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Letters to David Baker

22 July 1996, "Noodles of Nothing"

How's your academic life? Have you been reading any? Do you still subscribe to *Texas Monthly*? Or was it *The Smithsonian*, I forget which? Right now, in my spare time, I'm reading *Robert Oppenheimer: Letters and Recollections*. Mostly it's a collection of letters from when he was in college and graduate school. The fellow was an amazing writer: it would be hard to tell he was a scientist if you didn't know otherwise. Of course, my real interest is in peering into his thoughts as he was learning quantum mechanics; that's why I'm putting time into the book. But it is always good to absorb something of someone else's style.

Have you ever read anything by William James (the psychologist and philosopher – not to be confused with Henry James)? For some reason I'm just fascinated with his writing style; I would love to be able to pull the same tricks, and have it acceptable to do so. If you get a chance, take a look at the first few pages of his essay "The Dilemma of Determinism" just for the style. (You'll be able to find it in the library in any collection of his essays, probably with titles like *The Will to Believe*; the one I have at home is a Dover edition.)

There's a new phenomenon going on in my field: we've apparently reached the level where it's time for some books on the subject. While in Torino, I was approached by four people with some mention of the book they're writing on quantum computers or quantum information in general. That makes a total of five books on the drawing board that I know about personally. I wish I were in the group, but I'm lucky enough to be able to write a paper every now and then. Probably, if I'd just write a little less e-mail . . . !!!

27 July 1996, "Life on Long Island"

I asked whether you had read anything by William James, and then said that he should not be confused with (his brother) Henry James. That's OK; I'm sure I can take your answer to mean that you haven't read either of the two. William was one of the great American philosophers from the end of the last century. He's also known for his work in psychology. I suppose his biggest contribution to thought was in the founding (along

with Charles Sanders Peirce) of a philosophical system known as "pragmatism" – something I like very much, actually. Henry was a novelist and literary critic (and probably quite a bit more famous in general circles than his brother). I've never read anything by Henry.

I got to thinking about Mr. James again because of my last note to you. So, I was very pleased to find a book at my favorite used bookstore today titled *The Philosophy of Henry James, Sr*. I had never heard of this member of the family. As the "Sr." implies, he was William and Henry's father. Apparently he had something of a philosophical system of his own … which, the author of this book claims, is of interest in and of itself and not chiefly because of its relation to William's ideas. Anyway, I snatched the book, ten (Canadian) bucks. Also finally bought Kierkegaard's *Either/Or* (two volumes), and three books by Piaget: *The Construction of Reality in the Child*, *The Child's Conception of the World*, and *The Child's Conception of Physical Causality*. (The philosophical mysteries of quantum theory plague me just as always; I'm not proud, I look for clues wherever I can!)

The thing that intrigues me about James and Peirce is that they both rejected the mechanical view of the world that was the rage of their Victorian time. James, in particular, was led to believe something that had quite the flavor of the "many-worlds interpretation of quantum mechanics" – something some of the foolhardies of today would say is uniquely implied by the quantum mechanical formalism. (Many-worlds quantum mechanics was introduced in 1957 by one of Wheeler's PhD students Hugh Everett; James died in 1910.)

> To that view, actualities seem to float in a wider sea of possibilities from out of which they are chosen; and, somewhere, indeterminism says, such possibilities exist, and form a part of the truth.
>
> (*James, 1884 (address to the Harvard Divinity Students)*)

I'm sure I spent too much money on books again, but it's a nasty itch. The store I went to today is really excellent, even though it's much smaller than our apartment here. It's a wonder what an owner with taste can do. The bookstore is also especially good for me because the owner's husband is a physicist. He does much of the work in purchasing their science and philosophy collections. I got to meet the fella today for the first time; very nice – he was curious to know what quantum cryptography is. One day I was talking to his wife, and she was telling me how she had the good fortune to see Feynman lecture once. I said that I had never seen him, but that I knew his graduate advisor. She said, "My God, he must be old." I said, "well yes," and then went on to explain that it was John Wheeler. She said, "I know of Wheeler; around our house Wheeler is God!" That's how I found out that her husband is a physicist (particle physicist in particular).

I just poured a beer, a Sleeman's Lager. I like it. Actually I like a lot of the beers up here: different ones for different moods. When you come up, I'll introduce you to the whole entourage of Québecois beers. About your coming up … let's see, what can I say?

I think you'll have no problem finding things to do while I'm tied up. The neighborhood is full of surprises (and bars), and every museum is a metro (subway) stop away. I do have two "must see" bars for you: The Mad Hatter's Library (near McGill U) and The Yoda Den (near a smoked-meat joint). Oh yeah, there's also The City Pub … it's got a nice Kantian/"quantum mechanics is a law of thought" feel that I like (and good cheap food to go with the beer).

