Science In a Social CONtext

TECHNOLOGY, INVENTION AND INDUSTRY

John Holmes

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Technology, Invention and Industry

JOAN SOLOMON

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Introduction

Technology is a much-used word which tends to sound forbiddingly difficult, something that only skilled workers will know about. This book sets out to show that it has strong human connections as well as scientific ones. We will see how it arises from the needs of society, the part played by lucky chance, by invention, and by careful research. We will also be deeply interested in the impact it may have upon our ways of living, both intended and unintended.

The first part of the book contains stories of invention from which we can discover some of the ingredients that make for successful innovation, as well as its effects on industry and economic wealth. The second part studies two important modern industries in more detail. From the story of their development more is learnt about the interaction between new industry and all aspects of society, including war, medicine and education.

1 The Ingredients for Invention

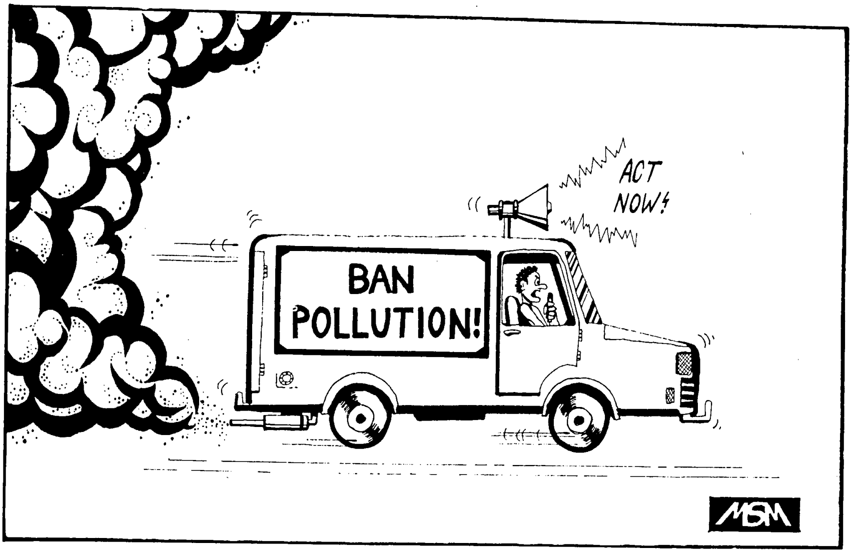
A successful new invention is not just a personal triumph for its creator, it is a force for change in society itself. That is why it concerns us all. Not only can it alter the way we live, a really powerful innovation, such as printing or television, can also change the way we think. This makes invention both exciting and challenging.

Some inventions have won amazing fortunes for their authors and great riches for their countries, others have saved thousands of lives, many have fizzled out and failed. In order to examine how science and society interact to produce inventions we shall have to understand the various stages in the development of innovation.

MARKET PULL

The most important point about any successful invention is that it should be *needed* at that time. Sometimes a new commodity is needed to replace an old one which has grown scarce or expensive. As the world's resources of fossil fuels run out, for example, government research laboratories and private inventors will try to find ways to use new sources of energy. There is always a need for *improvements* in existing technologies: faster cars, better communication, easier care of the home or cheaper manufactured goods. When a society *changes* its way of living, crowding into towns, or reclaiming land for agriculture, there will be an urgent call for new technology. How can roads be made safer and the air kept healthy? Is it possible to breed new plants that will 'fix' nitrogen for their own fertilising, or ones that will grow on sandy or salty ground? The government will always be prepared to pay for ideas to improve health, also, less happily, for more deadly weapons. The inventor must be in tune with the times.

What new processes can you think of that were invented to comply with anti-pollution laws?



SCIENTIFIC KNOWLEDGE

It is true that luck often plays some part in an invention, but that is only at the beginning. If there is no scientific understanding it will not be possible to decide what to do next. The best scientists, however, have not always made good inventors. They may fail to see what use could be found for the knowledge. When the atom was first 'split' by Rutherford's team in 1932, he declared that the idea of making useful atomic energy in this way was 'sheer moonshine'. How wrong he was!

TECHNOLOGICAL RESEARCH

Understanding the scientific theory is not enough. Once a *use* has been thought of – like the jet principle in aviation – a vast number of experiments, prototypes, and new inspiration will be required.

