Appendix of Extended Citations

(Alphabetical order)

Feynman.1

The Generality of QED:

"...In these lectures I want to tell you about the part of physics that we know best, the interaction of light and electrons. Most of the phenomena you are familiar with involve the interaction of light and electrons—all of chemistry and biology, for example. The only phenomena that are not covered by this theory are phenomena of gravitation and nuclear phenomena: everything else is contained in this theory ..."

QED, Electrons and Their Interactions, p. 77

The Coverage of QED:

"What I would like to do now is show you how this model of the world, which is so utterly different from anything you've seen before...can explain all the simple properties of light that you know: when light reflects off a mirror the angle of incidence is equal to the angle of reflection; light bends when it goes from air into water; light goes in straight lines; light can be focussed by a lens, and so on. The theory also describes many other properties of light that you are probably not familiar with... I can guarantee you (otherwise, the examples I'm going to show you would be misleading) that every phenomenon about light that has been observed in detail can be explained by the theory of quantum electrodynamics, even though I'm going to explain only the simplest and most common phenomena."

QED, Photons: Particles of Light, pp. 37-38.

Feynman.2

The Particulate Character of Light:

"... The first important feature of light is that it appears to be particles: when very weak, monochromatic light (light of one color) hits a detector, the detector makes equally loud clicks less and less often as the light gets dimmer.

QED, Photons: Particles of Light, p. 36.

The Strangeness of Light:

"To measure how many photons get past the front surface, another photomultiplier is placed at B, inside the glass. Never mind the obvious difficulties of putting a photomultiplier inside a block of glass; what are the results of the experiment?..." For every 100 photons that go straight down toward the glass at 90 degrees, an average of 4 arrive at A and 96 arrive at B. So "partial reflection" in this case means that 4% of the photons are reflected by the front surface of the glass, while the other 96% are transmitted.

QED, Introduction, p. 23

"... The other important feature of light ... is partial reflection of monochromatic light. An average of 4% of the photons hitting a single surface of glass is reflected. This is already a deep mystery, since it is impossible to predict which photons will bounce back and which will go through. With a second surface, the results are strange: instead of the expected reflection of 8% by the two surfaces, the partial reflection can be amplified as high as 16% or turned off, depending on the thickness of the glass.

QED, Photons: Particles of Light, p. 36

Feynman.3

"For many years after Newton, partial reflection by two surfaces was happily explained by a theory of waves, but when experiments were made with very weak light hitting photomultipliers, the wave theory collapsed ...[1] The wave theory made use of the fact that waves can combine or cancel out, and the calculations based on this model matched the results of Newton's experiments, as well as those done for hundreds of years afterwards. But when instruments were developed that were sensitive enough to detect a single photon, the wave theory predicted that the "clicks" of the photomultiplier would get softer and softer, whereas they stayed at full strength—they just occurred less and less often. No reasonable model could explain this fact, so there was a period for a while where you had to be very clever: You had to know which experiment you were analyzing in order to tell if light was waves or particles. This state of confusion was called the "wave-particle duality" of light... It is the purpose of these lectures to tell you how this puzzle was finally "resolved."

QED, Introduction, p. 23

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[1] The immediately following text is from Feynman's footnote, p. 23, QED.

Feynman.4

Probability Amplitudes and Vector Addition:

"...You will have to brace yourself for this--not because it is difficult to understand, but because it is absolutely ridiculous: All we do is draw little arrows on a piece of paper--that's all!...

QED, Introduction, pp.24-26.

The length of arrows:

"Now what does an arrow have to do with the chance that a particular event will happen? According to the rules of "how we count the beans", the probability of an event is equal to the square of the length of the arrow. For example, in our first experiment (when we were measuring partial reflection by a single surface only), the probability that a photon would arrive at photomultiplier A was 4%. That corresponds to an arrow whose length is 0.2, because 0.2 squared is 0.04.

The direction of arrows:

"We start by considering the various ways that a photon could get from the source to the photomultiplier at A. Since I am making this simplification that the light bounces off either the front surface or the back surface, there are two possible ways a photon could get to A. What we do in this case is to draw two arrows—one for each way the event can happen—and then combine them into a "final arrow" whose square represents the probability of an event. If there had been three different ways the event could have happened, we would have drawn three separate arrows before combining them.

Figure 2 [2]

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[2] Feynman's Figure 8, p. 26, QED.

Combining Arrows:

"Now, let me show you how we combine arrows. Let's say we want to combine arrow x with arrow y.... All we have to do is put the head of x against the tail of y (without changing the direction of either one) and draw the final arrow from the tail of x to the head of y. That's all there is to it. We can combine any number of arrows in this manner..."