03 August 1996, "Lonely Jazz"

Ms Holiday is playing in the background and I've got my first cup of the morning. I'm still pretty much exhausted. I ended up staying at IBM an extra day, and the whole affair was pretty intense from start to finish. I think we found something very, very nice … which, of course, was expected – that's why we got together in the first place. The idea is simple and it's this. Suppose Alice needs to communicate to Bob one bit of information, either a 0 or a 1. Also let us suppose the resources available to her for carrying out this task are two (noisy) fiber optic cables and two photons, one for each cable. The bit will, in some sense, be carried in the polarization of the photons; we allow two photons in the game to give Alice a little redundancy to help her get past the noise. Note that I've said nothing about how the photons are produced; I didn't say anything about whether they came from a single source (localized in some small region of space) or whether they are generated by two coordinated but independent sources. Now the question is this: can the transmission's fidelity be helped by allowing the photons to be generated at a single source AND combining them back together before Bob performs his measurement (for gathering the bit)? That is to say, can we increase Bob's chances of guessing the bit correctly by first generating the photon at a single source – so the two are "entangled" in a strange quantum mechanical way – and then allowing Bob to make a measurement on the two together, a measurement on the whole being greater than a sum of its parts? The answer is yes, and I find that so wonderful.

Why, you ask? Because, it's wonderful … period. And a bit unexpected too actually. I guess the thing I really like the most about so many of the questions we've been asking lately is that they really put "entanglement" to use. I just ran across a wonderful quote by Oppenheimer the other day, from a letter he wrote to Fowler soon after Hahn and Strassmann discovered uranium fission:

> The U business is unbelievable. … What do you think? It is I think exciting, not in the rare way of positrons and mesotrons, but in a good honest practical way.

The idea of entanglement has its origin in Einstein, perhaps as early as 1930 … though I can't recall for sure right now. In any case, a pretty clear statement of it and what he didn't like about it came out in 1935 in the paper of Einstein, Podolsky, and Rosen. (It's through Nathan Rosen that I have my "Einstein Number" 3: Rosen having written many papers with Einstein, Peres having written many papers with Rosen, and I having written a paper with Peres.) Its existence was something EPR considered clear-cut evidence that quantum

theory could not be a "complete theory." (I.e., by this time Einstein had already given up the idea that the theory was wrong, he just didn't think that it could be the whole story.) Since then, the notion just pretty much stayed an oddity, only thought about for the most part by the philosophically minded … that is, until its practical resurrection in quantum information theory.

By the way, I should point out that EPR were wrong in the sense that it was finally shown in 1964 that quantum theory could not be "completed" in their sense. Any such completion (that took entanglement away) would contradict experiment – and very fine experiments on this phenomenon have been done. What we have now is that, not only is entanglement required for consistency with observation, but also that it can be exploited for something interesting (and perhaps practical).

Enough physics, right? Ms Simone is on by now, I should say. Kiki and I are about to step out for Ethiopian. It's a place with a lunchtime buffet; we haven't tried it before. I had Ethiopian in DC once and was really taken with it, but I haven't been able to recapture the experience since then. Perhaps the fourth time's a charm. Then we're gonna do a little CD shopping.

Here I'd thought that I was gonna answer all your questions about Canadian beer and such this morning, but instead I just got carried away with science. Sorry about that. I'll be back later in the day with something more on the mundane (not the derogatory meaning of the word, but rather "earthly as opposed to heavenly").

17 August 1996, "More Meaning"

A lazy Saturday afternoon. I'm listening to a new CD, *Liza Minnelli (From Radio City Music Hall)*. Having an afternoon coffee, after an afternoon beer – a strange combination. New York, New York. Kiki's lying on the bed asleep, and I'm dreaming. Today was a day stranger than most. Albert apparently had a stroke this morning. He sort of lost control of much of his left side for a while, maybe 5–7 minutes. As the day has gone he's regained more and more control. Now everything is pretty much normal except he's still a bit wobbly on his left hind leg and I find myself more sentimental than usual. (Excuse me, now we have Mel Tormé.)

The things I live and breath for. *Twilight Zone*, *Star Trek*, Quantum Mechanics, and an open future. Maybe that summarizes it all. (It's been a long time since I've lapsed into Gertrude Steinisms.) The Mars rock has really set me off lately … so much so that I was even willing to spend $4.00 for a *Time Magazine*. I didn't find out much more about Mars that I didn't already know, but at least I learned that Audrey Hepburn was a notch on Jack Kennedy's bedpost. Actually, that really depressed me; I have quite a crush on her … the 1961–64 version of her, that is.

