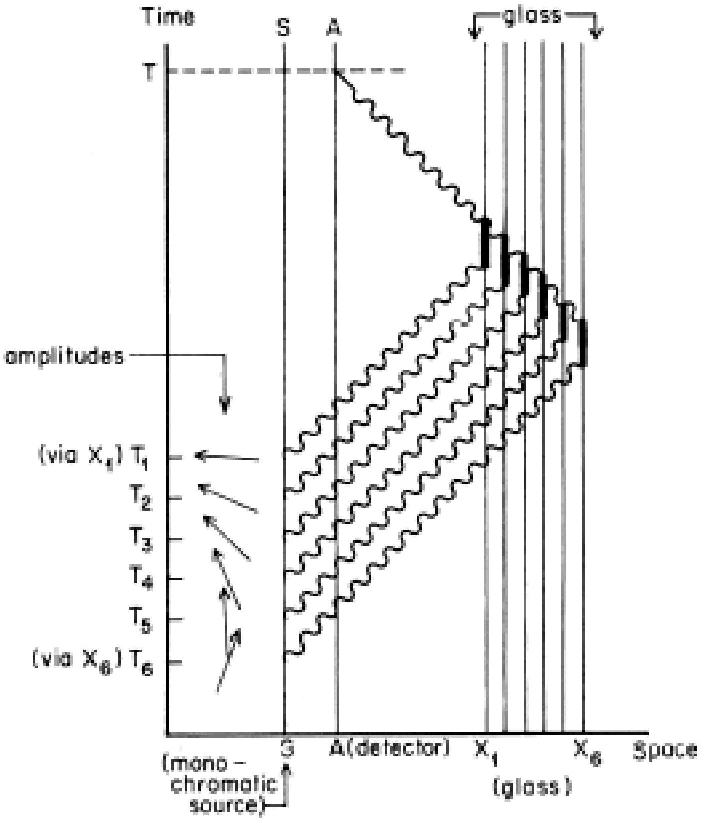




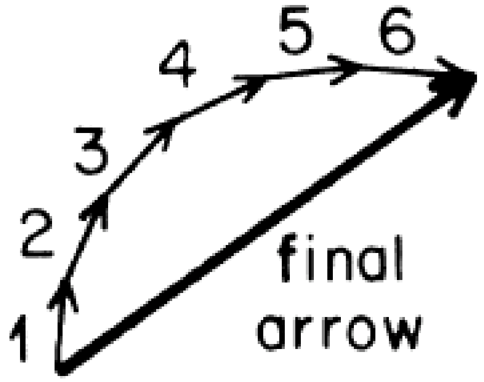
A: It doesn’t---it only appears to!

The Photons Scatter Inside with Precisely the Same Total Amplitude as that Predicted by Maxwell's Equations for Reflection from the Two Surfaces

