Sir Peter Knight

Interviewed by

Richard Sharpe

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By Zoom

Welcome to the Archives of Information Technology where we capture the past and inspire the future. And I think the future will be inspired by the man who's going to make his contribution to the Archives today. Today is Monday, 17th April 2023. I'm Richard Sharpe and I've been in and covering and writing about and researching the information technology industry, starting off on the computing side, since the 1970s. But a year before I was born, the man who makes his contribution today was born. He is Professor Sir Peter Knight, and we seldom have people from such a humble background who have risen so high in their profession. Let me just read you some of the things that Sir Peter has been. He is the President of the Institute of Physics – he was, anyway – from 2011 to 2013. He got his knighthood in the Queen's Birthday Honours List in 2005 for working in optical physics. He's Head of the Physics Department of Imperial College, past President of the Optical Society of America. He was the Defence Scientific Advisory Council Chair to the UK Ministry of Defence, etc, etc, etc. And all this from a man who's the son of a man who worked in a brickyard in Bedford. Welcome, Sir Peter. Your father, did he encourage you to education?

My father was really keen to see how we could really prosper. You know, he was a lovely man who, I think he started as a blacksmith and then the Second World War started and he was in the Royal Engineers doing movement control. When he left the army at the end of the war, at that point lots of reorganisation going on, and he joined London Brick Company, making bricks. And he always felt that one should try to seize one's opportunities, and one of the oddities about life in Bedford – I lived right at the outskirts of Bedford, more or less in a village outside – is that Bedford had a number of schools which were either independent schools or becoming independent schools, which had a lot of scholarships. And my father could see that provided one did well and passed the eleven-plus that existed in those days, you had the opportunity for a scholarship to one of the independent schools run by what was called the Harpur Trust, and those schools in Bedford relied on an endowment which was basically the ownership of Holborn, okay? So, my father was really very keen to make sure that we had every opportunity, my brother and I, to try and do well in the eleven-plus and really to take advantage of this rather peculiar relationship with the Harpur Trust schools. So both my brother and I did actually pass the eleven-plus and we ended up in a school called Bedford Modern School, BMS, which had the most remarkable science teaching. And that's really how we got there. So my father was really very keen to make sure that if there were opportunities, to make the most of those opportunities because he could see that for all sorts of historical reasons he wasn't able to and he was incredibly supportive.

And your mother as well?

My mother worked on and off. Mainly a housewife, although she did do some work. During the war she worked for one of the ancillary parts of Bletchley Park, by the way, but usually running around with messages from one place to another. And so I think it was one of the Bedford add-ons, if you like, to Bletchley Park. And both of them could see, you know, although we, we, you know, we had a very modest background. It was a little late Victorian cottage that we lived in, and I should say, it did not have water coming into the house, okay? So, outside loos, all the rest of it. And, but incredibly supportive family environment. So I think that we- I wouldn't have got through the eleven-plus without the encouragement of my parents.

[00:04:57]

You were born on 12th August 1947, which is an auspicious year, because we've got someone who was connected somehow, as you know, to Bletchley Park, Alan Turing, he publishes his paper on intelligent machines, which is something of a precursor to AI. And also in Manchester University they're working on the Baby, one of the earliest computers ever. And in Cambridge they're also working on their machine. So you're really there at the start, are you not? And you're one of the – I am part of this generation as well, born in '48 – we are a golden generation in the sense that we are so, so lucky, are we not?

Yeah. I think that's absolutely right. If I look at some of the challenges that my grandchildren face now, that I didn't have to face, you know, I got a scholarship to a really great school, really good teaching. I then went to university where I had a maintenance grant. I didn't have loans, I didn't have debt, it was affordable. My school gave me a book allowance when I went to university, and so on. It was quite extraordinary. So basically, there was a ladder up which you can climb, with lots of support, it was a golden age. And I think that the difficulties that my grandchildren now have, it's probably a different world we're in now. But of course, back in, you know, I went to university in 1965, a very small proportion of the 18-year-olds went to university in those days, so again, very lucky to get into a university at that stage, given my background.

Yeah. Also, given your background, yes, the ladder may be there, but, Sir Peter, you have to climb it, don't you?

Yeah, I guess you do. So to some extent the ability to climb a ladder may actually be facilitated by the ability never to look down, you just keep going. [laughs] And so one has a sense of direction which is really because, to be honest, what I've done over the years is really pursue a vision, which is, I think possibly verging on the monomania, because I really wanted to see it happen. And so you don't really think you're climbing a ladder, you just don't look down.

You drive yourself quite hard, do you?

I do. And I think that one of the golden rules that I've always tried to adopt is that when there are things that one can do, get on and do them and, you know, make the most of all the opportunities around you to enjoy life and to be productive.

You're 75 now and we had difficulty in scheduling this event because you were flying round the world.

[laughs]

You're still working very hard.

I think one never really gives up. If you're active in creating new knowledge and finding out ways in which that knowledge can be exploited, you know, both for societal benefit and economic benefit, you don't really stop because it's something you care so deeply about. So although technically I retired some time ago, I'm having a whale of a time in moving some of this new technology along, discovering new things, enabling other people really to participate in this fascinating journey at the same time. So, you know, I think the whizzing round the world stuff is a consequence of really trying to do one's best to make sure this technology that I've been involved in, quantum technology, really does make an impact.

You went to school first of all in 1954, quite a good year again, there were about 200 computers in the whole world then.

[laughs] Yes.

[00:09:22]

When did anybody turn round to you, or turn round to your parents and say, ooh, I think we've got quite a bright one here?

