LCD Applications

So, have many of you heard about liquid crystal displays before? No? How many have studied physics before? A lot of you haven't studied physics. Okay so, I'll try and leave a lot of mathematics out and I'll try and explain it in English. So today I'm talking about liquid crystal displays, liquid crystal displays, and these are the types of things you find in watches, calculators, mobile phones. So I have a liquid crystal watch, for instance, and maybe some of you have. This computer here, laptop computer, has a screen, this is a liquid crystal screen. I think you've noticed that even during your lifetime, televisions are changing: televisions used to be very large boxes with evacuated tubes – vacuum tubes – inside. And now the valve, or vacuum tube, has been replaced by transistors, switching, and the screen has been replaced by a liquid crystal display. So if you go to many shops now, you'll find not just liquid crystal, but you'll find liquid crystal and plasma technology screens. I'm going to talk today about flat screen, a particular type called liquid crystal. You probably notice when you push this, the numbers and letters change, they distort, and the reason is it contains a liquid. It's actually a little cell made up of two polymer sheets – two plastic sheets – inside of here, and between those sheets is a liquid: a special liquid, called liquid crystal. So, I'm going to talk about this. Now, the way we use liquid crystal is we place it into a cell which is formed from these two sheets, and we apply voltage across it, and that changes the liquid crystal. So we apply a voltage, an electric field, and the liquid crystal is changed by means of that field. And what happens is light can either pass through or not pass through. It's a switch. So we can make a switch so the light can go through – it becomes white – or the light does not go through – it becomes black. So that's all that happens, we cannot make colour, even though there's a colour screen here. The colour is made by some other materials called dyes which are placed inside the liquid crystal. Right, so I'm going to draw a complicated picture on the board now to explain a liquid crystal cell.

Right, it's going to contain many layers. The first layer is going to be glass. So there's the first layer, it's a glass layer, a sheet of glass. It's not any type of glass, it's a fairly flat glass and it's very thin, typically about 0.7mm thick – it's a very thin piece of glass. It doesn't have to be glass: it could be polymer or plastic. But the best quality are made from glass, so I'll talk about glass. And then we take another sheet, which I'll place here, the same – exactly the same – two sheets. This forms a cell. And we fill the cell with liquid crystal. Now, if we just had two sheets side-by-side, they'd touch each other, and there'd be no room for liquid crystal. So we have to hold them apart, by means of spacers. Okay, so we have a spacer here – [...] spacer. Quite often it's a small sphere, a glass or polymer sphere, ball, droplet. It doesn't have to be a sphere, it could be a cylinder. Maybe you know of very small cylinders made of glass – have you come across those? Optical fibres, they're used for telecommunications. So those optical fibres can be placed in here as well and used as spacers. Or even, you can buy sheets of material of a very constant thickness, you cut a small piece out and place it there. When we put two pieces of glass together, they cannot touch. Of course, we need more than one, otherwise we'd have a wedge, so we usually have quite a few of these scattered around. Wherever there is one of these spacers the liquid crystal device will not work as a switch, so they have to be very very small. The next thing we do, is we coat the surface in a special layer which is conductive, this is called electrode. So, an electrode is something which conducts electricity. Sometimes you might have electrodes going into a liquid, in this case we have them going into a liquid because we have liquid crystal in the middle. Electrodes there, one at the bottom. The electrodes are made of some material which conducts. You're probably familiar with metal, metal conducts, so if I put a metal plate here there would be electrodes, but that's not much use because no light goes through a metal plate. Okay, but there's some very special materials which are electrodes and also are transparent. And one of them is called ITO – that's the abbreviation – it stands for Indium Tin Oxide. That's for people doing chemistry. Most people just call it ITO, a transparent conductor. So now we have our conductors, we then coat the surface of the conductors with another material. And it could be a polymer material, and sometimes we deposit it just uniformly, and sometimes we deposit it at an angle. Deposit means, we lay it down. Okay, so we've got a layer. Okay, this is the polymer. And it's a very special polymer, what happens is it aligns the liquid crystal. So liquid crystal [...] liquid crystal consists of very long molecules. So the molecules are quite long. And they tend to fit together in the same direction – they like to lie side-by-side. So in one part of the liquid – liquid crystal the molecules would be like this. In another part they might be like this. And all the different directions. So if I had the bottle of liquid crystal here, it would look like cloudy water. It would be liquid, I could pour it, and it's a cloudy colour. And the reason it's cloudy is because different regions are aligned in different directions and they scatter the light. So when light tries to pass through, it bumps into these different regions and is reflected in different directions. So we take this liquid crystal, and if we put that inside of the cell it would look very cloudy. You couldn't see through very clearly. So what we have to do is we have to force all the molecules to align in the same direction. We do that by altering the surface of the polymer. It's a very easy way to do it, so all you do is you rub it. So you get a cloth, any cloth, and then you just rub the surface like that. It sounds a bit strange. So you can even do it on the glass – you don't have to do it on the polymer, but it's better on the polymer. So you take your polymer and then you rub it. So we have different cloths – obviously this is not much use because there's lots of little bits of dust coming out of it. So we have very special cloths which have no dust, to rub the surface. And we rub this polymer in one direction, like that, and the other polymer we rub in another direction, like that, in that direction. So they're at right-angles. So one polymer is that way and one polymer is that way. So, before I get to that stage I'll just tell you about another case: what happens if you rub them in opposite directions? Okay, so if you take two surfaces and rub them in opposite directions – so this one is rubbed that way and this one is rubbed that way – what happens to the liquid crystal?

