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We have reached the point beyond which the questions as to whether everything is 'makable' should in fact be made and whether everything we can change should be changed become increasingly pertinent. Controlling the weather is a case in point.

Technology makers, those who engender technology, are potentially powerful people. If they use their power, they become technocrats. Powerful people indeed ... In our democratic society it is only natural that we should desire to control the power of potential technocrats. The proliferation of discussions on the social relevance of research and development within the world of scientists and engineers is evidence that this desire is not restricted to the non-scientific, more politically orientated sectors of society.

Discussions on the subject are getting under way at the universities and in private corporate research and development institutes, so I think it was a good idea of the organisers of this congress to arrange for a panel discussion on your very special responsibilities towards society. I am sure the discussions will make a positive contribution to our thinking and will help us to mould our ideas on the subject.

I hope you will have a very successful congress indeed.

I now have the honour to declare the European Conference on Electrotechnics open.

Technology for the future [1])

by H. B. G. Casimir

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The conference we are opening today reflects the enormous width of the field of electrical and electronic engineering, as well as the depth of it details. A mere glance at the printed program should be sufficient to convince us of this.

Therefore it would be futile if I were to try in this opening address to really introduce the subject matter that will be dealt with in the course of these days. I will restrict myself to some general considerations.

I have chosen as a title technology for the future and this brings to mind the old saying that predicting is always difficult, but in particular predicting the future. This is not just a silly crack: it is a useful reminder that, when looking at the past, we may believe that we understand why things happened the way they did; we feel that we might have predicted the past – but this does not mean that we can predict the future with any degree of certainty. And so I will begin with a few historical remarks.

Electrical and electronic engineering is the primary and still the most important example of a technology that is science-based or perhaps rather science-originated. Architecture, mechanical engineering, windmill design and shipbuilding had already reached quite a high level as empirical crafts before the basic principles underlying these crafts were well understood, and practical engineers must have had a great many useful rules of thumb before a really quantitative treatment became possible. There was also quite a bit of chemical and metallurgical industry before the principles of chemistry were established.

Thermodynamics was created, the general notions of energy and of entropy were introduced, at least partly in order to understand the principles of operation and the limitations of thermal engines.

The case of electrical engineering was entirely different. Here, for the first time in history and through more than a century, observations and discoveries by physicists and physical theory preceded any type of engineering. There were no useful electric batteries before the work of Volta. No electric motors before Ørsted had observed that an electric current produced by a battery exerts a force on a magnet and vice versa. No dynamos were in existence prior to the discovery of electromagnetic induction. Maxwell's theory preceded the discovery of electromagnetic waves by Heinrich Hertz and it was several years after that, that these waves were applied by Marconi.

The notion of electrons was introduced by several theoreticians, foremost among them H. A. Lorentz, and their existence was established experimentally by J. J. Thomson. The first thermionic valves came soon after that ... but of course, the discovery of the electron came first. No entirely satisfactory theory of the conduction of electricity in metals was possible before quantum mechanics had been formulated. After the great breakthrough around 1925 it took only a few years to work out such a theory – at least, in principle: one is even today busily working on refinements. This gave rise to the notion of holes in energy bands, which in turn some 20 years later led to the discovery of hole injection into n-type Germanium and to the invention of the transistor. The laser, which is probably going to play an increasingly important role in telecommunications, is based on Einstein's ideas on emission and absorption of radiation from 1917, on notions on inversely populated energy levels, and, of course, on the beautiful basic work of Townes.

An interesting feature is, that not only did the work of physicists precede technical applications but they were entirely unaware of the technical consequences their work might have. This is of importance in connection with discussions on the social and economic relevance of research, a theme that is quite fashionable these days, although there are some doubts as to its social and economic relevance.