I don't know. I think possibly when we were thinking about the eleven-plus. And so I was at an interesting little school in Ampthill Road in Bedford, where they were – and in those days they coached you to go through the eleven-plus, there was quite a lot of coaching going on in this stuff because I think that, even in those days, it was a fairly competitive business and so, I think they could spot people who had a chance of doing well in the eleven-plus, and I think I got a lot of assistance in doing that. At the time, by the way, when I was at that little school, I was undiagnosed, but being really short-sighted. So, no specs. That meant I had to sit pretty close to the front of the class to actually see the blackboard, and I'm afraid that that was misinterpreted as keenness, rather than an inability to read. [laughs]

I'm such a bad parent that one of my son's, pupil's, friends came to me and said, I don't think he can see very well. I said, surely he can? No, I don't think he can actually, he squints at the board a lot. We had him tested. Yes, he needed glasses.

That was the suture [sp?] of how I knew I needed glasses, because I quite independently discovered that if one made a very small aperture, like so, you could see the board. [laughs]

True. Were you good at sport?

No. I'm not a very sporty per… I used to play rugby, and in fact I used to play right in the centre, the hooker in rugby, bust this collarbone playing rugby. But more enthusiastic than gifted, shall we say.

Right, okay. And what, apart from your work at school, your academic work, what were your interests in school?

I think that at the time, I was really, although I've worked most of my life in physics, at the time I was actually really interested in chemistry experiments. And so one of the things that we had, we had a barn and the barn had water coming in and the stove and so on, and I just re-equipped the barn as my chemistry lab, making – well, it was the usual thing for kids – making things that smelled vile and making things that went bang.

Yeah, true.

And so an awful lot of the time I was doing that. Plus doing stuff involving Scouts and cycling and Youth Hostelling and so on, usual things that kids in the late fifties, early sixties did. But very much having a lab of my own in the barn was good fun.

So you did nine O levels, three A levels and one S level. And you moved on in '65 to the University of Sussex, which was relatively new. Why did you choose Sussex?

We had a talk to the sixth form at school from one of the founders of the university where they were trying to demonstrate that they were doing something new. And it really, it really did impress me that they were attempting to do something, which was unusual in those days, which was to support interdisciplinary or cross-disciplinary studies and thinking. And so this talk to the sixth form did impress me, so I went down to Brighton to have a look at what they were trying to do. And I thought, you know, these people are really serious. They were quite an interesting group and the science side, many of them were kind of escapees from Oxford who could see that they could try to do something really different, and they were really quite inspiring. So I had a chat with them, I thought right, this is the thing, I'm going to apply to this place, and I liked the idea that you could bring together disciplines that crossed and interacted. So I went initially to do chemistry, but with a physics and mathematics sort of as minors. But it was that ability to actually have that blurring of those boundaries that really impressed me, and at prelims at the end of the second term, I immediately shifted across to physics, because it was the atomic world that really interested me. So, why did I go to Sussex? A new place, it was really, to be honest, it was quite glamorous, you know, in the 1960s and quite competitive to get into, but hugely supportive and enjoyable.

[00:14:46]

So, '65, we have Gordon Moore scratching his head saying, hold on, I think we're doing something here that's quite interesting, and he draws a graph. He's died earlier this year, unfortunately. But there he postulates, well, it's called Moore's Law, right, I think that's a bit of a silly name for it, it's not a law, is it? It's an observation, which the industry is trying to keep because Digital Equipment Corporation launches a funny little thing called a PDP-5 and the 1901, ICT 1901 is launched and the UK government forms the Computer Advisory Unit and the world has 29,600 computers, of which, 21,000 are in the United States. And IBM launches the PL/1 programming language. When did you first see your first computer?

It would have been not very long after arriving at Sussex, because one thing you had to do as part of your undergraduate degree, was to actually program a machine. And so there was a computer centre. I mean there was no such thing as having terminals around the place. There was a- what you did is that you wrote a simple program as part of your coursework. The one that I wrote was generating a string of random numbers. Okay? So I wrote a very simple program and it was on paper tape and you took your roll of tape along with you and you put it in a tray and you thought, well, if I come back in a couple of days, I wonder if I've got an outcome [laughs] on this one. And that's the way it was when I was an undergraduate. I cannot remember when we moved to punched cards, but it was before, I believe, that we were using lots of punched cards, okay? It was a queuing system and you came back and if you were lucky they said, yes, it's run and here's a ream of printed paper that we've got your results on, or if you were unlucky, no, it didn't run, come back again and do it again.

So that was my first exposure to- and basically it was a big machine room, you could see through windows that yeah, there were things in there that seemed to be revolving and so on, but you weren't allowed anywhere near the place. There was a sort of priesthood of defenders of the machine.

[laughs] Oh yes, yes. I was one of those because I was an operator. It was presumably an ICT machine?

It was, it was.

And what was the programming language?

D'you know, this was right at the very beginning of Fortran.

Oh, lucky.

Right at the very beginning of Fortran, yeah.

Which is an underrated but a lovely programming language, frankly.

Yes, I agree, and of course these days, teaching programming languages, it sounds like you're talking about something that's prehistoric to the students now. But we still run Fortran programs.

Good, I'm glad to hear it. You stayed on at Sussex to do a PhD, is that right?

I did, and the story for that is relevant, I think. One thing you had to do at Sussex as an undergraduate was a final year project which was really a very demanding full year project working within a research group. And so what I did is I was working on a piece of atomic physics called optical pumping. Relatively straightforward apparatus, where you could do things in a straightforward manner, it was sometimes fairly dangerous because the light source was a little bulb full of alkaline atom, which you put in the top of a tank circuit, okay? And the whole thing had to sit in time in a magnetically shielded container that was light tight, and you had to jiggle the little light emitting bulb into the top of the tank coil above this valve until it struck right, okay? So it means that several times a day I'd be hurled across the room, because I'd got one hand on the shield, the other hand – and it touches – bam, lots of volts. So it used to throw me across the room on a daily basis. But it was great fun because it taught me already that one could manipulate atomic systems, in terms of this weird idea of coherence, by the way, very strange concept. But it underpins what we do when we make atomic clocks, for example, you know, the things that generate GPS and so on.