It always tries to align to the surface, so at the surface – this is one surface, this is the other surface – the liquid crystal will always try to align like that. At an angle of about two degrees – that's very small – at about two degrees to the surface. So liquid crystal at the surface will all be stuck to the surface like this. And on the other surface exactly the opposite occurs, because we rubbed that in the other direction, so the liquid crystal goes the other way. And because the liquid crystal likes to align to itself, then all the ones in the middle gradually turn around and they align to the ones at the surfaces. So I'll rub these out a little. They tend to twist around until they're all aligned to this. Okay? So what we say is the liquid crystal has some order to it: it's not just a random liquid. If I took water, it's a random liquid. If I take glass, that's also random – completely random. But if I go for the liquid crystal there's some order. And the order is only local, we say: that means, it only applies to the small region around each of the molecules. That region is a little bit like a domain in magnetism, if you've studied that. So it's a small region in which all the molecules are roughly aligned to each other. And we say the direction of alignment is called the Director. So the director is a little vector – a little line – drawn in the direction in which all the molecules are aligned. So I've drawn a lot of directors, not molecules of course becuase molecules are too small, so I've drawn a lot of different directors. If I applied a voltage across that [...] – so these, these are special molecules containing a number of electrons – if I apply a voltage the electrons all go to one end. If I put a big positive charge here and a big negative charge, the electrons which are inside the molecule can move around and they're attracted by the positive charge so this end becomes negative and this end becomes positive. So all the electrons in every little molecule go to one end, the same as the directors, and now we have a special force which occurs which tends to twist this around. Okay, so this tends to be attracted to that, plus is attracted to that, so the whole molecule tends to twist. So inside the material, these twist around – I'll redraw it again to show you what happens. So this is with a voltage, they twist around to that direction. So the electrons go to one end, they're attracted, the least positive charge which is attracted, and the molecule twists, and the director twists, but the surface still has some effect, so very close to the surface they cannot twist, only in the middle they can twist. So there's a certain amount of grading as you go through the cell. So this end, they're slanted due to the surface rubbing – surface alignment – and as you go through they become vertical and they go back. So I'll just draw the two cases, I'll draw the other case over here. So this is no voltage. This has a voltage. Okay, so those are two cases. So, in fact, inside your watch or inside your calculator or your television, the liquid is actually turning round, the molecules are turning. And they turn quite regularly, they're affected by the viscosity – thickness – of the material, how difficult it is to pour it, how viscous it is. And this also affects light. So how does it affect light? Okay, there's a phenomenon which you might not have come across and it's called polarisation. So, if I write this somewhere. So this is called polarisation. Lots of words we have in English have different spellings in American – it's a z in the American – American English. So, we have this phenomenon called polarisation, what it means is: when light travels along, it travels as a wave. So light travels like this as a wave. And it can travel the way I've just drawn it, up and down, or it can travel from side to side. So there's two different types of light, you can think about it. What we say is, light is polarised in the vertical direction if it's doing this – and it's polarised in the horizontal direction if it's doing that. Think of it as two different types of light, if you like. Actually you can change one to the other quite easily. So light is either aligned vertically or horizontally. So light coming from these lights at random has an equal amount of horizontal and vertical, but the light coming out of my computer is completely polarised – it only has one polarisation. It only has one of these, it's very special light. Most of the time you don't notice it: your eyes cannot detect polarisation. Some animals' eyes can detect polarisation, but your eyes can't. If you had special sunglasses called polarised sunglasses, then you would be able to see this. You'd notice this because it'd look black – one eye would see this black, one eye would see it correctly. So that's something called polarisation. And we can put something here in front of it which is like a special filter, it allows through some polarisations but not other ones. So this one can go through and the other one, which I'll just draw as dots, can't go through. So it's called a polariser. Okay, so if I took my room light, passed it through a special crystal or polymer sheet, it becomes polarised. So now we go back to this diagram here, and we'll see what happens. And if I pass light through this, if the light is polarised from side to side, in other words like that, it goes through very nicely. If light is polarised the other way then the light travels very slowly through the material. So the speed is affected. So now we go on to the display – go back to the display. And you notice the top surface was rubbed in one direction; the bottom surface was rubbed at right angles. So there's actually a twist in the liquid crystal. So the liquid crystal here is like that, as you go down it twists and twists and twists 'til it's aligned that way at the bottom. So you can have more than one twist if you want, or super-twist. But usually it's just 90 degrees – a right angle. And what happens when you put polarised light through that? Okay, so polarised light – let's use a different colour – polarised light, let's say, is polarised this way into the board. And it comes upwards. As it comes up it meets this liquid crystal polymer, this director – I'll just draw it like this, but you know what that means, that means twist – it means it's twisted. So polarisation comes in and it's also twisted – it's twisted by the liquid crystal. That's the effect of the liquid crystal: liquid crystal twists the polarisation of light. So this one goes in and what comes out is that. Now, what happens if I apply a voltage to my electrodes? So between my electrodes I apply a voltage – not much, just a few volts, 3 volts, you know, just from a very small battery, you don't need a big power supply. Just a small battery, you apply a small voltage, and this changes so instead of looking like that what happens is it begins to look like this. Of course, at the surface there's some funny effect. So this is with the voltage, and this is no voltage. So now you notice I've divided it up into sections. So that's usually what we do, we divide it up into sections and we apply different voltages on different parts. And each section is given a name: it's called a pixel. Pixel: a picture element. So these are all technical words to do with displays. So in this region here there's no voltage; here there's voltage. So in this region here the light goes through, it twists, because the liquid crystal is twisted, and it comes out polarised the opposite direction. Now what happens in this case? So light goes into that region polarised the same way, but it's not affected by the liquid crystal and it comes out exactly the same. So what the liquid crystal is is a switch: it switches the polarisation. So it switches it either one way or the other way ninety degrees.