Now electricity is no longer unique in this respect: nuclear engineering is obviously in the same class. And it should also be pointed out that in other, older, branches of technology the situation today is not too different although the historical development was. Thermodynamics may have been created after the introduction of steam-engines but today no designer in his right mind would build a major thermal engine without a thorough theoretical study based on thermodynamics, hydrodynamics and so on. It is similar in other subjects. Windmills and sailing boats may have been built for ages and theoretical aerodynamics may not have been the strongest point of the brother Wright, but the design of a modern aircraft depends definitely on a very advanced knowledge of aerodynamics – and of quite a number of other things besides. Whereas there is also a lot empiricism, of practical tricks and of that hard-to-define but undeniably existing thing called experience in electrical engineering.

[1]) Vortrag, gehalten am 22. April 1974 anlässlich der Eröffnungssitzung der Eurocon '74 in Amsterdam.

Before we go any further, let us point out that if electrical engineering owes its very existence to physical science it has amply repaid its debt. As a matter of fact, later progress in physics was highly dependent on the technical tools made available by the electrical industries. The rapid progress in nuclear physics in the thirties, for instance, depended at least in part on the availability of electronic valves and on advances in high voltage engineering. Much of our present day knowledge on the structure of matter and of complicated molecules could hardly have been obtained without the use of large digital computers. Also in this respect electrical engineering is not unique, but we can agree that it offers the most striking example of what we call the science-technology spiral.

This particular origin of electrical technology is still making itself felt in the attitude of the electrical and electronic engineer, in his willingness to look at new phenomena in the hope that he may be able to harness them for technical purposes, in his ability to deal with complicated mathematics.

But now about the future. Let us first have a look at expectations of technical and scientific advances. Will the glorious pageant of new and ever more surprising discoveries in physics continue to be the vanguard of a host of revolutionary new realizations? There are some arguments against.

Physics is certainly not a closed subject. Such an idea has been put forward at various times. Zeeman once said that in his youth many people had discouraged him to study physics: they claimed that that was a closed subject and that nothing really new was to be discovered. That must have been in the eighteen eighties and the attitude may well seem surprising to us. Yet there was some truth in the statement: the principles of classical macroscopic theory were well established. Now in a similar way it may be said that that part of physics that is relevant for electrical and electronic engineering is 'closed'; it is closed in the sense that one does not expect drastic changes in theoretical description, nor entirely new phenomena. And therefore we do not expect anything as new as the electron in 1900, anything as spectacular as superconductivity (discovered in 1913), anything as useful and influential as the transistor.

But we could see advances principally along the following lines.

a) Besides the solids we know at present we shall certainly study others and specifically 'non-existing' or 'impossible' substances. That is, substances, structures, that cannot be made by 'normal' or conventional methods and that are not really stable although they may have a very long life. Layer structures that might be prepared by evaporation or by ion implantation are cases in point. There is some consensus of opinion that if superconductors at higher temperatures can be found it will be among structures of this kind. Unless they would be found in organic molecules.

b) As a matter of fact the electronic properties of macromolecules have been insufficiently investigated and rather surprising properties may yet turn up. A wishful dream is that one will some day find a diamagnetic plastic; a plastic with a μ of about 0. Not quite so useful as a superconductor, but still nice stuff to have.

c) Devices in the range of dimensions between atomic and macroscopic. At present the structures we make are not smaller than the wave-length of light, but living nature plays its games in structures of much smaller dimensions. There is no reason to suppose that we will meet with entirely new types of force, entirely new laws of nature in that region. That would be surprising: quantum mechanics and quantum electrodynamics work fine for atomic quantities and classical theory, which is just a limiting case, is satisfactory for larger objects.

No reason to suppose the theory would fail in the transition range. But yet the transition region may be a rewarding field with plenty of surprises, because the relative order of magnitude of various quantities and forces is different from what we are accustomed to.

d) We can certainly expect continuation of the trend to use lightwaves in a way quite similar to the way in which we use radiowaves – from the point of view of the electronic engineer that is the gist of the laser.