Frank Whittle first started work on the idea of jet propulsion in 1929 but the first prototype did not fly until 1941. In Germany von Ohain took out his first patent for a jet engine in 1934 and his prototype flew in 1939. Neither man knew of the other's work but both had to overcome exactly the same range of technological problems – a new design of turbine blades, stronger alloys for these blades, and a new way of burning the fuel to power the compressors which produce the jet.

PROCESS DEVELOPMENT AND PRODUCTION

After the prototype has been shown to work, it will still be necessary to develop new production processes to make the item on a large scale. Decisions will have to be taken as to whether the final product will be economical to produce, it will have to be tested for safety and reliability, and large new factories will have to be built. Even after the initial production of the new product there may be more problems to overcome. There may be long-term dangers either to the workers or to the users which could not have been foreseen.

INVENTION PUSH

It takes a lot of money, capital investment, to get a new process going. Once the factories have been built and the product is available there will be sound economic reasons for finding as many new uses for it as possible. It takes an inventive flair of another sort to think of these. The plastic material 'teflon' was produced almost by accident during industrial research; it was only then that non-stick frying pans were thought of. During the Second World War the production of aeroplanes had high priority, including the production of all the materials involved, such as aluminium. It was only after the war that aluminium attaché cases and aluminium frame greenhouses first came on the market.

One successful invention can push another in a more indirect way. The first production of cast iron by means of coke instead of charcoal was developed by Abraham Derby in 1709. He used it to make machinery, railway lines, and even a cast iron bridge which gave its name to the village of Ironbridge. It was a great stimulus to invention, including better steam engines where cast iron was used for the cylinders which were then strong enough to hold steam at higher pressures. Nevertheless coke smelting was difficult because coke did not burn as easily as charcoal. It needed the action of very strong bellows to keep the process going. The breakthrough came in 1776 when the steam engine was first used to produce the blast of air which gave its name to the great 'blast furnaces' of the iron industry. Invention push had acted in both directions between steam engines and iron production.

PATENTS

These are intended to protect the inventor of a new idea from imitation and unfair competition in much the same way as copyright protects the writer or composer. It enables the inventor to sue an imitator for damages in a court of law. On the other hand the aim of a patent is also to encourage innovation and development – even though it seems to grant a virtual monopoly. There are a few points which are interesting:

1 If, during the twenty years for which it runs, the idea does not seem to be developed industrially, the patent-holder can be forced to grant licenses to other companies for the use of the invention.
2 There are no world-wide patent agreements.
3 Nine-tenths of all patents do not remain active for even sixteen years.

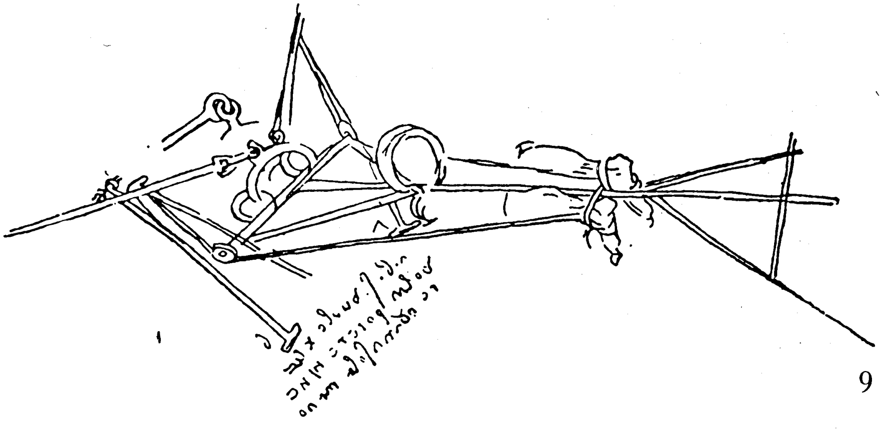
In whose interests is the rapid and cheap exploitation of a new idea? Could an inventor be paid by results, even years later, without a monopoly on the development of his idea?