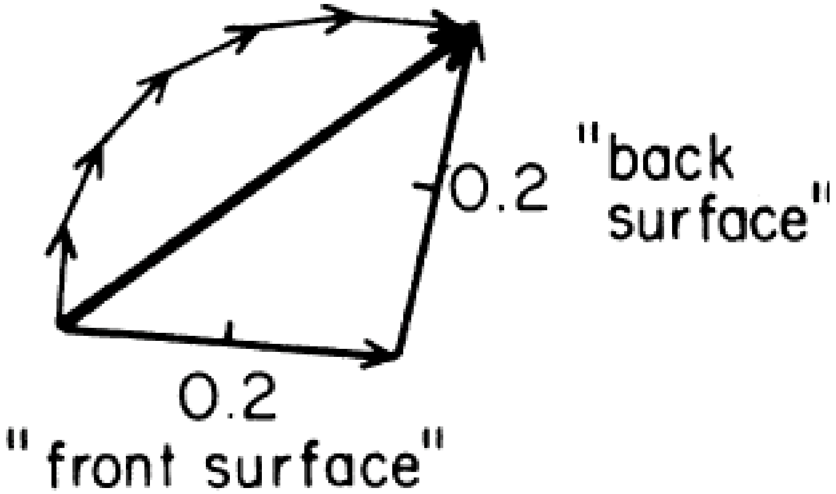


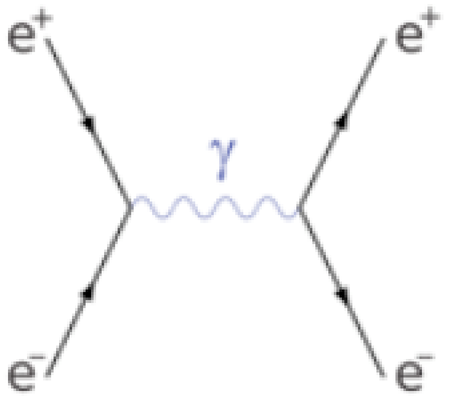


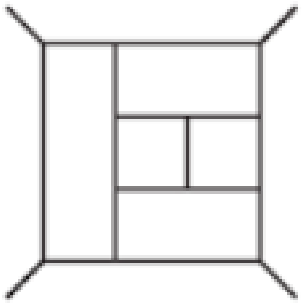
Sum the Internal Amplitudes

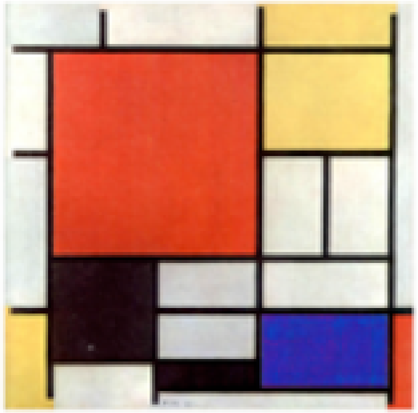


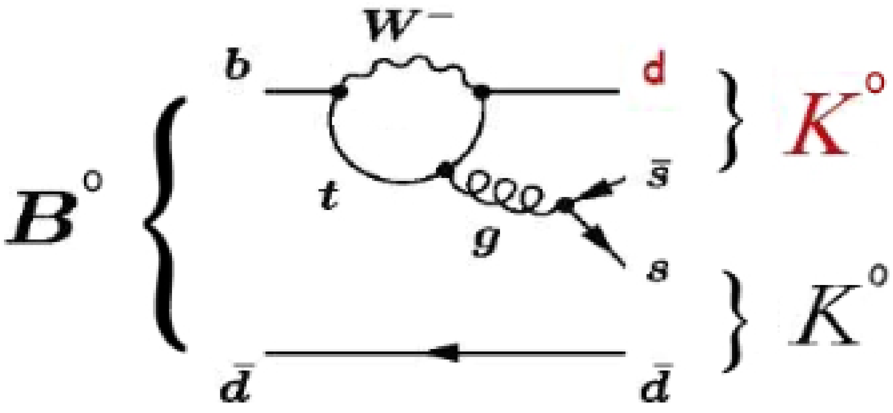
Sum The Surface Amplitudes

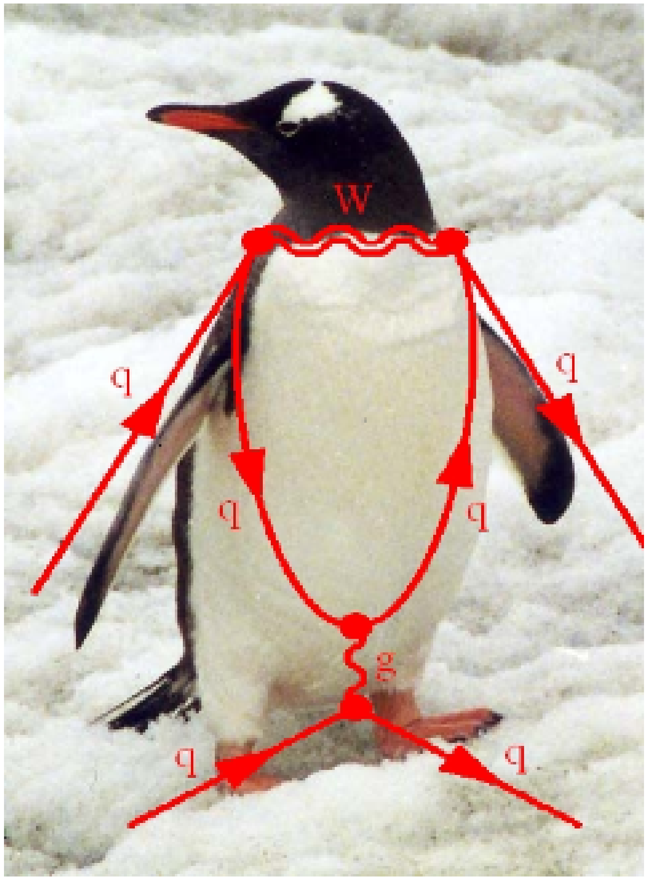






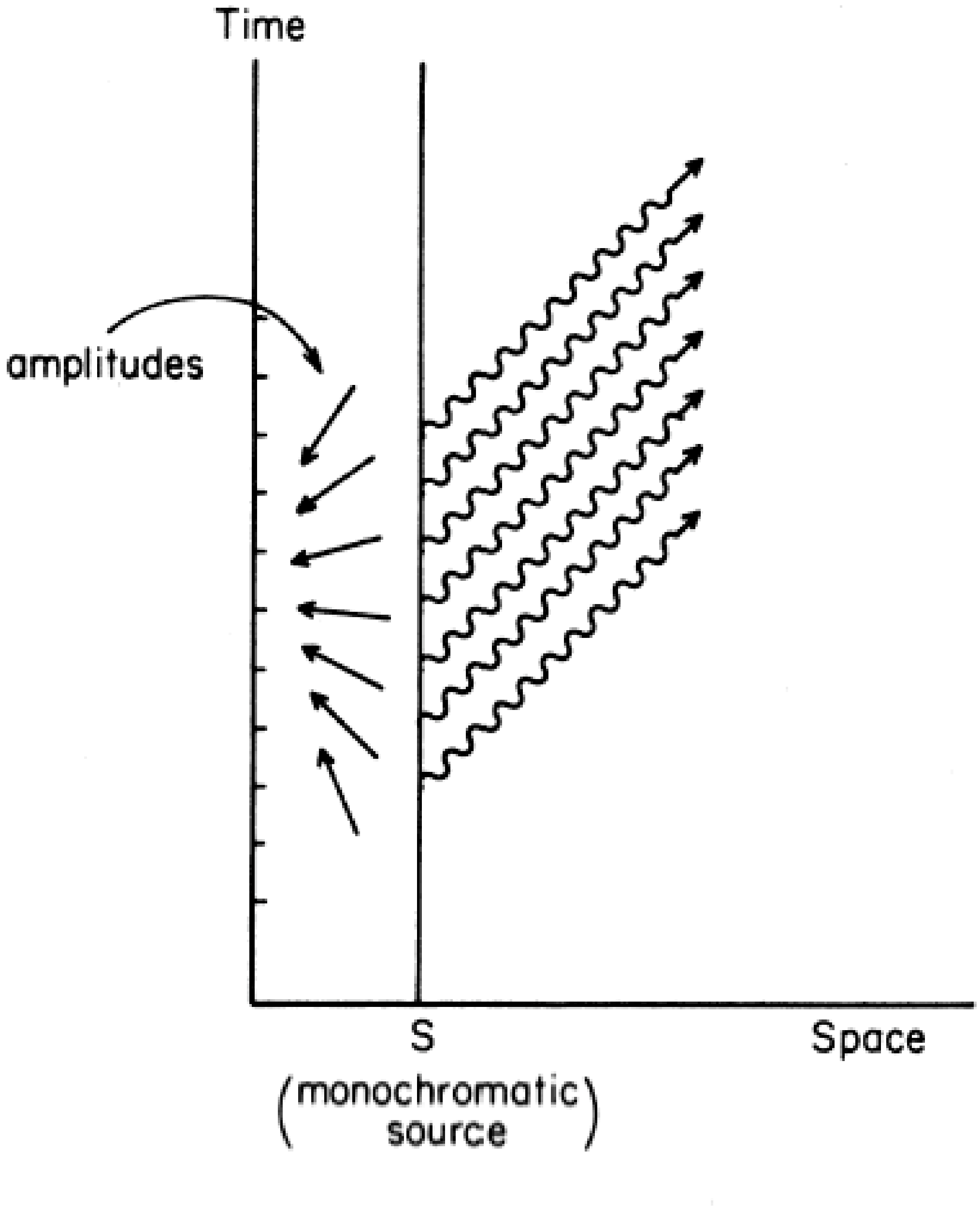


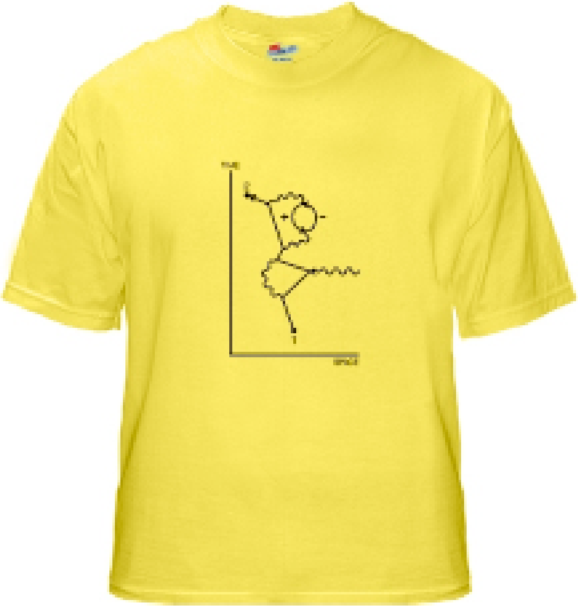




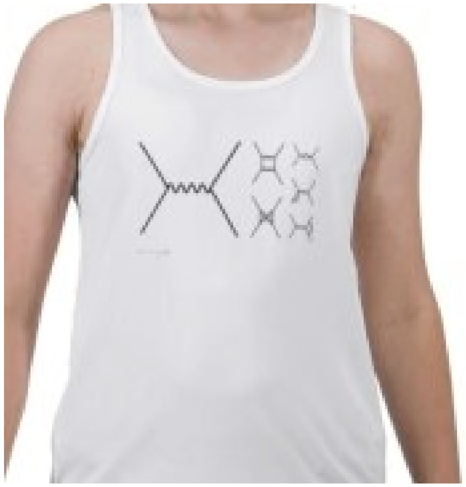
The story behind this seems to be that particle theorist John Ellis and experimentalist Melissa Franklin were playing darts one evening at CERN in 