Night Thoughts of a Quantum Theorist. Tonight it's my turn to cook. (A chicken dish I suspect.) The problem's not in the seasoning, but in finding the main ingredient. Those with little imagination restrict themselves to games with seasonings. Unfortunately, that's where I stand now. It's a good thing Kiki makes me cook every Saturday; maybe I'll get the hang of it eventually.

19 August 1996, "Self Promotion"

What's with the "cheers" thing? Corporate lingo, I suppose. I picked it up from the Brits, who always sign their letters to me that way. However, it's becoming a relatively general salutation in my clique. Depending upon my mood, I rotate it with, "best regards," "best wishes," "kind regards," "very best wishes," etc. On special occasions, and, in particular, if the addressee is an old German professor, I might end with something like, "with warm good wishes." But, I tell ya, that's nothing compared to some of the curlicues I saw in the Oppenheimer letter collection!

01 September 1997, "Mo' Investigative Work"

Allow me to reach into the depths of your knowledge of history. A couple of days ago, I came across the following question in Trivial Pursuit: Who said, "The victor will never be asked if he told the truth"? The answer was "Adolf Hitler." Now I would like to pin down the actual source of that quote (i.e., from what speech or what private conversation of Hitler's, to whom and when did he say it). Do you think you might be able to tackle this task? Of course my motivation for getting this straight has to do with some silly thoughts about quantum mechanics ... as you could have guessed.

21 February 1998, "Home a Short While"

Sorry to hear about your painful taste of dharma. Try to remember instead that, in the end, Brahman = Atman. That which is without is within. I've always tended to find more solace in that anyway.

02 March 1998, "Long Finicky Flight"

Well here I am again. A long flight in front of me ... they say 10 hours 58 minutes. You may not get this note for quite a while, March 10 in particular: I doubt that I'll be connecting much, if any, while in Japan (due to the difference in network protocols, etc.). My guess is that this will turn into a long note, as it usually does when I'm on a flight and I don't feel much like working. But right now I don't have a clue as to what the subject is going to be.

What can I tell you? To a large extent I've been pretty damned brainless the last few weeks. I'm not completely sure why that is, but it is. A lot of it is "shut down" I'm sure. I've got a zillion and one things I need to be doing, more than I can possibly handle. So instead of tackling what I can, I tackle none. A corollary to that is that I watch a lot of TV now.

Only 1.5 hours into this flight, and already I have one heck of a back ache. Do you really want to travel so much as you say you do? I'm still not completely sure how this summer's travels are going to turn out. The dates for the Torino conference are now set at June 29–July 19. But it looks like I'll also be invited to a conference in Benasque, Spain

(a small village in the Pyrenees) July 5–25. I'm not yet sure how I want to apportion the time. Almost certainly I will go to Spain for some of that time. However, I really can't say whether I'll be going to Torino. The travel has just gotten to be too much: the more I travel, the more shallow my thoughts become . . . and I've got to stop that. Last week I found out that I had the opportunity to go to Mexico City (expense free for the American taxpayer) in August: I think it's the first time I've done this, but I turned it down.

OK, maybe it's time for a little personal philosophy. Though my tolerance for equations is becoming less and less, I am finding that my view of the world is becoming firmer and firmer. Despite my own depression, I must say that I am finding myself believing that the world is more vibrant and *alive* than I ever have before. When was the last time I sent you a compilation of my philosophical ramblings? This much I have really started to share with my friend Herb Bernstein: the notion that there is a "reality" above and beyond man, everlasting and eternal, is simply outdated. It comes from a time when science could only make progress by extricating the human element from things; it comes from a back-reaction to religion. But now, with some hindsight from the quantum revolution, it seems clear to me that the world is so much more. It's far more surprising than Baconian science would have us believe, and it's far more participatory than any of the western religions (or eastern, for that matter) ever dreamt. The world, its description, and the laws that govern it, are not simply there independent of our actions. There was a time when they were, before complex organic molecules, but now that's not the case. The world and its laws seem to me to be every bit as evolutionary as life itself. And just as the idea of radical Darwinism becomes outdated when one realizes that random natural selection fails to hold, the second one being can say to another, "I love you," so it is with the universe. The world is a big pushme-pullyou. If I could talk to the animals . . . . Is that what I've been doing?

But I know you want to hear a little more philosophy. Herb describes our explorations as trying to get at a new category. He calls it "realit*y*" . . . that is to say, reality with a little something extra thrown in. It describes the fact that the world pushes back in an unpredictable way when you push on it. And the way it pushes depends on what you do to it. And, finally, that that push is not inconsequential in the least bit. Maybe you remember John Wheeler's "game of twenty questions (surprise version)"; I guess I subscribe to it more than ever.