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So right at the very beginning I was doing these. So relatively simple experiments that uncovered some basic understandings. I had the most enormous fun doing this, and the theory around it. And it completely misled me, because I thought, ooh, it's easy to do experiments. It wasn't. So I started doing both a mixture of theory and experiment as a PhD student in Sussex and it quite obviously, to everybody, became evident that I was completely incompetent as an experimentalist. And, you know, nothing seemed to work and, you know, I had this monstrous, enormous piece of apparatus which was really quite complicated, and I was the worst person to be let loose on it. But the theoretical stuff was really developing. And so towards the end of my first year I said look, we have to be realistic, I'm not going to make an experimentalist on this one, let's just focus on the theory side. And you could see the people I was working with heaved this great sigh of relief [laughs] that they'd finally found a way of getting me not to touch the bits of kit any more. So I became a theorist. Okay?

And in that period you went through 1968, a seminal year in student politics.

It was.

Are you, were you a political person then?

At the time I think all of us, you know, we basically had a sort of radical posture which I think, when I see photographs of those days I think, holy cow, is that really me? [laughs] But yeah, I think the whole university sector at the end of the sixties was peculiarly radical. It did produce some really interesting thinking, and of course it produced a great deal of nonsense, but well, we survived it all.

We did indeed. Again, a reason why we are a golden generation, I think, and a very lucky one, and being around in '68.

Well, at the end of that sixties, by the way, I had the opportunity for an alternative career, which I don't normally talk about, but I don't mind talking to you about.

This will go public, you know.

I know, but I think it's known outside. Is that I became a kind of social secretary at the university where my responsibility was to put on bands and dances.

Oh, oh.

And so I became quite good at this. And so we would organise, and, for example, I gave the Pink Floyd their first gig outside London.

Woah!

So there was a while in which I could have gone down in that direction. I'm quite pleased I didn't, but we had a lot of fun with that, you know, I… with, at the university with bands like Jimi Hendrix and Eric Clapton and so on. So that was very entertaining. It was a bit of a distraction from what I was supposed to be doing, but… And of course, it led us into unusual things. So those people who can remember the sixties and large bands will remember that we used to have an awful problem with feedback. Bands, there were whistling noises coming out of the speakers. We were supposed to be scientists, and it took a long time to think, well, you know, we have all these speaker cabinets at the back of the room and then the band and the microphones in front of them, maybe you could reduce the feedback if you put the speakers on the other side of the microphones. And you know it took maybe five years before anybody spotted that. [laughs] So the reason why all those feedback problems persisted in the sixties with bands was because we hadn't really thought it through in terms of pick-up and acoustics. Anyway, I went back to my PhD, so I, yeah.

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Sussex was also the host of the Science Policy Research Unit. Were you at all interested in the policy of science, because you became interested?

Yeah, at the time I did, because there were people in the physics department at Sussex who had associate roles with SPRU, the Science Policy Research Unit, Brian Easlea in particular, and Roy Turner. And so we were quite interested, so at the time people were already beginning to think things like the limits to growth report and so on. So policy was actually interesting at the time, but what I didn't know at the time was how scientific insights translated into policy advice and moving things along. And that took quite a long time, by the way. So it was really very much an amateur interest in you could see that if you were an evidence based scientist who was looking at decision making in terms of the evidence, how would that contribute to policy. And that's always been an interest of mine.

You left in '72, an interesting year because a quite dangerous and awful programming language was developed then, C. I don't understand C, I don't understand its appeal. I know it's a universal Assembler really, but oh, what a dog's breakfast it is. But the first pocket calculator is launched by TI and Intel launches the 8008.

Right.

So it's a relatively interesting year. You decide to do what after university?

So, the person that I, that took me under his wing at Sussex was Les Allen, who was really a pioneer of my field, and he'd had a sabbatical leave at the University of Rochester, which was the major centre for this kind of optical physics. And was in the process of writing a book, in fact, with one of the people at the University of Rochester. And he said, well look, Peter's looking for his first postdoctoral fellowship, and I jumped at the chance. And in fact it was actually much more interesting because that person was Joe Eberly, who has played a major role in my scientific life. At the time, he was about to go off on sabbatical, he went off on sabbatical leave to Stanford. So although I was Joe's postdoc, in fact his first postdoc, he was actually in Stanford, so I joined him in Stanford, although Rochester was paying me. And that was a remarkable time because, in terms of lasers, down in the physics department was Art Schawlow, who, Nobel Prize Winner for lasers and so on, but had an office up at the Stanford Linear Accelerator Center. One of the things that they did at SLAC is they had an enormous outreach programme for the kids in Menlo Park and so on. And they would run a science club on a Saturday morning in the cafeteria at SLAC. And, you know, sometimes I'd pop in to talk to some of these kids from the local high schools. Hindsight's a wonderful thing where you go back and you google who was around at that time. And of course, you know who was around, coming into that science club at Stanford at the time, was Steve Jobs. And it's quite interesting that, completely unaware to me at least, I could see this emergent group of young people thinking about, yeah, how did you turn computing into something you could have on your desk at home, okay? And that's what, and of course Steve Jobs was thinking about it, Steve Wozniak was one of the people that would come along to the Saturday club. So I don't think I could have identified from those kids that I saw at the time, Wozniak and Jobs, but they would have been there at that time. It's a curious intersection, you know, unaware intersection of lives. So then at the end of that period at Stanford, off back to Rochester. Rochester was absolutely at the heart of thinking about optics. Small university, very highly research focussed, but had some of the most pioneering people in optics. So Eberly was my boss, but also Emil Wolf who was the grand old man of optics, you know, **the** guru of the whole field. And Leonard Mandel, British, but had worked in Rochester for a while. And we would go off to lunch together. So there I was, age 24, younger than most of the graduate students in the group, with these tremendous world-leading characters that were just transformational. It was a great experience.