1977, and a bet was made that would require Ellis to insert the word "penguin" somehow into his next research paper if he lost. He did lose, and was having a lot of trouble working out how he would do this. Finally, “the answer came to him when one evening,leaving CERN, he dropped by to visit some friends where he smoked an illegal substance”. While working on his paper later that night “in a moment of revelation he saw that the diagrams looked like penguins”.

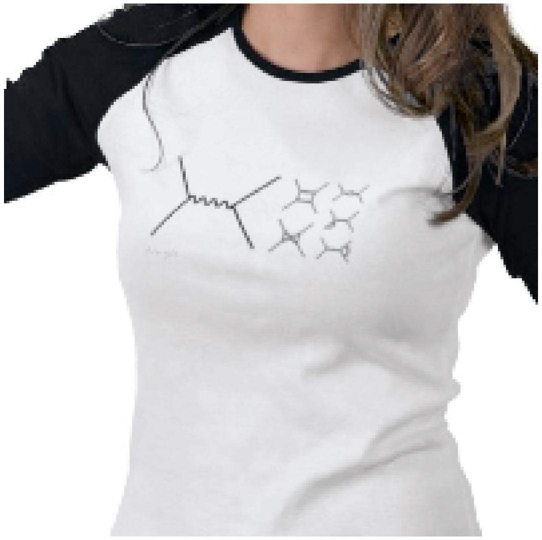
Time Dilation:
The Photons’ Clocks Cannot Tick!!!
The phase comes from the source