After having in this way provided some relief of the tedious gloom of my original statement, I yet want to assert that in my opinion the break-throughs of the coming years will not be triggered by new physics. Now, does that mean that there will be no surprises at all? By no means. Surprising new developments in painting were not dependent on new or other new ingredients. Nor is new architecture necessarily the result of new methods and materials (although, for instance, the use of prestressed concrete has given rise to new architectural forms).

I expect that in electronics it will be the painting rather than the palette that will change. The most striking new realizations will consist in surprising and original combinations of a choice out of the almost inexhaustible store of possibilities of todays electronics. I am inclined to believe that the days when a new memory device could lead to a new line of computers are over and though new memory device remain most welcome, yet, if the design of computers is going to be changed in a radical way, it will be because of new ideas on their organization.

'Do you mean to say that the honeymoon is over?' someone asked me quite a few years ago, when I put forward similar considerations at a conference on electronic devices. I answered: 'Yes, perhaps, but it is after the honeymoon that you should start raising a family.'

We may also say that in the future the emphasis will be increasingly on the systems aspect, on the system engineering. Those who know me well will be astonished to hear me say so, for I must confess to a thorough dislike of the hackneyed and fashionable word system. Today it seems imperative to deal in systems and before you know, a perfectly sound plumper is installing sanitary systems. I have not yet seen the combination of a glass of water, a tube of toothpaste, a tooth-brush and, possibly, a few tooth-picks advertised as a dental maintenance system, but this may come any day. Do we really need the word system in order to show that we understand that any apparatus is on the one hand a combination of many components whereas it has on the other hand to perform a certain function in the context of a larger aggregate? If a manufacturer of equipment decides to change his name and claims he is providing systems does this not suggest that he did not know what he was doing in the first place and therefore probably still does not know what he is doing? This may be an unjust accusation: others may not have my particular linguistic allergies. But I just wanted to show my old friends that I have not changed too much.

And so: systems and systems engineering, the Oxford dictionary defines: 'a group, set or aggregate of artificial objects or appliances arranged or organized for some special purpose', and who could find fault with that? And if we meet with cases where the interplay and interdependence between components is more complicated than the action of each of the components, then this situation can well be characterized by saying that we must pay special attention to the systems aspect. This systems aspect involves taking into account the interaction with the outside world: in systems design we are rarely dealing with a closed system.

And so we arrive at the conclusion that the scientific and technical development itself leads us into the situation where the future will be determined less by the progress of basic science and more by the requirements of our society as a whole.

But at the same time this very point is also coming to the fore in a quite different way. There is especially among the younger generation a profound distrust of science-based technology and of technology-supported science. There is a lack of confidence in the powers, that are a disgust with our spendthrift society, a moral indignation over the abusive uses of technology. And in the background there is a strong feeling of impending disaster of inexorably approaching catastrophe. There is emerging a kind of technical eschatology, that is a science of the ultimate fate of man, and the Meadows report the various nuclear war prophecies and perhaps even Brave New World may be said to be chapters of its apocalypse. This being so, there are also strong *human* reasons to look at technology not only from the point of view of the scientifically possible, but to regard it as an essential part of our society.

But as soon as the scientist has arrived at this conclusion he loses whatever certainty of judgement he may have possessed. He may be able to write down the energy-momentum tensor for matter in an electromagnetic field, he may know thermodynamics and be conversant with the derivation of the laws of thermodynamics by statistical mechanics. From a technical and scientific point of view he knows what he is talking about, whereas an economist or a politician usually does not. But this fact does not provide him with a marked advantage over economists and politicians when it comes to taking decisions on such matters as the desirable growth of energy production, the justifiability of working or refined electronic devices for purposes of war, or the threats to human privacy, dignity, freedom that may be inherent in computerization. So I am in a quandary: you expect me to make some remarks on these general questions but at the same time it can hardly be your wish that a professional lecture should end as a lay sermon, and still less that it should turn out to be a piece of political campaigning.

All the same, I shall take the risk and embark upon some general consideration of which I hope that they are of some relevance for the future, although they do not in any way answer the most important questions.