[00:30:08]

Just remind me for a moment – my background is not physics – what is the speed difference between a signal on a wire and optics?

Well, the frequency. The frequency, basically. So if you can imagine, if you're using telephony or whatever down a wire, you're limited by the bandwidth of what you can send down the wire, the frequency is limited and the move in particular to carry information using light was the great transformation. You know, both in free space and then down fibres. And all of that emerged during my early scientific life, by the way, the people working out how one could encode signals on light to carry information, how could you modulate the signal to send it, how could you pick it up and receive it, was really important. And all of that emerged towards the end, you know, in the 1970s, beginning of the eighties.

Yes. In this country STC were doing quite a bit of that work, weren't they? Optical fibre.

They were. So Hockham and Kao were the first people to think that you could actually do something down glass fibres. Up until that point people thought, look, honestly, glass is, although it's pretty transparent, it's not transparent enough and you're never going to get light down a long fibre. But Hockham and Kao really thought that they could do this. And at the same time, people at STL Harlow were looking at ways in which you could build the very first of the little diode lasers, little compact semiconductor devices that could form the injector of the signal in the first place. So the UK actually started a lot of this in a really exciting way. And then British Telecom jumped in very quickly to work out how this could happen, led by, well especially by John Midwinter. So, an enormous… so that was where my life started to engage a bit more between the physics side of it all and the engineering that turned it into something of real importance. So, you know, quite quickly we started to have useful interactions, especially with British Telecom.

Can I just pause for a moment and ask you a very general question, which we like to dwell on somewhat in the Archives, why in the UK were we so good at the early stages but we can't make much money out of it?

We should have been. If we go back to the late sixties, early seventies, we still had a number of companies of size and substance compared with our international competitors. Now, this is my personal view – usual government warning, this does not reflect government policy, okay – my personal view is that a lot of the electronics companies became so used to cost-plus contracts with the Ministry of Defence that they stopped thinking of mass markets and innovation and they became, if you like, suppliers rather than innovators. And I really honestly do think that that was the seed by which we started to decline in terms of our… Because we could have been there. Some of the work that was started in the UK, the optical fibre stuff I've just mentioned. Not only the ability to carry stuff down fibres, but the ability to build, for example, amplifiers that go into the fibres. Very much British thing. At the same time we had people working on semiconductor systems at Plessey and so on, of extraordinary competence, but somehow, you know, with the mergers and bringing together of companies that had started to think Marconi-like, and when Arnold Weinstock started to think that, ooh, the big surplus he had was much more profitable used as a bank, moving money around, rather than innovation, we lost our way. We really seriously lost our way. Of course we did have innovative companies. Earlier this morning I was on a one-hour call with Hermann Hauser.

Oh, Hermann, yes.

Hermann's an old friend and very much a supporter of what we do in quantum technology, and Hermann of course, through Acorn and then the BBC Micro and then ARM, it gives you an example of what you can do if you're imaginative and bold and innovative. We just didn't have enough of them in the seventies and eighties, I'm afraid.

[00:35:32]

Anyway. So my feeling is that we lost our way in terms of the ability to see things through at a time when our companies were diminishing in their appetite to work on new product. There were good companies that maintained a research activity to strike out to new areas; British Telecom is an obvious one. But it was a rare phenomenon. We had the most remarkable government laboratories at the same time that could have been the seed for lots of things. Liquid crystals came out of the work in Malvern combined with Hull, but we lost the ability to exploit them. A lot of compound semiconductor work was launched, for example, by Cyril Hilsum and colleagues in the UK, but we didn't scale it up. So the ability to be innovative and scale, we sort of lost for a while. We're trying to re-create it now.

And equally, National Physical Laboratory where you were adviser on research, I understand.

I had, I was CSA – Chief Scientific Adviser – to NPL, I was their first one. And NPL is still something I'm associated with. I chair their Quantum Metrology Institute. They're a wonderful example of the ability to do great science, to make an economic impact working with companies in terms of the importance of precise measurement and traceability. So I'm deeply fond of NPL. Right at the beginning you mentioned Alan Turing, of course Turing worked really hard on building a computational engine, based on some NPL structure, with mercury switches and so on. So if you go down to the bowels of Bushy House at NPL, you will still see component parts of the very early Turing machines down there. It's a wonderful legacy they have. They did pioneer atomic clocks, for example. They were, the first ever atomic clock was built in the 1950s by Essen and Parry at NPL. It's sad that it took the US to commercialise it and then to generate GPS.

Packet switching as well, with Donald Davies.

With Donald Davies, exactly right. So there's a great example of how you have the vehicle, they could work with universities, they ran as a nationally important lab, but then that transfer into industry was fragile. Sometimes it worked, sometimes it failed miserably. But as a technical authority, they were and are unparalleled.

[00:38:29]

You moved on from Rochester and Stanford to the Johns Hopkins University.

Oh, that was only really for a summer. And that was really because I was trying to work out what should I do longer term. Shall I stay in the US or shall I come back to the UK. So the time at Hopkins was really exploring what the opportunities were in the US, looking at the assistant professorship role and so on, talking to universities around the US, and then at the same time, talking to universities back in the UK about what the longer term prospects were. So that Hopkins one was just a pause really, to give me a chance to rethink what should I do. And I should say that I was terribly homesick, by the way, in the US.

Okay. What did you miss?

Oh, the ability to go into a town and walk around, the idea that you have pavements and pubs and, you know. The quality of life in the US is extraordinarily good, but there are things of a domestic nature in the UK that we do so much better.

So, I'm glad to say, you came back.