So that's part of the story. The next part of the story is this one, okay. We now take a polariser and we place the polariser on here. So the polariser is going to go here, at the bottom. Now, what will that do? The polariser at the bottom, what will that do? It takes light which has all polarisations and it just allows through – what? So this polariser here will just allow through that polarisation, even though the input might have every polarisation. So that gives me what I wanted. So here I had two different polarisations, but now I only have one. Do you see that? So this green layer is that polariser, and light comes from two different polarisations, and only one of them gets through. So that green layer just does what I want it to do, I want it to pass one polarisation. But there's another layer up here – two layers – so I put my other layer here. Now this layer, this green layer, had a certain alignment direction, it was aligned to let through that polarisation. But the one at the top is going to be twisted 90 degrees. So the polariser at the top only allows through that polarisation, because I've twisted my polariser – it's a sheet of polymer, or crystal. Yep? So, the light comes in here, goes through, twists in the liquid crystal, and comes out. That's fine, perfectly okay. Let's take the next pixel, this pixel has a voltage. The light goes in, does not twist through the liquid crystal and is blocked by the polariser. This is blocking. That's how we change a polarisation switch into a black and white switch. So liquid crystal really only switches polarisation but when we put polarisers on the front on the bottom and the top we can make it turn into a black and white switch, so it gives black regions and white regions. So we can turn this round again. So this region up here is black, that means the light is going through with one polarisation and is being blocked by the polariser which is on the front. The front of this has a polariser, and the back also.