FOUR STORIES OF INVENTION

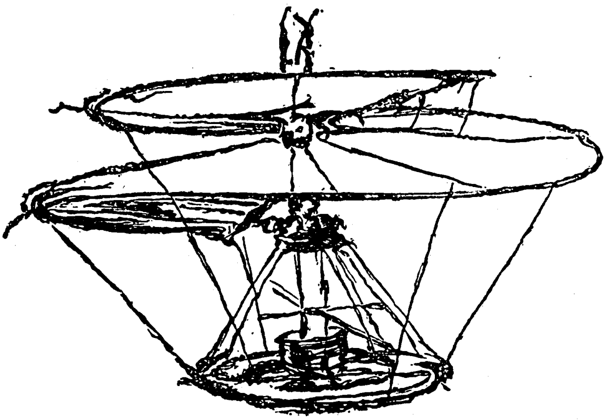
Now bear in mind these ingredients when you read the following stories about real inventions. Some of them failed, some succeeded; you may be able to offer your own reasons for this.

1 *Leonardo da Vinci's flying machines*

These date from about 1500 AD. The first picture shows a man-powered aeroplane; the wings have joints which mean that they can be moved like the wings of a bird. The second shows a flying platform



worked by a large flat rotating air screw fixed above it – more like a helicopter than an aeroplane. Leonardo recommended that the air screw be made out of starched linen. (The first helicopter flew in the 1930s).



Like most inventors Leonardo prized his ideas highly and even developed a secret way of writing so that no one could read his notebooks and steal his ideas. (It is not difficult to break this code; try it with a mirror and a knowledge of Italian!) As far as we know Leonardo did not build working models of either of these designs. Could he have done so? Would they have worked?

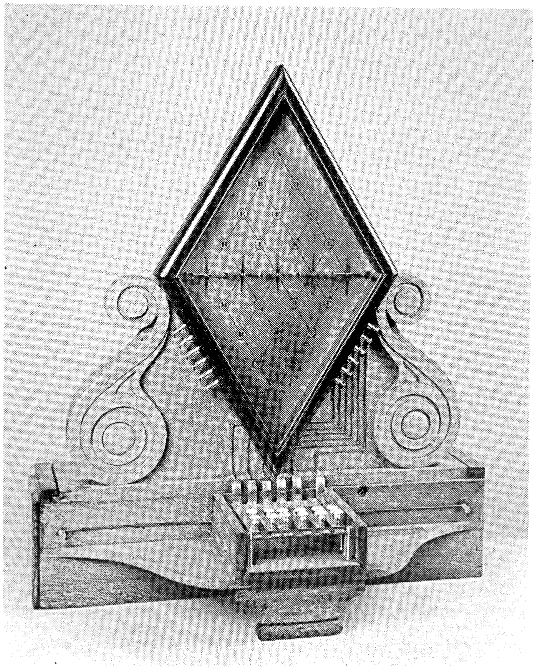
2 *Why improve the battery?*

Now we advance nearly 300 years for our second example of invention. An Italian physiologist, Luigi Galvani, was engaged in a series of experiments to examine the effect of electricity on the muscles of frogs. When he touched the electrode on an exposed nerve the muscle contracted. Later he was astonished to find that some of the dissected legs, which he had suspended from iron railings by brass hooks, actually twitched of their own accord when damp! Galvani decided that electricity must be coming from the frog's own muscles.

Alessandro Volta had a different explanation. He believed that the electricity was made from the contact of the different metals, i.e., the iron railings and brass hooks; he therefore built a pile of discs of copper and zinc which were separated from each other by paper soaked in salt water or acid. Connecting wires to the top and the bottom of the pile Volta could deliver a small but convincing shock. He had invented the very first electric battery and he published his discovery in 1800.

Thirty-six years were to pass before any real improvements were made to Volta's battery. Of course the scientists like Davy, Ampère, Oersted and Faraday seized the opportunity to investigate all the properties of electric current. Many discoveries were made, but, at first, the battery seemed to be of little practical importance.

The breakthrough came via the needs of electric telegraphy. As early as 1770 there had been hopeful designs for sending signals down wires by pulses from electrostatic machines. It was fast, but receiving the message was not so easy – the operator had to hold the bare wires and record the shocks he felt! However, once Oersted and Faraday had shown that an electric current could operate a magnet and pull down a lever, much better designs for telegraphy began to appear. 1837 was the year of the first British patent in this field, and of the first public demonstration in America by Samuel Morse.



Cooke and Wheatstone's five needle telegraph, 1837.

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By its powerful agency Murderers have been apprehended, (as in the late case of Tawell,)—Thieves detected; and lastly, which is of no little importance, the timely assistance of Medical aid has been procured in cases which otherwise would have proved fatal.

The great national importance of this wonderful invention is so well known that any further allusion here to its merits would be superfluous.