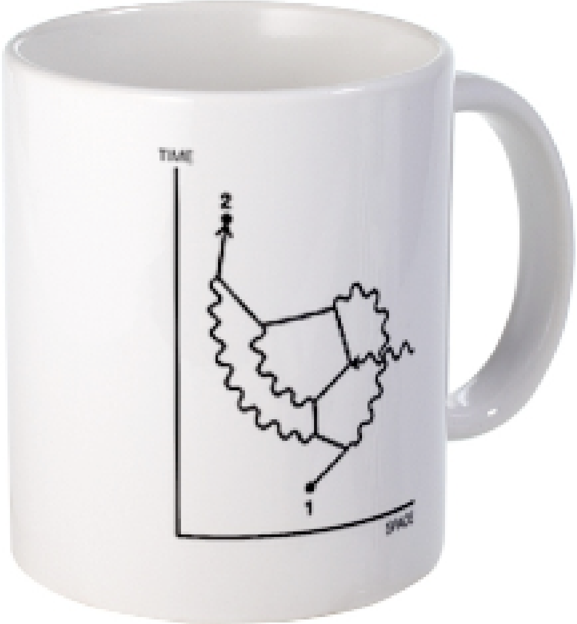



I believe that a scientist looking at nonscientific problems is just as dumb as the next guy.






Physics is like sex.
Sure it may have some practical results,
but that's not why we do it.
-Richard Feynman


TIME
2
1
SPACE


e⁻
e⁻
W
W
ν
ν
u
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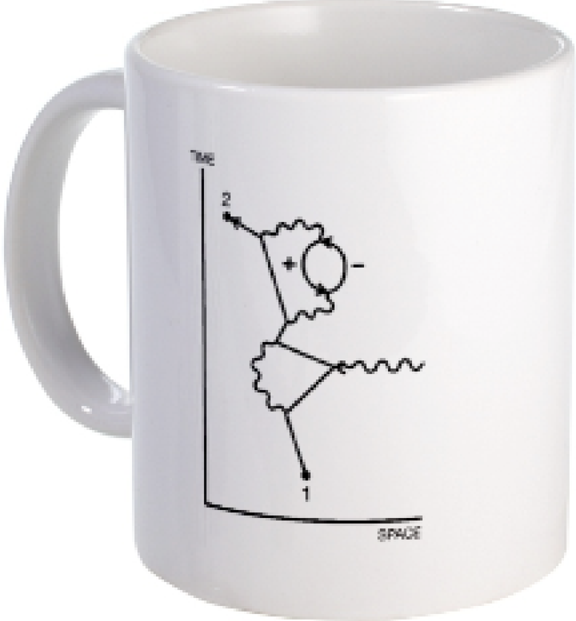
d
d


Happy Birthday
Michael!
Age
Age
Yeon
Michael
Michael


TIME
2
+
-
1
SPACE

Path integral gives us insight into the extremely nonlocal nature of quantum mechanics.

So, why not teach the path integral method from the very beginning?

Path integral is much more difficult than Schrodinger equation for simple NRQM problems, viz., hydrogen atom and spin.

On the other hand, easier or comparable to the canonical method for relativistic problems.

up and cause constructive interference! For the paths deviating from the classical one, the change in the action (i.e. the phase) will be so large in terms of $\hbar$ that the interference will be destructive instead. It follows that for macroscopic particles only the classical trajectory will contribute to the motion.

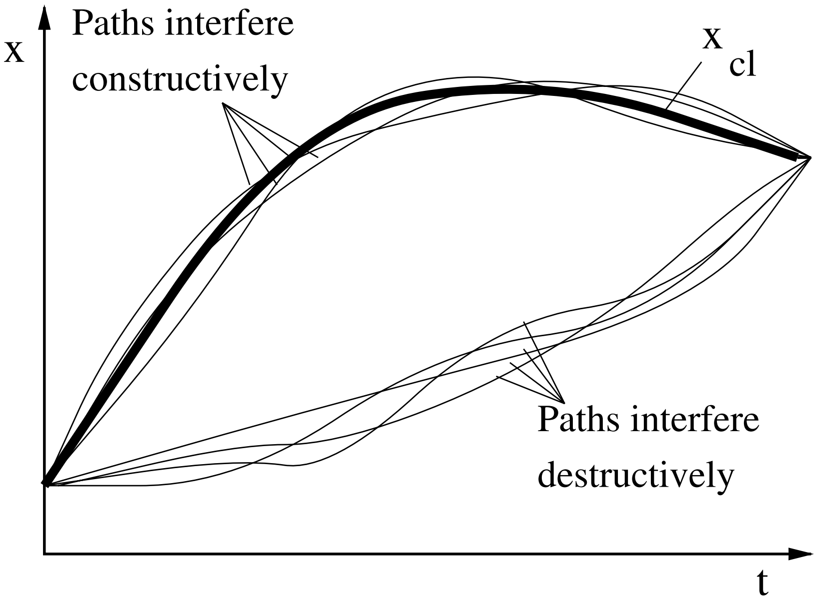


Figure 5.1: *Emergence of the classical limit. There is constructive interference between paths close to the classical trajectory (thick line) whereas the trajectories further away tend to cancel because of the rapidly changing sign of* $e^{iS[x(t)]/\hbar}$.