Okay, any – well, I'll put all questions at the end. Okay, so the next stage is to say, how do we get the light into this? So we've made a liquid crstal cell, and if we make pixels we can apply voltages to each pixel separately so we can have little black and white squares. The squares are very small so – if I draw it over here. So, it's made up of lots of small squares, these squares are very very tiny – 100 microns in size, they can be as small as 11 microns. So do you know micron? No, no, okay. So what this means is a small fraction of a metre, it means a millionth of a metre. So, micron is the same as saying one divided by a million of a metre. Very very tiny. Okay, so how are we going to get the light in? I've got a slide here which I drew before so I'll show you this. So, light comes in in this way. And all of this here is inside this layer. So it's all to do with layers. I've described the liquid crystal device itself with many layers. Now I'm going to describe the structure around it which gets the light in. So, here we have normal light; over there we have fluorescent tubes. So, do you understand fluorescent tubes? You've seen those? So, a fluorescent tube is a very long cylinder of glass. It has a gas inside – a mixture of two gases, mercury and argon, different gases inside. You apply an electrode at one end – the same type of electrode again if you want – and an electrode at the other end, in this case you apply quite a high voltage. It's not like a liquid crystal display, you might need quite a high voltage. And what happens is the light turns into – sorry, the gas inside there – turns into a material which emits light. But the light you cannot see. The light is invisible and it comes out and it's called ultra – ultraviolet, abbreviated to UV. So this is a type of light and it comes out of this fluorescent tube. And of course that would be of no use to us because our eyes cannot see that either. Our eyes cannot see polarisation and they cannot see ultraviolet. So we need something to convert that into light we can see. And there are certain chemicals which are called fluorescent – fluorescent materials. And some fluorescent materials – well, here's some – here's a fluorescent material, I shine ultraviolet light and this material will emit red light. Okay, so it's a kind of chemical that converts ultraviolet light which you cannot see into red light which you can see. And you can get other materials where you put ultraviolet light in and you get green light out, and other materials where you put ultraviolet light in and you get blue light out. Okay, so what colour light do you want? You can choose: by choosing your chemicals and mixing them together you can choose the colour. So if you have an equal amount of red, green and blue, you get white. So these lights are not emitting white light, they're emitting red, green and blue but it looks like white light to your eye. When you mix red, green and blue light together in your eye your eye sees it as being white light. Okay, so we have one of these tubes in here. So, there's my laptop and inside the laptop is a fluorescent tube. Now, we don't have to have fluorescent tubes, we could have other ways of generating light. We could have a laser. A laser's not a good idea because it would come through into your eyes and damage your eyes. We could use a light emitting diode. There is some work at the moment on replacing fluorescent tubes by light emitting diodes. So light emitting diodes, the type of things you – well, these little green lights down here are light emitting diodes, you must have them in your mobile phones. So, I'm just going to talk about the fluorescent tube, this is the most common. Why's it the most common? Because it's very efficient. Well, I say very efficient, but now I'm going to explain why the overall structure of this is not very efficient, okay. The fluorescent tube is efficient alone, but somehow the light has to get from that fluorescent tube, and go behind the display and come through the display to your eye. And in that process a lot of energy's lost. So, I'll just explain that now. [...] So this circle here is the fluorescent tube. This part here's what I drew on the board, this is the liquid crystal cell. There are the spacers. Here we have our polymer layer, which I've called polyamide in this case, it's one type of polymer. Sometimes it's separated from the ITO – this is the ITO, indium tin oxide, which is the conductor, the electrode. Sometimes we separate it by another layer just to stop them damaging each other, [...], I did mention that. Coming down to here, we take our fluorescent tube, and then at Christmas some of you might have cooked some bird, some chicken and wrapped it in some aluminium foil, yes? – okay, so we just take some aluminium foil, cut it out and put it round. It's actually that simple, if you open up one of these you'll see the aluminium foil. So, it's aluminium foil, it's acting as a reflector because all the light going this way is wasted otherwise. So we put that round, and the light is reflected into this – this kind of wedge. This is made out of, again, glass or polymer. And the light goes in, bounces around and usually doesn't come out unless you ruffle the surface. So there's two ways of ruffling the surface, you can either ruffle the top, or you can ruffle the bottom. It doesn't matter, in either case the light will come out. So you take a piece of glass, you shine light through it – you can try it yourself: if you hold a piece of glass, hold it up, let sunlight come through, it wouldn’t come out the side unless you scratched the side or ruffled it in some way. Sometimes people paint dots on the surface. So these could be rough regions, or they could be painted regions or scattering dots. So the light bounces around. One important thing to think about is that the light needs to be uniform in the display. And if these dots were uniform, then the light coming out would not be uniform. And the reason for that is because the light is scattered out – only a certain percentage of the light is scattered out, so a fraction of the light is scattered out. At this end there’s a lot of light, so quite a lot of light comes out. This end, there’s not much light, because most of it has come out, so the light coming out here is quite dim. So to get uniformity, what we have to do is to have stronger dots here, or more dots, or a rougher surface here to scatter more light, and these dots have not quite so much roughness. Another trick we use, is we vary the thickness. So here we have a very thick plate of polymer. That means light density is very low so not much light comes out. And over here, we compress the light by squeezing it in the thickness, and therefore we get more light coming out. Okay, having done that, the light is still not very uniform: if I looked at this I would see the dots. So we have a special material here called a diffuser. We can make diffusers out of polymer. I don’t know [...]