I did, I did. Initially to Sussex, for a little while, on a government fellowship which was part of the scheme to reverse the brain drain. In other words, they pay for you to come back, and they paid your salary and your removal expenses. And so I seized upon that to get me back, to get a bit more re-established. And I moved from there to a wonderfully supportive institution called Royal Holloway College, which was a very small University of London college at the time. And don't forget, this was before the cuts had really started to impact universities. So it was a very small department, beautifully equipped still with lots of facilities and the ability to use those facilities and to build one's own group for the first time. So that was a great, I loved being there and again, as part of this attempt by government to support early career people, they instigated a scheme of fellowships for five years to do what you like. And so I got one of these, called an advanced fellowship. And – this is probably quite unscrupulous – but the chair of the panel was also the head of department at Imperial College and – this was Dan Bradley, and Dan did a wonderful thing, he telephoned me in the evening and said, 'That worked really well, your interview was a great success, we're going to offer you one of these things, but why don't you take it at Imperial. And I said, 'Well, if you offer me a tenured job at the end, of course I'll take it'. And it just demonstrates how you could do things in those days you can't do any more, you know, HR would forbid it. Dan said, 'Okay, done. I'll send you a note guaranteeing it'. [laughs] So I moved to Imperial College and…

Holloway is west of London isn't it?

Holloway is pretty close to Windsor, yeah.

Yeah. And Imperial is right in Kensington?

It is, right at the back of the Albert Hall.

It's part of all of that complex which came out of the Great Exhibition, the money from that, and led to the wonderful V&A, the Science Museum and to Imperial College, is that right?

That's right. The Great Exhibition, in that one year that it ran, was attended by about a third of the population, and it made a very substantial profit. What Lyon Playfair and the Prince Consort did is invested that money to buy the whole site from the park right down to the Cromwell Road, for what the Prince Consort called 'the encouragement of the practical arts'. So part of it was museums, part of it was various colleges. Now, some of those colleges came together to form Imperial, some of them stayed out. So the Royal College of Art stayed out, okay? The Royal College of Organists and the Royal College of Music stayed out, but we have obviously links with them. And so that- and then, it wasn't until much, much later that the constituent colleges, you know, the engineering part, called City & Guilds, and the natural sciences part, all came together to form Imperial. And so it's an interesting place, because for the most part we don't own that part of South Kensington, the Great Exhibition trustees still own it. So much, much later in my career I was able to participate in buying a site as large as South Kensington, but over by our medical campus. We bought the BBC World Studios, and that was when I was Deputy Rector and I was part of the group that said to the BBC, who'd moved up to Salford, you know, honestly you could do worse than sell it to us. And that's our big White City innovation campus. And that was…

[both speaking together]

Sorry, go on.

That was pretty much the last thing I did when I was still a paid employee of Imperial College. So South Kensington, lovely site, but you're boxed in. It's a bit like a huge jigsaw puzzle, you know, if you move one part you're going to move all the other part… well, more like a Rubik cube, in fact. You can't go up because of planning, you can't go down because of the river underneath, you can't go sideways. So it was a great site, but basically, over the years, we basically grabbed every little piece of space in South Ken that we could use. But it was a great place to be.

It has a tower, doesn't it?

The Queen's Tower is the last part of what was then called the Imperial Institute, which is nothing to do with Imperial College. It became later on the Commonwealth Institute and moved. Okay? And I love that tower, because I always point out to visitors, it's the only very large tower that you can see from all over London where the bottom two floors are new.

[laughs]

Because the building that it used to be part of has gone. [laughs]

[00:45:53]

You have at Imperial several disciplines apart from science, don't you? Or didn't you?

Well, we had, what we had when I first went there was natural sciences - physics, chemistry, biology and so on - mathematics, and then a really powerful engineering school, they were a wonderfully powerful engineering school. And they were the two components. We had other parts of it in terms of humanities and so on, but not very much. Basically, it was a big engineering and natural sciences school. We acquired medicine much later. So it was really at the end of the nineties that we started to acquire, in the big reorganisation of the University of London, we acquired St Mary's, the Hammersmith, Chelsea and Westminster, and so on. But that was later. So the medics and the way that Imperial transformed itself in this century was actually quite late.

I heard a joke about Imperial in that if you were up in the tower, you could tell from looking down who were the sociologists and who were the engineers, because the sociologists would always be doing this, as in class or people, always putting quotes around things. The engineers wouldn't bother to do that, because they were dealing with the real world. Now…

Right. And in fact the distinction between engineering and physics was, you know, because I worked quite a lot on lasers and quantum stuff and so on, and in engineering there were a lot of people who worked on optics and information and so on, so there was a cross-talk between engineering and that. So although I've always been interested in the applicability of light to do things, you know, I've always been on the physics side of it all, but I've always had a close relationship with our engineering colleagues as well.

Why don't we have optical processors yet?

Ah. Right. Well, in a sense you probably will. There was a lot of fuss back in the eighties about optical computing, by the way, and the way that one could use non-linear optics as a switch. And it looked really quite – I mean I've even written papers on this stuff – but it turned out to be really difficult because you could turn these switches on really quickly, but you couldn't turn 'em off really quickly. And that became a bit of an obstacle to all optical computing using non-linear optics. But at the same time, it didn't go away, and in fact, not only did it not go away, it started to come back with a vengeance, because one of the things that one can do, especially in data centres, is to start to link up the ability to move information around using light with the ability to switch and couple. So the people are using integrated optics in terms of chip-based processors within data centres. So it's come back with a vengeance. So I think the fusion of data centres, processors and so on, that's already been transformational because you can't use conventional switching techniques in a big data centre and hope to control the, if you like, the power budget. And so if you look at what's going on in data centres, there's a big investment in terms of integrated optics now and silicon-based chips and so on. So silicon photonics with very fast switches, the ability to modulate and so on is right now at the heart of what we're doing in terms of big data centres.