For microscopic (quantum mechanical) particles on the other hand, the action is typically of the order of $\hbar$. Hence it takes a comparably large change in the action to achieve a significant change in the phase $S[x(t)]/\hbar$. In other words, for very light particles even paths that deviate much from the classical will be of importance. In this case one can no longer talk about the trajectory of the particle, but rather of a superposition of different paths.

In the limit $\hbar \rightarrow 0$, even very small particles will obviously behave like classical particles, since their action will then become large compared to $\hbar$. The limit $\hbar \rightarrow 0$ is also the limit where the quantization of energy etc disappears, which is another effect of considering the classical limit of quantum mechanics.

Visiting Einstein one day, I could not resist telling him about Feynman's new way to express quantum theory. "Feynman has found a beautiful picture to understand the probability amplitude for a dynamical system to go from one specified configuration at one time to another specified configuration at a later time. He treats on a footing of absolute equality every conceivable history that leads from the initial state to the final one, no matter how crazy the motion in between. The contributions of these histories differ not at all in amplitude, only in phase. And the phase is nothing but the classical action integral, apart from the Dirac factor h. This prescription reproduces all of standard quantum theory. How could one ever want a simpler way to see what quantum theory is all about!

Doesn't this marvelous discovery make you willing to accept the quantum theory, Professor Einstein?"

Einstein replied in a serious voice, "I still cannot believe that God plays dice. But maybe", he smiled, "I have earned the right to make my mistakes."

John Wheeler

Up until now: $H = H_{matter} = KE + PE$

Two more terms: $H_{radiation}$

$H_{interaction}$

$$H_{total} = H_{matter} + H_{radiation} + H_{interaction}$$

Fermi's First Golden Rule is the result of applying second-order TDPT (time-dependent perturbation theory) to quantum scattering and resonances.

Fermi's Second Golden Rule is the result of applying first-order TDPT (time-dependent perturbation theory) to absorption.

Practicing the Golden Rule without a license is a common offense, although it tends to pale compared to the misuse of the uncertainty relations.

Herbert Kroemer

"What Makes A Qualified Physicist?"

Quantum mechanics: Perturbation theory, first and second order (Fermi's golden rules).

George Nickel

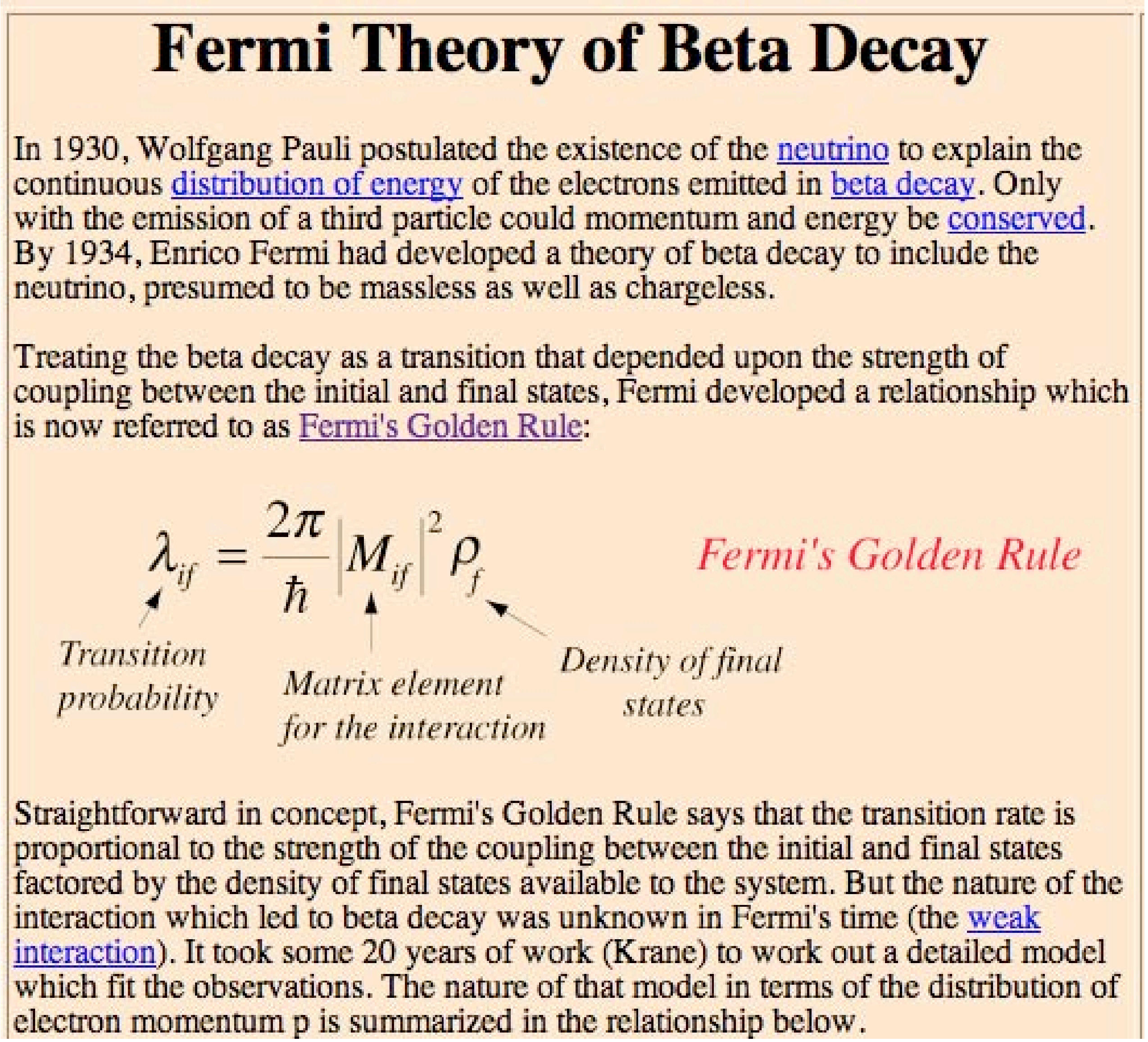
Why did Fermi refer to the second-order result as the First Rule? I would like to think that it was because Fermi considered scattering more important than absorption.