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Advertisements for the Great Western Telegraph, 1846.

The establishment of telegraphy then stimulated a need for better batteries. Major improvements appeared in 1853, 1862 and 1866 culminating in the invention of the Lechanché cell which was the forerunner of the common torch battery.

3 *The smokeless explosive*

Our third example dates from 1846. A Swiss professor of Chemistry, Christian Schönbein, spilt a mixture of sulphuric and nitric acids on the kitchen floor – so the story goes. The first material that came to hand was his wife's cotton apron, so he used it to wipe up the liquid, rinsed it out and hung the apron up to dry. Suddenly it burst into flame and disintegrated – a new explosive had been discovered!

Schönbein was quick to see its possibilities. As soon as he had identified the substance, he published his results in a scientific paper, *omitting* his method of preparation, and also applied for a patent.

Since the discovery of gunpowder in the fourteenth century there had been no other available explosive, and gunpowder had one very serious drawback. Guns and cannon produced so much smoke that after firing a few rounds in a battle the opposing armies could barely see each other. Contemporary paintings of Trafalgar and Waterloo show this quite clearly. Schönbein's 'gun-cotton' on the other hand was almost smokeless. Within the year he had sold his secret to both England and

Austria. A year later chemists in France, Germany and Russia had made independent discoveries of its preparation, and all five countries built factories for its production.

Fifteen years later the whole project was closed down. At least six factories had blown up accidentally, resulting in a large loss of life. Gun-cotton on its own never became an important explosive. (Only when Alfred Nobel later combined it with other stabilising materials did it find use as a constituent of gelignite and cordite).

4 *Lead for anti-knock petrol*

This example brings us up to the present day, it concerns the lead which is added to petrol. Once better metal alloys could be used to make the cylinder head of the car engine – the place where the petrol vapour and air mixture is exploded – it became possible to use higher 'compression ratios'. This means that the mixture could be squeezed into a smaller space before igniting it, because the metal could withstand the pressure. This gave more power to the engine.

Unfortunately there was one serious drawback to this. When the mixture is compressed so much it tends to overheat and ignite before the plug sparks; this is called 'knocking', and is very bad for the engine. Using high quality petrol reduces this knocking but this is more expensive. Then a discovery was made. If a compound of lead (tetraethyl lead) is added to normal grade petrol it can increase the 'octane number' of the petrol and so prevent knocking. Our 'four-star' petrol now has about 0.45 grams of tetraethyl lead per litre, and an octane number of 98.

Lead was first added to petrol in 1923. It was known that airborne lead was a poison and could affect the nervous systems of those that inhaled it, but there were few cars on the road so those at risk were only garage attendants and policemen. There was some concern, but the additive was allowed.

By the 1970s the situation had changed. The number of cars on the roads had increased enormously, and the air near motorways was so full of exhaust fumes that it now contained a considerable amount of lead. So did the dust on the pavements and in the school playgrounds. A study of city children living near motorways showed that those who were 'hyperactive' and had difficulty concentrating on their lessons in school, had high levels of lead in their blood. Did this come from car exhausts or from lead paint? There was a great deal of concern about the problem.

In 1975 the Environmental Protection Agency in America insisted that lead-free petrol should be on sale in all petrol stations. It costs more, and car engines have had to be adapted in order to use it. In 1981 the British government announced their intention of reducing the amount of lead that may be added to petrol. New types of engine which can run efficiently on low octane fuel, or new lead-free additives which raise the octane number, are being actively researched at the present time.

Now use these stories to find examples of:

a inventions which failed through lack of market pull
b inventions which stimulated scientific research
c scientific research which stimulated technological progress
d inventions which faltered through lack of technology
e inventions pushed by other inventions
f inventions failing after production
g inventions which failed through lack of scientific knowledge
h simultaneous invention

2 Research and Development in Industry

ACCELERATION

Nowadays the process of invention and its exploitation has been speeded up. We seem to have an appetite for change. People say that our society has become more materialistic, others claim that advertising makes us dissatisfied with what we have and creates new needs. Perhaps, unlike our grandparents, we have grown accustomed to change and really appreciate improvements. How do you rate these different explanations?