What is this thing called language, and how does it fit into the whole of everything I wrote you above? I always think of Linda Henderson and the introduction to post-modernism that she tried to give us way back when I ask a question like this. I don't think I would have ever believed in 1983 that I would be thinking of her words 15 years down the road. Looking back on it, I have to wonder whether she had just been making a bedtime reading of Foucault or Derrida, and had been trying to share it with us. You probably don't remember this, but John Simpson and I fought some of the things she said as silliness, tooth and nail. Linda once said, "Without language there can be no thought." We said, "That's simply ridiculous." Now I find myself saying to myself, "Without language and the collective action that it leads to (through the demagogues, the communicated

scientific ethic, the body politic, the media, etc.), the world we see would scarcely be the same."

But maybe that's enough for now. I'll get back to you after something of a nap.

14 April 1998, and to Herb Bernstein, "Hawking on Evolution"

I know that you have listened to me patiently in my speculation about Darwinism becoming more and more outdated as we are ever more able to inject planning and purpose into evolution. However, in case you haven't had enough, you may be interested in listening to Stephen Hawking's side of the same story: it's a pretty good talk on the whole I would say. (I certainly don't agree with some of his Everettista views nor his "end of physics" sermons, but much of the rest of it is really good stuff.) You can find a webcast of it at the following site, http://www.sun.com/newmedia/whitehouse/stephen_hawking.html.

17 May 1998, "The Electronic Itch"

To be honest, I don't have much to say, but still I have the itch, the need to write something down. This is my essence as far as it goes.

I think I am in the last two hours of my flight to Chicago. Then an hour and a half in the airport, and finally three more hours back to LA. I arrive just at the peak of rush-hour traffic; so more than likely it'll still take me one hour from there to get home. What a life.

I come back from my second trip to the fatherland still impressed. The food in this part of Germany, very near Luxembourg, was quite different from the Bavarian style that I was getting used to. But still it was very, very good. The landscape was beautiful and full of life. Yesterday and last night, I stayed in Mainz – an old town, just on the river _____ (let's see if you remember your geography) – feeling lonely and searching through the archetypal archive in my soul. Weird things like this make me take a little stock in Jung's thought. The country seems to do something to me.

It's funny contemplating this future of ours. I keep thinking more and more about it. Some of that is spurred by my now constant watch of the exponential growth in computing power. And I am sure some of it comes about by my predisposition to think that we've yet to discover any real laws of physics – the last four hundred years being an elaborate phenomenology to fill in the gaps. I keep feeling that something really, really big is about to happen. Sixteen months ago, I bought this 133 MHz Pentium I machine with 16 megabytes of memory, a $\approx$1 gigabyte hard drive, 800 $\times$ 600 resolution screen, and a 6x CD-ROM, all for $3000. Right now I could buy a 266 MHz Pentium II machine, with 64 megabytes of memory, a 4 gigabyte hard drive, 1024 $\times$ 768 resolution screen, and a 24x CD-ROM, all for $3000. (This is much more like a factor of 4 difference, not the factor of 2 that everyone talks about in "Moore's law.") Eighteen months from now, laptop computers will be at least twice as powerful as this one. Where is this going to lead? Where can it lead? It makes me wonder; it makes me religious in a rather strange sense. I don't think it unreasonable to

expect that it won't be long before we'll see a full-scale reconstruction of our species. Certainly less than two hundred years from now. But then what? This question eats at me sometimes.

14 August 1999, "Rampant Repine"

And the boredom overtook us . . .

Guess what I'm doing again? (Buzz like a bee.) I'm scheduled for an early arrival in Los Angeles in a little over an hour. What I hate about that is that I always get my hopes up only to have them dashed: inevitably an early arrival leads to sitting on the runway for extra time. It never fails that there's another plane still parked in the scheduled spot. Two seats in front of me is Hugh Grant, the actor. (For real, escorted on and everything.)

Have you ever read Borges? I bought a collection of his short stories while I was living in Canada, but I hadn't really sat down to read it until now. I read "The Garden of Forking Paths" the other night and really enjoyed it; it was quite eerie.