. You can make it out of diffuser or you can make it out of holographic material. This is a piece of diffuser material, it looks like a cloudy piece of polymer. And you probably can’t see it – I don’t know if you’ll be able to see this, let’s try it. So this is a laser beam going through a piece of diffuser – can you see the light? So the light is spread more horizontally than vertically. So there’s my laser spot, I put it through here, light spreads more in the horizontal direction. And if I twist it this way it’s spread the other way. So this is a clever kind of diffuser called a holographic diffuser, and what it does, is it spreads the light in more than one direction. Now, why do you want to do that? Well, to go back to this – when you’re looking at this you tend to be standing here or here or here, you don’t tend to be standing here. Yeah? So if you scatter the light – and you’re not laying your head on the keyboard, are you? – so, if you spread the light in all directions you’re wasting some of it. You’re throwing some light towards the ceiling, which is a waste. So what we do instead is we have a diffuser which spreads light horizontally so you can see all it [...]. That’s a diffuser. Okay, the next layer are these two layers of very small prisms. So a prism is a small – usually polymer or glass – a small triangular shape. I’ll draw it on the board again. So we have a prism which is that kind of shape. [...] What’s the purpose of a prism? The purpose of the prism is to try and get all the light to come almost out of the front of the display. So we use a word called collimation. Collimation means if the light is spread over a very large region, this device will tend to squeeze it so it’s generally roughly in the same direction. So you can’t make rays perfectly straight if it’s coming from fluorescent light, so you can only roughly do it. So it’s called collimation, and this will only collimate the light in one direction. So if you want to collimate it in two directions you need an array of these one way and an array the other way. So these are special films, called brightness enhancement films – brightness enhancement films. And this is one array of prisms – not very well drawn – that’s another array of prisms, then we have the structures I talked about: polariser, the glass, some pixels, some different separating electrodes, okay, and all the way through, all the way through to glass at the other side. But there’s this very special layer here: this is to give a colour display. What we do is we have different pixels and each pixel just gives black or white, it’s a switch. So to make it give a colour, we have to paint it. So each pixel is painted, and one is painted red, the next one green, the next one blue. It’s just that simple. We don’t have a single pixel which can change colour, all we have is we have a red pixel and a green pixel and a blue pixel. And by turning them on or off by different amounts, we can change the colour. If you turn them all on, it looks like white. This looks like white to you. It’s not white: if you come and look very closely you can actually see the red, green and blue pixels here. They’re not caused by that; they’re caused by that, ‘cause that also has the same thing in – a liquid crystal display. And then, coming out of that, we have, of course, our polariser and then we come out. So it’s very – very complicated multi-layer sandwich. So this has been around for quite a while and people have been working on it and trying to improve things. And one of the main things we want to improve is the efficiency of getting light from here to the viewer. So let’s just talk about that efficiency for a short time. The light from the fluorescent tube – the ultra-violet light – does not all get converted into visible light. So, this process is not perfect. The conversion is not perfect so we lose some energy, which causes heat. The light does not all couple into this polymer slab, or sheet, so some light is lost at that point. Light is scattered downwards as much as scattered upwards. So we can overcome that, we put a mirror at the back. We put a mirror at the back. Any light going down is scattered back up. Okay, so we come through here, the polariser throws away – the polariser throws away half of the light. Because the light coming into the polariser is polarised in two directions, and one is totally removed and thrown away. So we lose half the light. That’s very inefficient, yes? So the polariser throws away half the light, and of the light which gets through – let’s say the green filter – the green filter lets through green light and stops the red and the blue. So the green filter throws away two thirds of the light. So when you multiply those two together: fifty percent through the polariser and only a third is getting through the colour filters, then you can see it’s very inefficient. So people are trying to develop new ways of doing this, and they’re using red, green and blue light-emitting diodes instead of using fluorescent tubes. This is quite new work, and it’s being carried out all over the world. And what they try and do, is they try and take the red light and focus it only through the red pixels, and the green light just through the green pixels and the blue light just through the blue pixels. And that can actually be done. And if you do that you don’t need to have those colour filters. Because all the blue light is not – you don’t lose any of it after the polariser. So people are now working on polarisers and trying to see if they can make polarised light come out of the LED – light-emitting diode – and go up through here.