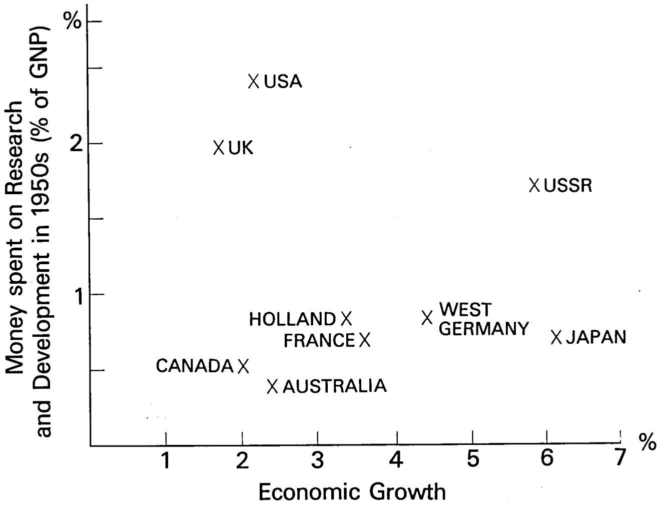
The chart below shows this acceleration.

Date of Discovery		*Interval before commercial innovation*	
1770	Telegraph	66 years	First established Paddington (London).
1802	Electric Arc Lamp	56 years	Dungeness Lighthouse.
1831	Electric Motor	48 years	Electric train, Berlin.
1861	Telephone	15 years	Alexander Graham Bell.
1887	Radio	9 years	From Hertz to Marconi.
1909	'Cracking' process	13 years	Dubbs (for making petrol).
1923	Jet Engine	19 years	Frank Whittle (RAF).
1927	Nylon	12 years	Carothers at Du Pont, USA.
1928	Penicillin	13 years	Fleming (first patent 1940 but insufficient to complete treatment).
1933	Polythene	5 years	At ICI, England.
1938	Nuclear Reactor	11 years	Fermi's demonstration pile (1942).
1947	Transistor I	4 years	Bardeen and Brattain, Bell Laboratories, USA.
1948	Transistor II	5 years	Shockley's junction transistor, Bell Laboratories, USA.

Some firms prefer to buy proved inventions and only develop them for special uses. Other companies spend freely on both *research* and *development* (R and D). In the plastics industry for example, during the years from 1946 to 1955, we find that ten per cent of all the patents granted worldwide went to just one American firm – Du Pont.

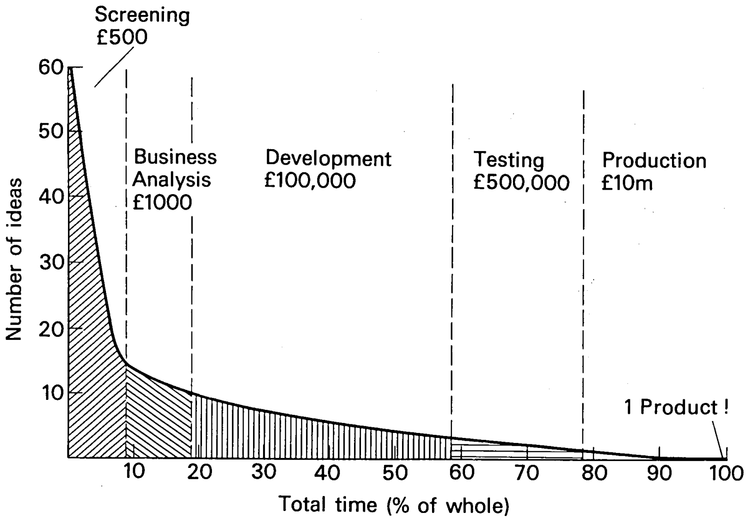
We hear a lot about R and D because it is widely believed that this is the way to stimulate progress on an industrial level, and economic growth at a national level. In the UK during 1975 – a year of high inflation and industrial stagnation – the government itself contributed to R and D to the tune of one third of the total spent. If R and D for military purposes is included the government contribution rises to over one half of the total.

Although it seems as though investing in scientific research must be the right way to make industry grow it has not always proved so. During the 1950s, as the chart shows, the UK and USA spent liberally but did nowhere near as well, in terms of economic growth, as did Japan and West Germany – the very countries which, within twenty years, were leading the whole table. Military research brings a country less economic reward than industrial research.



Does research help to raise our standard of living?

Good judgement and forecasting is also of tremendous importance in this field. Barely one out of every 60 bright new ideas finishes the course as a profitable product. All failures are expensive and 'near-misses' can be financial disasters. In the next chart the figures given for the amounts of time and money must vary enormously from one industry to another, but the general outline is correct.