First of all, we cannot do away with technology, there is no return possible, in any case not without complete destruction of our civilization and the death of a very large percentage of our population. Certainly, writers have time and time again indulged in inventing pastoral Utopias but although in their imagination they may be Eutopias with Eu, that is good places, they are very definitely Utopias with U, that is lands that are nowhere. My apologies for this pun. Fowler's Modern English Usage warns against worn-out humour and this pun dates from 1516. It is characteristic that the most remarkable pastoral utopia I know, Robert Graves' Seven Days in New Crete, states specifically that here we have a small civilization that has somehow managed to escape radioactive rains, etc. Incidentally one of the laudable practices described in that book – a book that is not as well known as it ought to be – has to do with the recording of the work of poets. A poet gets at the beginning of his career ten silver plates and one golden plate in which he can engrave his work, and that is all; the rest he may write in the sand on the beach to be washed away by the next tide. Sometimes it seems to me that a similar practice might usefully be applied to young physicists and engineers. Excuse the digression. What I was saying was, that we cannot conserve anything like our present civilization without technology. Let me read a passage from a book that *does* present a kind of blueprint for a political future: '... not the arrest or reduction of technical progress, but the elimination of those of its features which perpetuate man's subjection to the apparatus and the intensification of the struggle for existence – to work harder in order to get more of the merchandise that has to be sold. In other words, electrification indeed, and all the technical devices which alleviate and protect life, all the mechanization which frees human energy and time ...'. The passage is from Marcuse's Essay on liberation and I do not think we can suspect this author to have excessive sympathies for modern industrial enterprises.

My second point is that we have to worry about waste. This remains true even if we admit that some statements may be over-pessimistic. We may doubt some of the estimates that have been made on the reserves of fossile fuel; we may be optimistic about the possibilities of fusion.

We may remark that scientists have in the past nearly always underrated the scale on which their discoveries and inventions might be applied and that therefore, although it seems at present unlikely that we might cover thousands of square miles with solar cells, this cannot be excluded with any certainty.

We may point out the enormous progress that is still possible in mining and prospecting methods and that for many purposes rare materials can be replaced by others with no great loss of performance (and even often with distinct gain). But the simple fact remains that in many fields we have now been having exponential growth for more than a century – in the field of scientific literature and in the case of numbers of scientific workers for more than three centuries – and that this cannot go on very much longer.

Third point. The environment. In a way this is also a question of waste. We cannot afford to go on wasting open spaces and beautiful scenery and clean water and clear air. And should yet travel not be considered not only a waste of time but also a waste of distance. A ten miles walk provides you with more impressions, more change of scenery, is more enriching than a 1500 miles flight.

How can we reconcile the three exigencies I mentioned? How can technology remain advanced and advancing and yet reduce consumption of energy and materials and respect and even restore the environment?

A man like Marcuse advocates a total revolution in our sense of values, a total negation of the present arrangement of industrial society – in which he includes Sovjet Russia as well as the United States –, a biological change of mankind. Personnally I am not looking forward to that kind of thing. But a much less drastic change seems quite possible. In every technological realization there enters energy, materials and a quantity of information. Now we may gradually learn to appreciate primarily the information content: the more information is offered for the same amount of energy and material the better. There exist already examples of this: A lady will treasure her wrist-watch, because in a small compass it does the same as the much larger and heavier watch that has become an almost indispensable part of male attire and she is willing to pay – or to have somebody pay for its being small. I have at home a Dutch bible from 1702, an impressive volume weighing 10 kg, but the same text in smaller but as readable characters can be easily packed in a volume that is ten times smaller. And in preparing this lecture I have used the Compact Edition of the Oxford dictionary, the complete text reproduced micrographically. You have to read through a magnifying glass, that is true, but on the other hand the volumes are easier to handle and to keep on or beside your desk than the standard edition and they certainly are more convenient than would be the Oxford dictionary chiselled in slabs of stone – or engraved in silver plates, for that matter.

Now I maintain the view – and have said so on several occasions – that in this respect electronic technology is a technology for the future. I shall use the remainder of my time to elaborate this idea.