Electromagnetic interactions (photons)
Real Photons
Absorption
Stimulated Emission
Spontaneous Emission
Photo-ionization
Photon Scattering
Molecular Spectroscopy
Virtual Photons
Electrons in semiconductors
Phonon Scattering

Weak interaction (W and Z bosons)
beta decay
muon decay
tau decay
neutron decay
pion decay

Strong interaction (gluons)
alpha decay
Delta to proton+pion decay
proton-proton scattering
proton-neutron scattering

Fermi’s Theory of Beta Decay



Fermi Theory of Beta Decay

In 1930, Wolfgang Pauli postulated the existence of the neutrino to explain the continuous distribution of energy of the electrons emitted in beta decay. Only with the emission of a third particle could momentum and energy be conserved. By 1934, Enrico Fermi had developed a theory of beta decay to include the neutrino, presumed to be massless as well as chargeless.

Treating the beta decay as a transition that depended upon the strength of coupling between the initial and final states, Fermi developed a relationship which is now referred to as Fermi's Golden Rule:

$$\lambda_{if} = \frac{2\pi}{\hbar}\left|M_{if}\right|^2 \rho_f$$

Fermi's Golden Rule

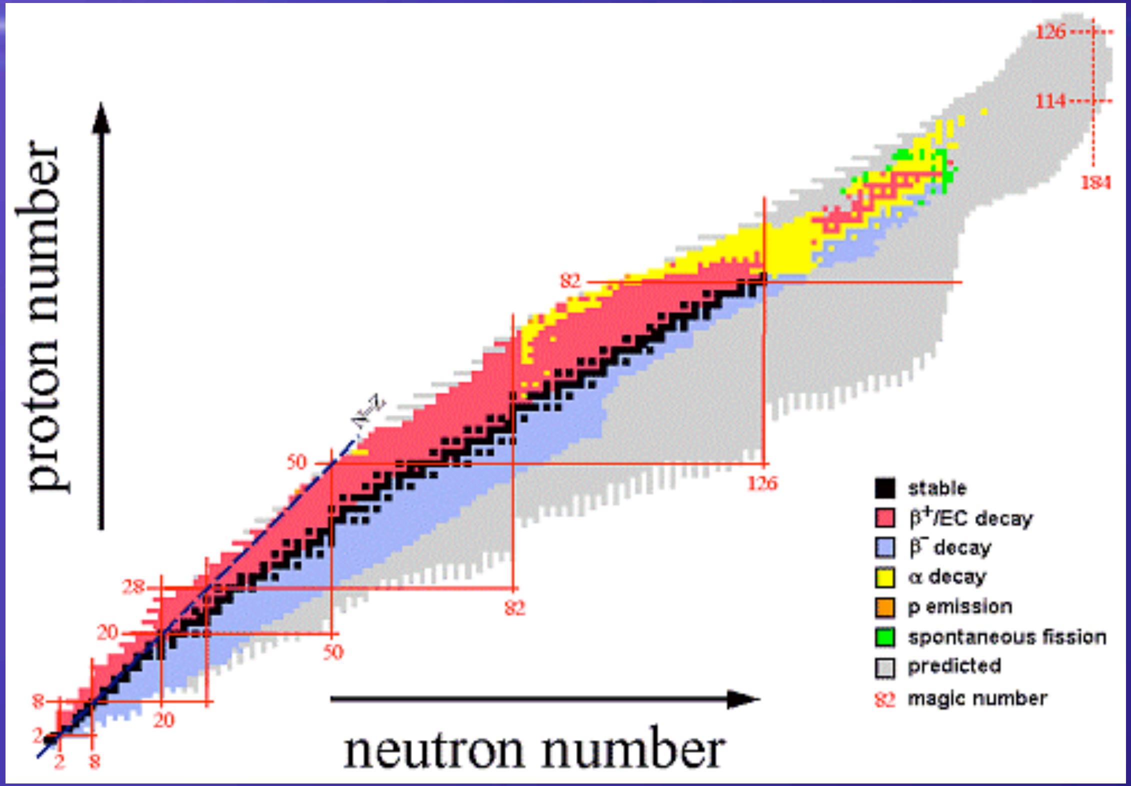
Transition probability

Matrix element for the interaction

Density of final states

Straightforward in concept, Fermi's Golden Rule says that the transition rate is proportional to the strength of the coupling between the initial and final states factored by the density of final states available to the system. But the nature of the interaction which led to beta decay was unknown in Fermi's time (the weak interaction). It took some 20 years of work (Krane) to work out a detailed model which fit the observations. The nature of that model in terms of the distribution of electron momentum p is summarized in the relationship below.