Screening: Will it work?
Business Analysis: Can we afford to go ahead with it?
Development: What sort of purposes will it serve?
Testing: Is it safe and reliable?
Production: Are the public ready for it?
Are the factories economic to build?

All for one successful idea!

3 Case Study of Plastics

NEED AND CHANCE

This particular story begins in the year 1900 with a small Indian insect which lived on a type of acacia tree, and a Belgian chemist who had just sold his latest invention, the first photographic printing paper, for a million dollars. The name of the chemist was Baekeland.

The female of the insect secretes shellac as she feeds on gum from the tree and, in the end, becomes totally embedded in it. Natives then scraped the insects off the tree and purified the resin – shellac – which was in great demand both as an insulator for the growing electrical industry and also for making the new gramaphone discs. Since it took 15,000 insects to make one pound of shellac it is not surprising that production could not keep pace with demand. Baekeland decided to try to make a substitute for shellac. This was a clear case of market pull.

New industrial methods had recently made formaldehyde (from wood) and phenol (from coal-tar) comparatively cheap raw materials. Baekeland knew that these materials sometimes formed sticky resins, a fact which had previously caused chemists a great deal of irritation. Now Baekeland set about finding the best conditions for its formation. After five years he struck a combination of five atmospheres pressure and 160°C at which a hard, amber-like material moulded itself to the inside of the container. This was more than an excellent insulator and a lacquer, it was the first completely man-made plastic – Bakelite.

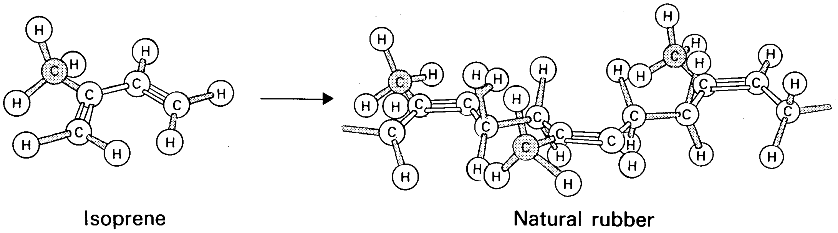
Baekeland took out his patent just one day before the British electrical engineer James Swinburne, applied for an identical phenol-formaldehyde patent. Multiple discovery as we have seen is a comparatively common occurrence in the history of invention. Can you suggest any reasons for this?

In 1909 Baekeland demonstrated his versatile new product to the American Chemical Society with an address including these words:

> '. . . here you have before you a grindstone made of Bakelite (combined with grit) and on the other hand a self-lubricating bearing which has been run dry for nine hours at 1,800 revolutions per minute without objectionable heating and without injuring the quickly revolving shaft.'

The discovery of Bakelite was a success story, although it did not come into common use until the 1920s, yet chemists still had no real understanding of the material they had made. When other problems arose, they did not always prove so simple to crack. Scientific knowledge was missing.

In the early years of this century there was also an increasing demand for rubber, due in part to the growing popularity of the motor car. The great rubber planations of the Far East were the world's sole source of supply and chemists in England, Germany and Russia had already tried to produce a synthetic rubber with no real success. In 1882 the English chemist William Tilder had shown that natural rubber consisted of a huge collection of *isoprene* molecules linked together in some way. He had even shown that if isoprene was left on the shelf for a period of years it did gradually join up to make a soft and sticky kind of rubber. Tilder tried everything he could to hasten and improve this process, but he failed.



Could isoprene be turned into natural rubber?

SCIENCE STEPS IN

The 1920s were a time of great progress in the understanding of big molecules, and, in particular, of the long chain molecules, *polymers*, built up by the linking together of many smaller units. Both Bakelite and rubber, it turned out, were indeed very large molecules. This breakthrough of knowledge depended, in turn, on two new practical techniques which had recently appeared in the laboratories.

1 High-speed centrifuges which could separate the largest molecules

2 'X-ray diffraction' which could probe the actual structure and shape of the molecules, especially if the long polymer chains, from which plastics are made, could be crystallised out.