Feynman.5

"The general principle of quantum theory...[is that] the probability of an event is found by adding arrows for all the ways the event could happen...".

QED, Photons: Particles of Light , 53

"Quantum theory can be used to show why light appears to travel in straight lines. When all possible paths are considered, each crooked path has a nearby path of considerably less distance and therefore much less time (and a substantially different direction for the arrow). Only the paths near the straight-line path... have arrows pointing in nearly the same direction, because their timings are nearly the same. Only such arrows are important, because it is from them that we accumulate a large final arrow...."

QED, Photons: Particles of Light , 53
(from the caption to a Figure)

Feynman.6

"Let's investigate this core of light more closely by putting a source at S, a photomultiplier at P, and a pair of blocks between them to keep the paths of light from wondering too far away....Now let's put a second photomultiplier at Q, below P, and assume again for the sake of simplicity that the light can get from S to Q only by paths of double straight lines. Now, what happens ? When the gap between the blocks is wide enough to allow many neighboring paths to P and Q, the arrows for the paths to P add up (because all the paths to P take nearly the same time), while the paths to Q cancel out (because those paths have a sizable difference in time). Thus the photomultiplier at Q doesn't click.

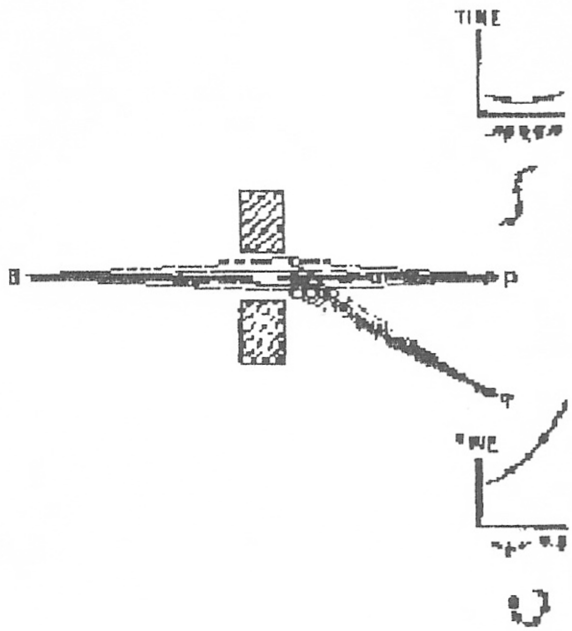

Figure 8 [3]
(graphics needs to be improved)

"But as we push the blocks closer together, at a certain point, the detector at Q starts clicking ! When the gap is nearly closed and there are only a few neighboring paths, the arrows to Q also add up, because there is hardly any difference in time between them either.... Of course, both final arrows are small, so there's not much light either way through such a small hole, but the detector at Q clicks almost as much as the one at P ! So when you try to squeeze the light too much to make sure it's going in only a straight line, it refuses to cooperate and begins to spread out....

QED, Photons: Particles of Light, pp. 54-55

"This is an example of the "uncertainty principle": there is a kind of "complementarity" between knowledge of where the light goes between the blocks and where it goes afterwards -- precise knowledge of both is impossible. I would like to put the uncertainty principle in its historical place: When the revolutionary ideas of quantum physics were first coming out, people still tried to understand them in terms of old-fashioned ideas (such as, light goes in straight lines). But at a certain point the old-fashioned ideas would begin to fail, so a warning was developed that said, in effect 'Your old-fashioned ideas are no damn good when...' If you get rid of all the old fashioned ideas and instead use the ideas that I'm explaining in these lectures -- adding

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[3] See Feynman's Figures 34 and 35, pp. 55-56, QED.

arrows for all the ways an event can happen -- there is no need for an uncertainty principle !..."

QED, Photons: Particles of Light, p.55-56 (raised from footnote)

Langer.1

"The main concern of early physicists was understanding puzzling events; each scientific venture grew from a problem, the solution of which threw unexpected light on other problematical phenomena. It was always in such a light that the concepts of physical science were set up. But the chief preoccupation of the social scientists has been with the nature of their undertaking, its place in the edifice of human knowledge, and—by no means last, though seldom candidly admitted—their own status as scientists.

"[T]he founders of the "young sciences" today... began their work under the tutelage of physics, and -- like young ones emulating their elders -- they have striven first and hardest for the signs of sophistication; technical language, the laboratory atmosphere, apparatus, graphs, charts and statistical averages.