Electronics always deal with information. With the transmission of imformation like in telecommunications. With the display of information – television and, with a slight extension of the meaning of display, also radio and reproduction of recorded sound. With the storage of information – memory devices of various kind. With the processing of information – calculators and computers. And with collecting information – measuring devices of various kinds. All these activities are well represented on our program. It is obvious that electronics try to achieve its aims using less and less material and less and less energy. In this respect the progress that has been made since the Second World War is spectacular. Look at telecommunications. The carrier-telephony systems from the thirties were already a great improvement over single channel cables, but since then we have witnessed the development of coaxial cables, with far greater bendwidth, and of microwave relays. And it seems safe to predict that in a none too distance future an even more impressive stream of information will be carried by a single glass fibre. It may seem at first somewhat exorbitant to launch satellites in order to obtain better communications, but the cost per channel is going down rapidly and, after all, empty space is cheaper than copper. Progress is almost even more spectacular in the field of calculators and computers. Some of you will remember the early computer at Aberdeen Proving Grounds. It was a very impressive installation filling a pretty large room – or should I say hall – that had to be provided with powerful air-conditioning to get rid of the heat of the thermionic valves. Now I have not made an exact comparison, but I am reasonably certain that the same performance could be obtained today with a little box fed by a modest battery. Nor is the development at its end. As I indicated before, it may well be that we shall make even smaller components.

In measuring instruments the situation is of course slightly different but also here more information can be extracted from less and less. One of my acquaintances told me a few years ago that he had worked out that the radio-astronomers had been working up to then with a total received energy of one erg, this one erg having provided us with an enormous amount to knowledge concerning the structure of our galaxy and so on. I found this most interesting way of looking at things (and in parantheses, how nobly does the unit *erg* appear in this context. I do not like to give a general lecture without making at least one quip about the MKS-system which I dislike even more strongly than the general word systems, and I am grateful that a logical opportunity for this presents itself). Now I suppose that by now the total amount of processed radio-astronomical energy must have increased quite a bit but it will still be in the microjoule region.

Of course in displays in general and in entertainment display in particular, things have to be of human size. We could construct a micro-television tube at which one would have to look through a microscope but I do not see much of a market for that. But apart from the matching device between the apparatus itself and the human being everything can be quite small. It must be granted that a 23 inch cathode-ray tube is a rather big thing and by the way, in 1948 or so it seemed quite unlikely that such a bulky contraption would ever be made in large quantities. One more example that scientists and technicians underestimate practical possibilities, thinking about implosion hazards. One even spoke about bombs. That was of course gross exaggeration. The implosive energy of the largest cathode ray tube is less than the combustion energy of one tenth of a cubic centimeter of petrol, and no one who carries a cigarette lighter is worrying that he is going around with a bomb in his pocket. Perhaps he ought to. As to use of raw materials, glass is not a very rare material and in any case the quantity of glass that passes our homes in the form of milk, beer and other bottles and jars is larger by far. Seen in this light, the practice of throwing beer bottles at tv tubes – once a favourite demonstration and even a test procedure in one of the Philips development labs – assumes a new and deeper significance.

So much about the products of electronics. The manufacturing processes themselves are reasonably innocent, do not cause much pollution, or, if they do, this can be avoided at no great cost. The energy consumption is on the whole quite low. For the time being I do not see an indication of the necessity to limit the growth of electronics.

These considerations are also of importance in connection with developing countries. To provide India or Java with the same number of motorcars per head of population as the United States does not at present seem an attainable nor a desirable goal, but there do not seem to be cogent reasons why these countries should not have excellent communication systems.

But what about power engineering? There the situation is different. We have seen that even Marcuse would not like to do without electrical power. We have to recognize the enormous role of electricity in reducing human toil and drudgery and only those who had other people to do their washing or cut their timber will scoff at laundering machines or electric saws. But one should like to control the growth and one should carefully weigh the advantages and possible dangers of various alternatives. Section I of this conference deals with such matters, and the composition of the program bears witness to the fact that scientists and engineers are well aware of the measure of their responsibilities. Allow me to make a few stray remarks.