[00:50:00]

A great white hope was Josephson junctions in fifth generation for Japan and also for IBM. What happened?

Well, again, they turned out to be quite noisy, okay? And, but it never went away, people carried on working on Josephson junctions in interesting ways. I have a colleague in Australia, Cathy Foley, who ran the CSIRO Labs, and she'd worked on Josephson junctions for a long time, and worked out that they made really good sensors. So one of the things that she did is built a Josephson-based sensor that could be used by the mining industry. You can fly these things off helicopters and work out where the mineral resources are. It can be transformational. So there's a side-line, okay? But the other part of it is that as people started to work on these quantum interference devices using Josephson junctions, they've become one of the leading candidates for quantum computing now. And it's definitely the route that's being pushed by IBM now. So there's been a resurgence of interest in this so that the largest quantum computing chip progress that's being made is by superconducting devices now. So it's not gone away. There's still a bit of a noise problem with them, but they're a really promising platform. So IBM maintain their interest, you know, they acquired quite a lot of expertise way back in this, with bubble memories and all sorts of things, but that division has transformed itself into their quantum division, it's a real power.

I'm not sure that IBM is given enough, not credibility – there's a word there I'm searching for… - for its real innovation. It is, it became, I know, to an extent its monopoly processes and so on and so forth, but it really did innovate incredibly well. The disk drive, for instance. I know it's a Cinderella-like technology, but where would we be without it?

Sure. And where would Northern Ireland be without Seagate, for example, manufacturing them. Yeah.

All these people who think about these things as clouds in which things appear and then things are taken down, and I always tell them, no, there's a physical head moving – well, hopefully not on the surface – but close to the surface of a disk, somewhere it's moving to get you that information that you've just asked for.

And it moves at an incredible speed and incredibly small distances as well. It's amazing it does not crash. I know.

Yes, it does. If it crashes you are in trouble. You are climbing the ladder.

Right.

As you climb the ladder you get responsibility for management.

Right.

How are you as a manager?

I think I'm pretty good at the people side of it all, of getting people to work together for the common good, and I think I'm, I've got, I believe, the right sort of talents to engage with people. I think I've always needed somebody much more administratively competent behind me to support me on these things, okay? So basically, I'm not bad at the visionary part, I'm not bad at the people stuff, but I always need an operating officer right behind me to make sure that we actually deliver what I dreamt up, okay? So if I had to find a fault, it's that, you know, basically, coming up with ideas is all very well, but seeing them through to- you need patience and, you know, and I've always had, by the way, exactly that support structure to enable me to do things.

Or have you built it?

I suppose so, in the sense that you find people with that kind of talent, you encourage them and so on, so yeah. So for a while, you know, the way that I started, I built up this research group at Imperial and then I became what was called a Head of Group, so it was all of the laser and optics side of things. And so most of the people in the group were experimentalists, okay? I'm still a theorist and I was allowed to be Head of Group provided when I went in the labs I kept my hands in my pockets, okay? But no, there's a serious part of this. I think almost all of my career I've tried to make sure that we're engaged with people who actually carry out the experiments and do the realisation of stuff. You know, I can come up with ideas and concepts, but the marriage of theory and experiment together is really, I think, the most advantageous thing. And my whole career has been working on exactly that. And sometimes the structural mechanisms to do that have not really been in place in some places. You know, in many universities in the UK, theorists sit in a different department to the experimentalists, and so on. I think I was really lucky at Imperial that they never really had those constraints. And I think the marriage of theoretical ideas, experimental verification and exploitation, the whole purpose of Imperial was to do that, by the way. It was part of the Royal Charter that you carry out great research for the benefit of people. And I swallowed that hook, line and sinker, I think it's important.

[00:56:20]

Sir Peter, you might have noticed that we're not in the European Union any more, I'm sure that hasn't passed you by.

Mm.

What are the relationships like between people like you and your colleagues in continental Europe? Will we be able to put those things that seem to have been put asunder back together again?

Well, my colleagues in the rest of Europe are deeply saddened by our inability to continue to engage with them. They really want us there, we really want to be there. I've had years and years of wonderful engagement with the rest of Europe. At the peak of my research group at Imperial College, half of the members were from the rest of Europe, okay? It was enormously profitable in terms of an intellectual satisfaction. You know, we really made a difference. The ability to move around Europe and engage with people was transformational and we hugely miss it. Brexit has been enormously damaging to the scientific enterprise. So the scientists across Europe look back at those days with nostalgia, as we do, because it was the most perfect way to engage and it meant that we were part of an intellectual powerhouse that could rival the world. Being on our own out on this distant island has really fragmented things. So, you know, I really hope that we get better engaged and, you know, there are movements towards Horizon Europe and whether we can or not. But, you know, the damage that was done through the Brexit negotiations has generated big barriers to us getting better engaged in the future, so there is institutional damage that we need to repair, but the scientific willingness to get engaged has never gone away. So I meet up with my colleagues from the rest of Europe and we often lament the good old days because it was of great benefit to the UK, as well as to the rest of Europe.

And you were a visiting professor at the University of Lorraine, were you not? Louvain, sorry?

Yeah. The situation in the universities in Belgium was kind of complicated in that the big tension between the French speakers and the Flemish speakers meant that every university was split, okay? So I was a visiting professor and in fact did it over several years, with Louvain-la-Neuve, which was the French speaking bit that split off from Leuven.

Oh right.

Okay? And then, you know, that really, at this very early stage, told me that these sorts of splits could be both silly and dangerous. When that university split happened, they had to break up the university collection, Leuven University was really a famous library.

Yeah? Oh no.