"This ambition has had some unfortunate effects on a discipline for which the procedures of classical physics, for instance, the experimental techniques of Galileo, may not be suitable at all. It has centered attention on the ordering and collating of facts, and drawn it away from their own intriguing character as something distinct from the facts encountered by the physicist, and perhaps differently structured...."

The Idols of the Laboratory, Chapter 2 in
Mind: An Essay on Feeling, S. Langer (1967), pp.33-34

Langer.2

"The cult of borrowed mathematical terms is especially pernicious when it invades serious original thinking, where there are really fundamental psychological concepts in the making, which are obscured and turned from their own implicit development by the unessential though enticing suggestiveness of scientific words. In a sober but trenchant article, I. D. London has shown even so influential and important a venture as Kurt Lewin's "field theory" to be only verbally modeled on the field theory of relativity physics, since Lewin's key concept, "force," has no real analogue in real topology, and his psychological "field" conforms to no known geometry. The result is that Lewin can use none of the powerful principles of substitution that make topology reveal new facts in physical science... The host of theorems that form the actual machinery of topology should have been made to function and so to take over the work of rigorous deduction. Lewin in reality does not utilize one single theorem of topology."

"Here, I think, we have the central and fatal failing of all the projected sciences of mind and conduct: the actual machinery that their sponsors and pioneers have rented does not work when their "conceptualized phenomena" are fed into it. It cannot process the interpretations that are supposed to be legitimate proxies for its abstract elements... The reason for the failure...is that abstract concepts borrowed from physics, such as units of matter—even with the adjective "living" to qualify them—and their motions do not lend themselves readily to the expression of psychologically important problems."

The Idols of the Laboratory, Chapter 2 in
Mind: An Essay on Feeling, S. Langer (1967), pp. 40-43

Lewin.1

Lewin offered the following as an interpretation of the role of quanitification in the physical sciences:

"The increased emphasis upon the quantitative which seems to lend to modern physics a formal and abstract character is not derived from any tendency to logical formality. Rather, the tendency to a full description of the concrete actuality, even to that of the particular case, was influential, a circumstance which should be especially emphasized in conjunction with present-day psychology.... It was the increased desire, and also the increased ability to comprehend concrete particular cases, and to comprehend them fully, which, together with the idea of the homogeneity of the physical world and that of the continuity of the properties of its objects, constituted the main impulse to the increasing quantification of physics...."

The Conflict Between Aristotelian and Galilean Modes of Thought
in Contemporary Psychology, K. Lewin (1935), pp.11-12

Lewin.2

Among the reasons for this belief, Lewin noted these:

"The concept formation of psychology is dominated, just as was that of Aristotelian physics, by the question of regularity in the sense of frequency. This is obvious in its immediate attitude toward particular phenomena as well as in its attitude toward lawfulness. If, for example,

> one show a film of a concrete incident in the behavior of a certain child, the first question of the psychologist usually is: "Do all children do that, or is it at least common?" And if one must answer this question in the negative the behavior loses for that psychologist all or almost all claim to scientific interest. To pay attention to such an "exceptional case" seems to him a scientifically unimportant bit of folly.... The individual event seems to him fortuitous, unimportant, scientifically indifferent.... [T] hat which does not occur repeatedly lies outside the realm of the comprehensible.
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> "The field which is considered lawful, not in principle but in the actual research of psychology - even of experimental psychology - has only been extended very gradually.... [R]epetition remains, as it did for Aristotle, to a large extent the basis for the assumption of the lawfulness or intelligibility of an event.... It is evidence of the depth and momentum of this connection (between repetition and lawfulness) that it is even used to define experiment, a scientific instrument which, if it is not directly opposed to Aristotelian physics, has at least become significant only in relatively modern times...."

Lewin, Ibid. p. 13-15

<u>Piaget.1</u>

Reflective Abstraction is discussed in several places in Piaget's Biology and Knowledge (1971), the most interesting of which I find on pp. 320-321, as follows:

> "In the case of logico-mathematical abstraction... what is given is an agglomeration of actions or operations previously made by the subject himself, with their results. In this case, abstraction consists first of taking cognizance of the existence of one of these actions or operations.... Second, the action noted has to be "reflected" (in the physical sense of the term) by being projected onto another plane - for example the plane of thought as opposed to that of practical action, or the plane of abstract systematization as opposed to that of concrete thought (say, algebra versus arithmetic). Third, it has to be integrated into a new structure, which means that a new structure has to be set up.... These then are the characteristics of a "reflection," but now we are taking the term in the psychological sense, to mean a rearrangement, by means of thought, of some matter previously presented to the subject in a rough or immediate form...." p.320

Piaget.2

to be entered.