So, I’ll stop at that point. We’ve got about ten minutes for questions. I’ve covered quite a lot. I’ve talked about the liquid crystal itself; the structure of the cell – alone the cell doesn’t really do very much because it only changes the polarisation of light and you can’t see that. So you need to have the polarisers to turn it black and white. But then to make a real system such as this display or a television, you need to have all these extra layers: to put the light in, and to colour it, and then it comes out and makes an image. So, over to you. Who’d like to ask the first question? Okay, yes.

How do we [...]? So I don’t think I fully followed the question, but the idea is that you take white light and separate it into red, green and blue. And the red, green and blue comes into your eye and is mixed together in your eye and you see a colour.

[question] [...] Our eyes can’t see polarisation.

No, you can’t see polarisation and you can’t see ultraviolet.

[question] I just want to ask, what is the final [...]

Right, so if I understand you then the fluorescent tube is emitting ultraviolet light, it’s converted into visible by means of some chemicals. You paint the surface with the chemicals – you make the red, green and blue converting chemicals, you paint it on the inside of the tube and those fluorescent tubes have it and it looks white to our eyes; actually it’s red, green and blue. Our eyes have sensors, they can sense – inside your eye you have cells which sense red – the difference between red and green, for example, your sensors inside your eye.

[question] [...]

[...] You’re not from this field. No, no – it’s quite a big field, but it goes into biology if you start thinking about your eye. Or chemistry if you start thinking liquid crystal.

Any other questions? Okay, well I’ll just tell you a bit more then. No, any questions? Yes...

[question] You mention different countries are developing – which are the main countries which are developing screens?