All the books with an even catalogue number stayed in one place, all the ones with an odd catalogue number went to the other, separated by, you know, maybe 30 kilometres, by the way. So you'd have volume one in one place and volume two in another. [laughs] That really demonstrated that harmony is a good thing. Anyway, so Louvain-la-Neuve, lovely place with some really interesting folks to engage with. It was part of a big European Union collaboration that I led, in fact, on this sort of stuff, so I was always pleased to be there, they seemed to be pleased to see me too. We had joint PhD students as well.

[01:00:12]

You were also at the University of Konstanz?

Yeah. That was when I had my Humboldt Prize. Humboldt Prizes are lovely, they're really lovely. They're six months where you're a guest of colleagues in Germany. In my case it was with Jürgen Mlynek in Konstanz, beautiful, beautiful town right on the border with Switzerland, on the lake, doing the most innovative work in my field. And so six months I spent with them was really lovely. Completely freed me up from administrative responsibilities and so on. And better than that, they allowed a lot of my students and postdocs to come over on visits and so on, and that built relationships that continue now. You know, some of my former students have continued those relationships. So Konstanz was a beautiful place, but a stimulating place as well.

What are your languages like?

Terrible.

Are they?

Absolutely appalling. It's one of my great embarrassments, and I can almost get by, but really quite awful. I think it's really lucky for me that the rest of the world use English as their language of science. I'm very fortunate.

Okay. I was on some international projects across Europe, publishing projects, and what I found was that a strange process went on, people seemed to revert into national characteristics.

Yeah.

The Brits would say, 'Let's do it'. The German would say, 'Where's the timetable?'. And the French would say, 'Where's the philosophy behind it?'.

[laughs] Yes.

And the Italians would say, 'Yes, we'll do that', because they were so polite, but they wouldn't do it. Did you find that?

Yeah. Although I did find my Italian colleagues actually rather good at doing as well. [laughs] Especially the people in my field in Florence, were just extraordinarily good. Yeah, I… but I think that you've got to remember that because of European Union networks and so on, there was a homogenisation of workforce, you know, you'd turn up in Konstanz and find, you know, there you were, you'd have people from France, from Finland, from the UK and so on, and it was a wonderful melting pot of talent and opportunity.

It seems to me, and I may be completely wrong, but I've been hearing for the last ten years at least that probably next year we'll have some really successful quantum computers.

Right.

What's taken it so long?

Well, if you look at the way that a quantum computer's supposed to work, compared with a classical machine, what you have to do is to exploit the very peculiar quantum concept of being in a superposition of states at the same time. You know, it can be in a bit state one and a bit state zero simultaneously, okay? Now, these things are quite rare and very fragile and the slightest engagement with the outside world, with the environment disturbs that lovely superposition. Now, if you have one of these things at superposition it's fairly straightforward to keep that superposition going. That's called an atomic clock, and we've been exploiting it for years. So quantum technology already gave you GPS. Now if you put two together, that's an entangled state, and that's quite fragile, and you do more and more of them and it gets worse and worse. So the ability to get screwed up by noise in the environment is infinitely worse than in a classical machine. It's called the decoherence problem. So the…

Sorry, the what problem?

The decoherence problem.

The decoherence problem?

Yeah. That's been the great challenge for all of us, because when you make these superpositions they're incredibly sensitive to the outside world. By the way, you then turn that into an advantage, because that turns into, the ability to sense the outside world is what you want in a sensor. And so in fact the more immediate things that we can exploit are quantum sensors that use that ability to get screwed up by the outside world. So a lot of what we're producing in the quantum technology programme is actually a by-product of this fragility. So we can build quantum sensors that can sense the gravitational field around you. Now, does that matter? Well, yeah, because half the holes dug up in London are in the wrong place, because they don't know where the buried infrastructure is. If we can improve by a factor of two that ability to sense below your feet, think of the impact. That's what we're doing, we're building those gravity sensors. You can imagine a situation where the ability to measure magnetic fields from the brain is really straightforward. Okay? That's called – I can never pronounce it properly – magnetoencephalography. There we go.

No, I think you got it.

[01:06:03]

Right, well, if you tried to do that sort of brain imaging, you get shoved into one of these big superconducting tunnels that's deeply scary, yeah? What our quantum programme can do, led by this wonderful group in Nottingham, is to replace all that stuff by a thing that looks like a cycle helmet. And the little sensors sit in the cycle helmet and once you're in the shielded room, you can move around. Now that's hugely important if you're trying to diagnose children, because you can't easily put a child into one of these big superconducting tunnels, unless you sedate them. So that has already generated a new product and a new company called Cerca Magnetics. They're the only one of our start-up companies that's actually turning a profit at the moment, by the way, okay? And they are selling machines to Great Ormond Street and to SickKids in Toronto and so on. And it's being used by surgeons treating juvenile epilepsy. Now, how about that? So, coming back to your question though, if we're going to build a quantum machine, we've got to inhibit this ability to talk to the environment and make it quieter and quieter. And what that meant is that we had to do much better in terms of the quality of the fabrication of the bits. And it wasn't until about 2015 that we could get that noise level down in such a way that we could be relatively confident we could build a fault-tolerant machine. Now, if you look at a classical machine, it's extraordinarily fault tolerant. You know, you build those error correcting codes in and the ability to actually control what's going on in a chip on a classical machine is superb. We're orders of magnitude away from that at the moment in a quantum machine. So the best machine that exists in terms of doing something only has of the order of a hundred fairly noisy qubits at the moment. But our guess is that we will – and it is an educated guess – is that we will have a machine of substance, of consequence within about a decade.

A decade?

A decade.

Okay. Is Moore's Law working here, or is there something like Moore's Law working here?