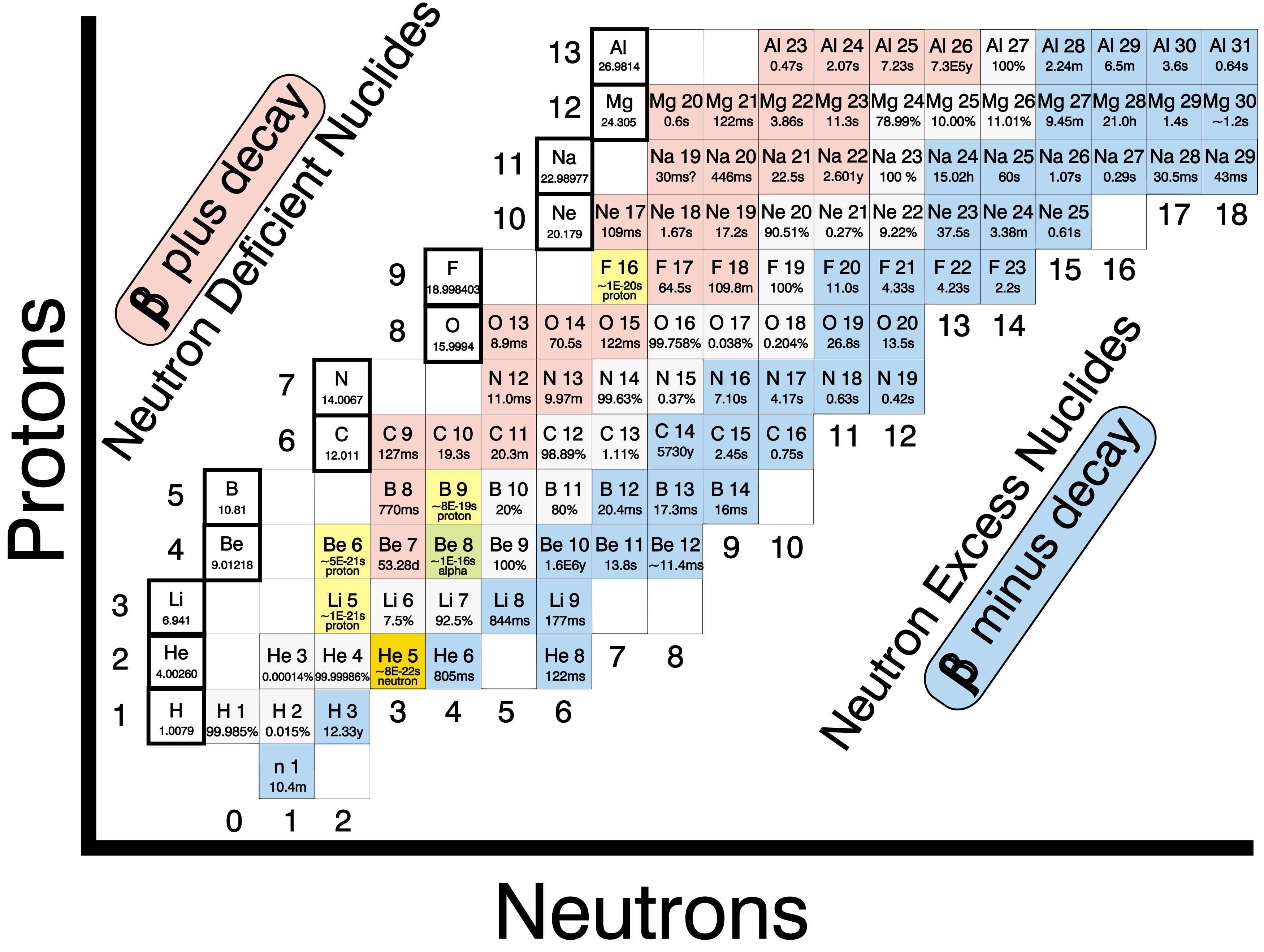
Requirements - I



1.) $m(A,Z) > m(A,Z+2)$

2.) Single beta decay must be forbidden ($m(A,Z) < m(A,Z+1)$)
or at least strongly suppressed (large change in angular momentum)