Lately too I've been turning my psychotic side to thinking about acid. Namely, how it must induce certain kinds of connections in the brain that aren't normally there. And similarly how it must suspend other ones that we normally rely upon. Is it a priori obvious that that sort of rearrangement of the brain would be a bad thing? We've always been told that it is surely so, that it suspends our function in society. But I've been wondering what might happen if we took a large community (whose transportation is based on the bicycle rather than the car!) like Amsterdam, and surreptitiously gave the residents a small dose of acid in their water supply for something like five or ten years. Would anything interesting and permanent crop up. The acid-eaters would in this case not be isolated in society (as they always have been in the past) but would be the complete community. What form would that community evolve into? What form would their art and literature take? And most importantly for me – i.e., the real reason I'm thinking about this – what form would their scientific investigations and insights start to take? What would they be able to see in systematic ways that we cannot see at all? Could they capture in a scientific way, whole aspects of the world that we are just blind to? Would they in their discussions ask (fruitful) questions about nature that would never have occurred to us?

There's a lot of reasons I've been thinking about this. But one certainly takes its roots in a slide that I use in some of my talks. It's a chart of the raw genetic differences percentage-wise between various species of animals. I have both man and dog marked with a yellow marker. The wonderful thing is that there is only an 11% difference between the two species!! We're so accustomed to thinking that mankind is the pinnacle of creation – and surely we are – but how this hints at a wonderful new slant on the story. This difference in intelligence and understanding that we (subjectively) suppose as almost infinite, might not be infinite at all. In reality it might itself only be 11%. How wonderful that would be!

28 July 2000, "The Role of Registered Phenomena"

I have been thinking a lot about John Wheeler's registered phenomena lately. And, I have decided that on this count John was just wrong. There simply is no real world "out there" completely independent of our interventions into it. Now that our kind is here, we are an integral component of that which constitutes nature as a whole. John had hoped that there was still something of a bedrock to the world – most likely a trapping from his training in classical physics – and it was to that role he assigned the "registered phenomenon." I am forced instead to ask myself over and over which aspects of nature can we at least treat as effectively real, if not real in any absolute sense. For certainly we see an independent world around us: we stub our toes on rocks when we least expect it.

My opinion is lately this. We tend to call something real when it is beyond our control to change it. But that is only a subjective state of affairs, one controlled largely by our lack of information or technology, and sometimes, sadly, by our lack of genuine will. As Archimedes told the king, "Give me firm support and I shall move the earth." When we know all that we can know about a physical system, modern quantum mechanics tells us that we can mold it to our purposes. And, as such, it can no longer retain an independent reality. But when we have less than maximal knowledge of it, degree by degree, it becomes every bit as real as the rocks and trees about us. By this account, the independent reality of our world comes about solely from the mystery it holds for us.

Congratulations on the birth of your daughter. She was at the moment of her birth, and will be from that time forward, a mystery with which you must reckon. She will likely be the most real thing to ever arise in your life, for you will never know her completely. Every day she will bring you a new surprise. And when, years from now, she is on her own and away from your protection, you can look back and know that you partook in creation in the most absolute of senses.

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Letters to Howard Baker

29 September 1997, "Quantum Information Questions"

I think I'll answer your questions somewhat out of the order in which you asked them. I hope you don't mind: it may fit what I'm thinking more closely that way.

Bakercise 1: *How important do you think these papers are to Quantum Information and the quantum technologies (computing, communication, cryptography and teleportation)? Are they a major step forward? And if so, why?*

In my opinion, the Holevo–Schumacher–Westmoreland (HSW) result was the most technically difficult one in Quantum Information Theory to be proved last year. In the long run, the papers are certain to be classics. As far as importance goes, it was certainly one of the top two results (the other being a consortium of papers to do with fault-tolerant computation on quantum computers).

The HSW papers solve a long-standing problem that was on Holevo's mind as early as 1978. Holevo actually had a paper conjecturing this result in 1979, but somehow it escaped all of our attention until Richard Jozsa and I met him last September in Japan. He told us of the old paper then. (I've done a citation search since then, and, believe it or not, this paper had only been cited five times in its life. Stranger still, three of those citations were for the wrong reason – the result they were citing was in his 1973 paper!) Once Holevo knew of the earlier Hausladen, *et al*., result – which he learned of at the Japan conference, 25–30 September 1996 – things must have fallen into place pretty quickly . . . because his paper appeared on the Los Alamos e-print archive 14 November 1996.

As best I can piece it together Schumacher and Westmoreland must have found the result almost simultaneously with Holevo. They saw his paper on the archive as they were in the course of writing theirs. They were disheartened a bit, but felt that the methods of their proof were sufficiently different that they would go ahead and finish their writing and submit the paper anyway. (They related this to me when we met at the PhysComp conference in Boston around Nov 20.)

Is this a major step forward? Yes, because I think this is the first paper that shows an effective way to deal with asymptotic problems to do with quantum communication channels. In a way, this result does for classical communication on quantum channels what