There is, wonderfully, a double Moore's Law working to our advantage. The ability to actually build better and better bits, quantum bits, has got a Moore's Law with about an 18-month time, okay? At the same time, the people developing algorithms that are going to run on this thing have become less and less demanding. So there's a negative Moore's Law running on the demand from the algorithm developers. That's why I say it's a double Moore's Law. So I'm reasonably confident that quite soon we'll be able to find ways in which we exploit these noisy intermediate scale machines for doing something in terms of the simulation of things, an optimisation. So some of that is already underway, I reckon, so we're beginning to see something of economic importance quite quickly from those noisy machines. Building a large-scale machine, which is what the press always concentrate on, is harder and that will be a decade away, at least. So people often talk about the fact that a quantum machine will undermine our entire internet security, because at the moment, with TLS and RSA and the rest of it, we're wholly dependent on the inability of a classical machine to conquer what's technically a hard problem, and it's basically factoring. Okay? Checking you've got the right answer is dead easy, it's called multiplication, and it's only polynomially dependent. But the factoring is exponentially dependent on the size of the problem. But a quantum machine changes all that, because there's an algorithm, Shor's algorithm, which shows that you can, with a quantum machine, turn what was an exponentially demanding problem into a polynomially… problem. So, for example, within about ten years we have to assume that everything that we use to secure the internet has to be replaced by something which is immune to a quantum attack.

Okay.

[01:11:00]

And that, I've been working quite a lot on this issue, along with many others, if your best guess for a large-scale quantum machine is a decade away, how long does it take to completely re-engineer all of the things that secure your internet, your cryptographic primitives. And you work out the timescale for that, and it's about a decade. So when do you start working on rolling out quantum safe encryption or post-quantum cryptography, well, you'd better do it about a year or two ago, okay?

So part of our problem space is to work out how we can make quantum resilient or quantum resistant architecture in the internet. And we know in principle how to do it, okay, but it takes a while, you have to stress test it, road test it, you red team, blue team it to make sure that you haven't left any vulnerabilities in and so on. And it's a long process that's underway. The second part of it is to start working with all of the sectors of the economy that depend upon this to make sure that they're alert to the need to be quantum ready. So part of what we've been able to do is build this thing called a quantum readiness programme, where we are talking to the banks and to others and to the data centres and providers to make sure that they have an alertness to what is necessary to engineering this. So, you know, that is a, even though you don't yet have the machines to do that cracking of conventional cryptography, that rollout procedure has to take place. So working with the banks, working with HSBC, for example, or Barclays, they are now all fielding quantum teams to work on what has to be in place to make sure that we have a resilient internet.

You're also working on another technology, which connects to this, because the amount of processing power that will be available from quantum computing is really going to be demanded by AI, is it not?

Right, it is.

And HSBC, Barclays and many other organisations are looking very, very, very seriously at AI. Did you try to or did you sign that letter? The now famous letter?

No, I didn't. Although I am, you know, I think it's worth considering seriously about the dangers of AI. I was in Washington two weeks ago where we had a couple of presentations on the dangers of AI and the ability to, you know, to undermine, if you like, societal responsibility for decision making. And, you know, I am thinking really quite hard about it. By the way, AI and quantum are not alternatives, they could well come together.

Oh yes, yeah.

So quantum machine learning is something of real substance that's worthwhile. The thing about AI is that because you need to develop these large learning sets and then to grind through the whole learning process is that it can actually be quite demanding on power.

Exactly.

A quantum machine may actually supplement parts of those algorithms to say, oh, maybe you don't need to grind it that way, you grind it this way. So the ability of a quantum machine to do stuff in parallel may actually be advantageous in reducing that power demand.

[01:15:00]

How do you get over the problem in AI of the black box? The computation is really unknown to a human being, but the outcome is there.

Well, yes, that's exactly the problem isn't it? The ability to verify that decision making has happened, based on the right sort of inputs and control mechanisms, exactly right. Black boxes are dangerous things. Some of the work that I do concerning defence and national security has an issue with this, by the way. Because, you know, if you apply machine learning to the threat space of people that may be malevolent and you churn through your big database, in principle it's never going to forget any of the inputs. Okay? You can't sunset the data, it's gone into the churn and it's there forever. Some of that information may have been acquired by time-limited warrantry [sp?]. I think we may be seeing a field day for lawyers soon in this sort of space, because you can't disentangle it. And your black box characterisation is exactly right, it is a black box and there's a complete inability to look to see how it did it.

What do you prefer, research or teaching?

Oh. It's not either… I hugely miss teaching. I was enormously enthusiastic about teaching, so it's not either/or, it's and. And uncovering new ways of thinking is often stimulated by doing a course and getting some bright young person say, 'Why is it like that?' Okay? So it's been a joy to teach and I miss it enormously. I paint a rather sad figure, I wander round the department hoping that someone will ask this Emeritus Professor to give a guest lecture.

[laughs] I love teaching, because I just love the engagement with young people. I do miss it tremendously as well, because I was teaching at University of East London on journalism. What are the biggest mistakes you've made in your career?

Oh, biggest mistakes? Biggest mistakes? Let me think. Let me think. I think my biggest mistake was being so single-minded about understanding this whole area that I've been working on the quantum stuff, that to some extent there's been a bit of neglect of family life.

Oh.

Okay? I think my kids, and my wife especially, have been extraordinarily patient with me, but it has been pretty single-minded. So I think my biggest mistake is not to think harder about life balance, to be honest. You know, there are many things that I've done, I think oh, I could have done differently on this or that or the other, but that's the big thing. You know, to be honest, this journey that I've been on has been pretty single-minded. I think that sometimes it would have been great fun to say I'm stepping off the merry-go-round, just for a little while, on things.

Okay. That's a very honest answer and that's been a very honest contribution to the Archives. Thank you so very much, Professor Sir Peter Knight, for your contributions. I said it was going to be interesting and stimulating, and indeed inspiring, and it has been. Thank you very much.

Well, thank you so much for inviting me, it's been great fun.

[end of recording]