Okay, very good question. So, who’s working on this type of thing? Alright. So, some of the original work on liquid crystal, going back into history a little bit, was carried out in England in a place called RSRE – RSRE, the Royal Systems and Radar Establishment, based at Malvern. And they developed many different types of liquid crystals: there’s not just one type, there’s many types. And one of the main companies that make this is a company now called Merck. Probably you’ve heard of that company; it’s been in the news. They make pharmaceuticals as well. So we have companies making the liquid crystal itself, in different countries. Merck’s one of them. And liquid crystal’s being researched into at a university in England called Hull University. And they make new types of liquid crystals. Because if you can make liquid crystals which turn around much faster, you can make faster displays. That’s one thing. That’s the area of liquid crystals. The area of the display – this display, a lot of work has been carried out on that in Japan – that’s the main place. Many companies have worked on this, one of the biggest is maybe Sharp. Sharp has a base in Oxford in a research laboratory there. And they’re still working on these displays, trying to make faster ones, bigger ones. At the moment the trend is to make large ones to try to cover the wall of your house with a single television screen. So that’s one aim. Other companies are looking at making mobile displays that look like pieces of paper. So it’s a display, you plug it into the wall, input data, download a book, and you can carry it around and it looks like a newspaper maybe – it’s black, it’s only black and white – and you look at it and you can read books and turn the – press a button and turn the page. It requires very very little power, [...]. So as I say, a lot of the work’s in Japan, but it’s now changing, it’s moving towards Korea. And recently there’s been really a massive move from Japan towards Korea. Samsung is one of the companies. LG, another company. So, I think Sharp is still making these displays but they’re making very specialist ones. So, if you know some of the – Nintendo Gameboy, you’ve seen that? – the display’s a Sharp display. Sharp are making some very interesting displays – three dimensional displays. So they make a laptop computer and you press a button and it becomes a three dimensional display. You can actually see through it. Another company that’s doing this is Phillips: Phillips in The Netherlands. So Phillips is the main European company making displays, and they’ve just made a new type of display, and again it’s a little bit like the Sharp one: you press the button and it becomes three-dimensional. They’re using something that I invented to do that. So I’m very pleased about that. It hasn’t yet come out, you can’t buy that. So, which other companies and counties? Oh, backlights. Backlights, all this area – all this – is being made by different companies. This one here is made by 3M – a company called 3M – they make polymer films of different types, they can make the micro-prisms. And this thing at the back is constructed – you put together many layers, and again Korea’s doing a lot, Taiwan’s doing a lot. I think probably the main – most of the work is in Taiwan, in fact. I guess as time goes on, all of this will pass into China. I expect – that’s just my expectation, that most of these displays will probably end up being manufactured in China, [...] and the backlights will be configured together and assembled in China. Does that cover all your countries? No?

[question] [...] radiation [...]

Radiation. Right, okay. So if you take a normal television. [...] So here’s a – here’s a normal television. We have a tube which is evacuated, it’s a vacuum. At the back of the television there’s a gun, not a normal type of gun: it’s called an electron gun. So we have the electron [...]. That fires a beam of electrons, and when the electrons are slowed down very quickly it generates radiation. So electrons are slowed down very quickly and fall onto a special layer. This layer is the same as I drew before, it converts the energy of the electrons into red, green and blue. But also you can get other things coming out, so you end up with red, green, blue and maybe some x-rays, and more dangerous radiation, even heat. Many years ago when computers were just developing, people made screens and they were very inefficient and they generated a lot of heat.

And when you sat in front of the screens the front of your eye would dry out. Extremely painful – you try to shut your eyelid on top of your eye, but there's no liquid there. But that's now improved so heat's not so serious. Then people began to worry about the x-rays, and they put other layers on the front to try and block the x-rays. So again that's – they're now safer. So, no radiation. Let's talk about this case. What's happening here is light is coming through and so the light comes through and the only radiation we have is light, we don't get x-rays, we don't get anything else. Maybe when you're at high voltages to your electrodes you get a little bit of electromagnetic interference. But the voltage is very small, it's only about three volts, so it's not very serious. Another thing is, if you look at these screens, they – these are called Cathode Ray Tubes, normally abbreviated as Cathode Ray Tube, the old type of television. If you look at it very closely the image is moving, and it can be moving in all sorts of different directions, it can be expanding and also going from side-to-side. And if your eyes are watching that it's very very tiring. If you watch that for hours and hours and hours you'll get very tired and you won't know why, because the movement's so tiny you can't – your eyes are trying to track it. In this case, the pixels are fixed, they're cannot move because they're formed in exactly in the right place, they cannot move. So it should be less tiring for your eyes. I don't think anyone's done those psychological tests yet, I expect they will do after people have televisions in their homes [...].