1. It is obvious from the program that much work is being done to increase efficiency.

2. One has to consider the total efficiency of the system. I remember an old advertisement of General Electric: 'All the electric energy that goes into a General Electric heater is converted into heat'. I do not doubt the truth of this statement but one should add: not all the heat that goes into a General Electric Powerplant is converted into electric energy. But the waste heat may be used.

3. There is no shortage of fascinating and challenging problems.

Then, two remarks that have no direct relation to the program. It is my personal opinion that in developed countries part of the population is living at a level of energy consumption that seriously impairs their well-being and therefore lowers their standard of living. Further: The use of nuclear energy and the widespread distribution of fissionable and of highly radioactive material will require severe safety measures. A question we have to ask ourselves is whether adequate measures can be taken in a society that respects personal freedom, or whether, after a few serious incidents, a military dictature or some other form of absolutist control will emerge as the only answer.

Let me for a moment return to electronics. Electronics can play the watch dog to detect potential or actual threats to the environment. It can also provide process control that will minimize pollution.

And one last point. I should like to stress that in many cases the use of energy and materials can actually be replaced by using more information. Telephone conversations avoid a lot of travelling. Picture-phone or however you want to call it may reduce business travel even more and so does document transmission per capita or should I say per caput, energy consumption on a flight is much reduced if the plane carries a full load. This can be reached by the simple device of waiting until the aeroplane (or the bus or whatever the conveyance may be) is full, a practice not unknown in more primitive countries. But the same result may be obtained at considerable less inconvenience to the passengers by an adequate computerized booking system. Also tv can replace in part the printing of rapidly obsolescent material.

Seventeen years ago, at a symposium that formed part of the celebrations of the golden anniversary of the state of Oklahoma, I finished a lecture in the following way:

'Although our technical civilization is the result of a joining of forces of philosophical inquisitiveness and industrial zeal, our desire to understand nature is not only justified by its practical importance. It corresponds to a noble urge of the human race, that is an aim in itself. Even the most diehard materialist feels dimly that the mathematician dealing with an impressive edifice of abstractions and the astronomer probing the structure of the universe are doing valuable things and are in some way contributing to the richness of human experience.

There enters some of this even in a simple piece of applied research. To feel that one's work is not only of practical use but has also inherent value and beauty, is one of the things that make life worth living. We research people should count ourselves fortunate beings.'

That was seventeen years ago and in those days I was less worried about the future of our society than today. Certainly, there was also then the threat of atomic warfare, the fear of total annihilation, but there was not the same distrust of technical progress in general, not the same doubt about the future of mankind, even if it manages to avoid nuclear holocaust. And I was still experiencing a kind of technological euphoria, because I had witnessed how industrial expansion had helped my country to regain a state of relative prosperity and well-being after the dismal years of wartime occupation.

Can I say exactly the same to-day? Not quite. I feel that I have to emphasize moral responsibilities of the scientist and the engineer, make it clear that we can not get away with saying that technical products are neither good nor bad as such and that it is none of our business what other people are doing with them. And I must point out that the very fascination of our work itself holds the danger that a man, who is personally by no means of a murderous disposition, may work happily on the technically and scientifically intriguing problems of murderous and morally unpermissible contrivances.

And yet. Looking at our program, at the vast number of tasks ahead of us, at the wide range of possibilities for bettering the lot of man by application of our skills andour knowledge I would still say: we research people should count ourselves fortunate beings.

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Berichtigung. Im Artikel «Zum Théveninschen Theorem», von W. Herzog [erschienen im Bull. SEV/VSE 65(1974)12], sind in Fig. 5 die Pfeile des Stromes I_k entgegengesetzt einzuzeichnen. Auf S. 898, 1. Spalte, muss es heissen: $I_k R_i = I_k' R_i'$.