CHART OF THE NUCLIDES



Protons

β plus decay

Neutron Deficient Nuclides

								13	Al 26.9814			Al 23 0.47s	Al 24 2.07s	Al 25 7.23s	Al 26 7.3E5y	Al 27 100%	Al 28 2.24m	Al 29 6.5m	Al 30 3.6s	Al 31 0.64s
								12	Mg 24.305	Mg 20 0.6s	Mg 21 122ms	Mg 22 3.86s	Mg 23 11.3s	Mg 24 78.99%	Mg 25 10.00%	Mg 26 11.01%	Mg 27 9.45m	Mg 28 21.0h	Mg 29 1.4s	Mg 30 ~1.2s
							11	Na 22.98977		Na 19 30ms?	Na 20 446ms	Na 21 22.5s	Na 22 2.601y	Na 23 100 %	Na 24 15.02h	Na 25 60s	Na 26 1.07s	Na 27 0.29s	Na 28 30.5ms	Na 29 43ms
							10	Ne 20.179	Ne 17 109ms	Ne 18 1.67s	Ne 19 17.2s	Ne 20 90.51%	Ne 21 0.27%	Ne 22 9.22%	Ne 23 37.5s	Ne 24 3.38m	Ne 25 0.61s		17	18
					9	F 18.998403			F 16 ~1E-20s proton	F 17 64.5s	F 18 109.8m	F 19 100%	F 20 11.0s	F 21 4.33s	F 22 4.23s	F 23 2.2s	15	16		
					8	O 15.9994	O 13 8.9ms	O 14 70.5s	O 15 122ms	O 16 99.758%	O 17 0.038%	O 18 0.204%	O 19 26.8s	O 20 13.5s	13	14				
			7	N 14.0067			N 12 11.0ms	N 13 9.97m	N 14 99.63%	N 15 0.37%	N 16 7.10s	N 17 4.17s	N 18 0.63s	N 19 0.42s						
			6	C 12.011	C 9 127ms	C 10 19.3s	C 11 20.3m	C 12 98.89%	C 13 1.11%	C 14 5730y	C 15 2.45s	C 16 0.75s	11	12						
	5	B 10.81			B 8 770ms	B 9 ~8E-19s proton	B 10 20%	B 11 80%	B 12 20.4ms	B 13 17.3ms	B 14 16ms									
	4	Be 9.01218		Be 6 ~5E-21s proton	Be 7 53.28d	Be 8 ~1E-16s alpha	Be 9 100%	Be 10 1.6E6y	Be 11 13.8s	Be 12 ~11.4ms	9	10								
3	Li 6.941			Li 5 ~1E-21s proton	Li 6 7.5%	Li 7 92.5%	Li 8 844ms	Li 9 177ms												
2	He 4.00260		He 3 0.00014%	He 4 99.99986%	He 5 ~8E-22s neutron	He 6 805ms		He 8 122ms	7	8										
1	H 1.0079	H 1 99.985%	H 2 0.015%	H 3 12.33y	3	4	5	6												
			n 1 10.4m																	
		0	1	2																

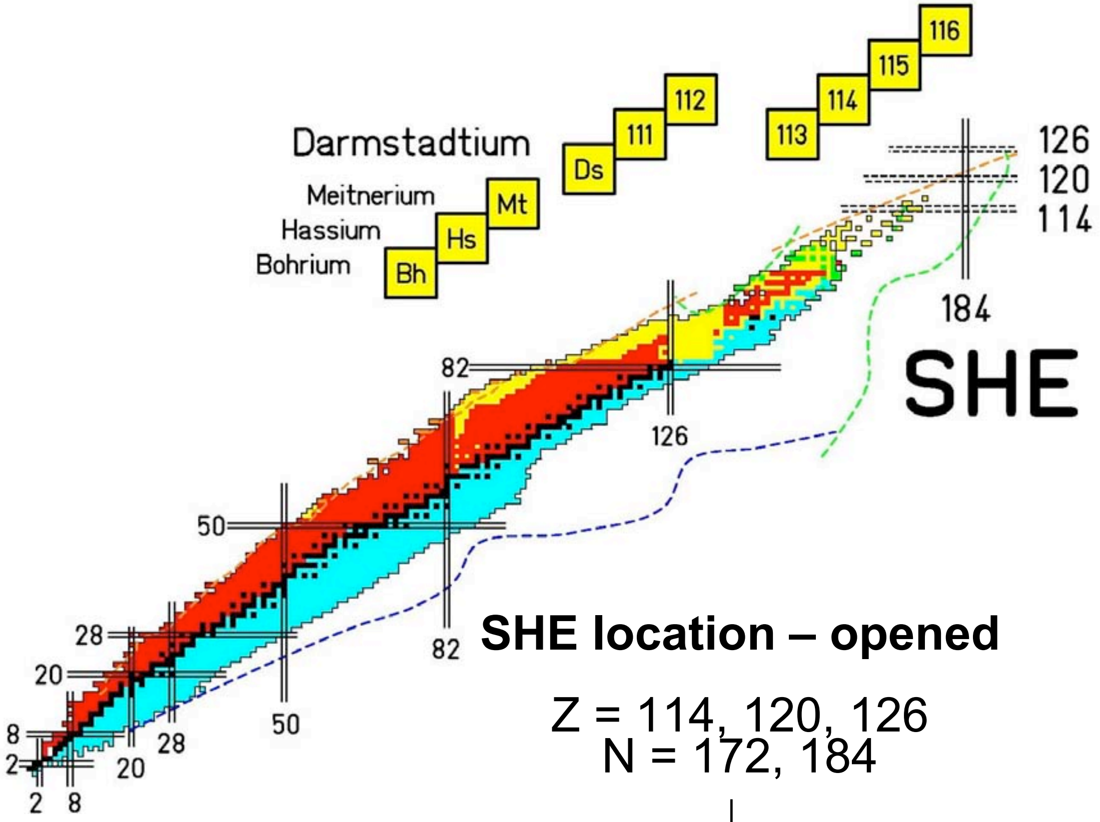
Neutron Excess Nuclides

β minus decay

Neutrons

Physical Motivation

Predictions of the island of SHE



SHE location – opened

Z = 114, 120, 126
N = 172, 184
↓
fundamentals of spin-orbit force

- nuclei beyond Fm exist only due to shell effects
- predictions of highly stabilized SHE (T_{theo} ~ min -y)
- failure to synthesize SHE by reactions of the type Pb + Pb (U + U)

1) Production of SHE via “hot” and “cold” fusion

2) Systematic study of nuclear structure of transfermium isotopes