The next development beyond that is to make flexible displays. So what they're trying to do is make it really like a piece of paper that you can – well, not fold up, but you can roll up and put into your bag. And you can unroll it over the whole wall like wallpaper. And so some people are working on liquid crystal flexible substrates instead of the glass [...]. Some people are working on flexible backlights. Not many people are working on designs of new backlights, there's really a – there's really a need to try and make very efficient new backlights, but there aren't enough people working on it. It not exciting enough. The liquid crystal device is exciting 'cause it switches light on and off. The backlight doesn't do that, it just diverts light. So not many people are working on the backlight, there's room for plenty of new inventions in the backlight. Any other questions?

[question] what kind of liquid [...]

What kind of liquid? Okay, so there's many types of liquid crystal. So one type of liquid is called Nematic, another one called Smectic, another one called Ferroelectric. You can have Smectic A, Smectic C. So these are all different types of liquid crystal, we can have Lyotropic and Thermo. They're just some names. This one's affected by temperature, yeah? In fact, if you look inside your own bodies; if some of you are biologists, if you look at your cells through microscopes, your body is made from liquid crystals. Your cells are actually made from a material which is liquid crystal. And that's really where liquid crystals was first discovered. We don't take people and mince them up and make liquid crystal, we actually form the liquid crstal by proper chemical means, organic chemistry. This type of liquid crystal has molecules with fixed charges, so one end is always plus and the other one's always minus, so this is not used in displays. This is the one I've talked about today. It's called Nematic. So if you wanted to be very – very correct, you'd call it a Twisted Nematic Liquid Crystal Display. Twisted Nematic. But remember it only has one twist, there are other people working on two twists and three twists. Supertwist. Any other questions? Yes?

[question] [...]

Ah, okay, alright. For making a very big display on the wall, you don't tend to sit very close to it. If you have a very large display – if this was the display, if I stood here I can't see anything. So you tend to stand a long way back, and when you stand back that means there's no point having very small pixels. It's hard work making small pixels, so you might as well make larger pixels. If you're making a special display that's in your glasses – some of you are wearing spectacles, glasses – some people are making liquid crystal displays you put there in front of your eye. Then you have very very small pixels. And another type of display is one that projects the image on your retina, so you can actually have special projectors that project – similar to that one's projecting on the screen – you get some projectors that project into your eye and form an image on your retina at the back of your eye. And they've got to have very very tiny pixels. The pixels have to be the same size as the cells in your eye that's detecting the light, at least that's the smallest size the pixel wants to be.

Oh, one other thing I can tell you is there are people now also working on – working on the front of the display. There are special films you can stick on the front of the display that stop reflections. So if you look at a display in sunlight sometimes you can't see it very well. I mean, maybe you can't see this either because I've got the room lights on. But you can actually make special films you put on these screens and also on liquid crystal screens and it stops reflections so you can see very clearly. So the whole thing – you need to get the idea that the whole thing is a whole series of different layers, different polymer materials, quite complicated optical procedures, dealing with polarisation and colour. And finally you end up with something that you're all used to looking at: some kind of television or liquid crystal screen, say in your watch. Some of the lights come from behind, [...]; some of the lights come from the front. You don't have to have a light in the back. If I took this light here and I took it out and I turned it over and put it on the front then it would work just the same in the opposite direction. If I put a reflector at the back, what would happen is that the light would go through, bounce off the reflector and come back. And that's called a frontlight. So some watches and mobile phones have frontlights instead of backlights. And some of them don't have any lights: they use sunlight. So sometimes you don't have a light at all, you just have a mirror, and the sunlight comes in and reflects and you can see your watch. Obviously it's no use at night, you have to have a light at night.Okay, so I think I'll stop there and if anybody wants to ask a question, come up to the front. Thankyou.