Much of this progress was made by the German chemist Hermann Staudinger. He was, indeed, so impressed with the new power to analyse and even put together these enormous chain-like molecules, which so commonly exist in nature, that he believed that he had hit upon the secret of life itself. Cellulose, for example, is a constituent of almost all plant tissue; Staudinger had not only proved that it was a giant polymer of glucose, he had even synthesised it (produced it artificially). This success encouraged him to claim that *living* materials containing these long molecules could all be formed by controlled chemical reactions in the laboratory! Like an echo of the controversy over Darwin's theory of Evolution, it seemed for a while as though science and religion were poised to fight out the issue of creation.

THE LARGE CHEMICAL FIRMS EMERGE

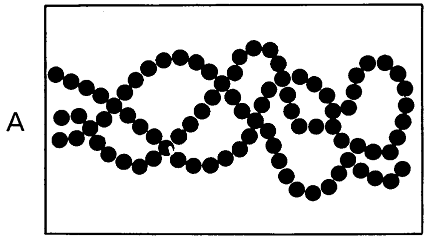
As well as this scientific progress the recent war had also changed the evaluation of the chemical industry. The 1914–18 War has sometimes been called 'the Chemists' War'. Germany was cut off from supplies of nitrates for explosives and had learned to manufacture her own. Britain and France had done the same to a lesser extent. A blockade on natural rubber had seriously injured the German war effort, and finally the hideous new weapon of gas-warfare had underlined the destructive potency of industrial chemistry.

In 1925 several German chemical firms combined to form I.G. Farben, a company which led the world in industrial chemistry for two decades until it was dissolved after the Second World War. In 1926 the British government helped to form ICI (Imperial Chemical Industries) by a merger between four existing companies. At the same time the American firm Du Pont was growing to equal status by commerical competition and buying up smaller businesses. As soon as it became clear that science had something to offer in the new field of polymer chemistry all three of these firms were eager and ready to finance their own research laboratories. They could afford it.

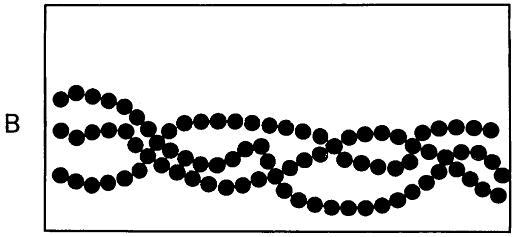
I. G. Farben was the first chemical company to recruit 'pure' research scientists to work in a speculative way in their laboratories. They were not given a specific technical problem to solve; the idea was simply that they should follow their own interests in polymer chemistry in the hope of turning out some product or information which might later prove useful. The policy certainly paid off. It is said that these laboratories kept up a rate of one new polymer synthesised a day for about three years!

Not all these products were equally useful of course, but among their number were such now familiar names as polystyrene, poly vinyl chloride (PVC) and perspex. Most important of all they were the first to synthesise a good substitute for rubber.

Scientific analysis of natural rubber had shown that it was a semi-liquid mess of long coiled polymer molecules (A). When rubber is pulled out the long molecules unstretch rather reluctantly (B). When the tension is released they will coil up again either in their original positions (A) or, if they have flowed past each (as they do in chewing gum), in new positions (C). Obviously this is not useful – it would lead to floppy sagging balloons, pyjama trousers with an embarrassing tendency to fall down, and soft, useless tyres! The rubber industry had partially cured this problem by adding sulphur to the raw rubber – vulcanisation. This formed links between the chains anchoring them so that they could not easily creep into new positions (D).

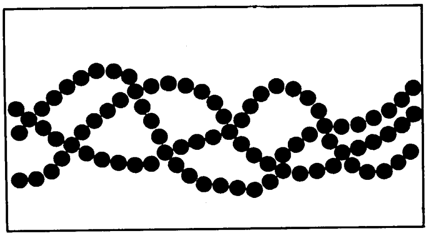


Natural rubber polymer molecules: before stretching.



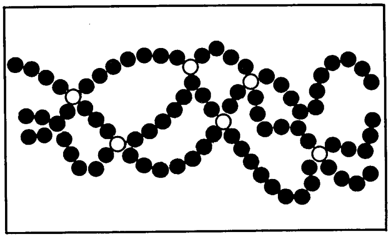
Stretched: the coils straighten out.

C



After stretching: they re-coil into new positions.

D



Vulcanised rubber. After stretching: they re-coil into the same positions.

When the chemists in I.G. Farben set about making a synthetic rubber they used *butadiene*, which could be made from coal or oil, linked it into polymer chains with *styrene*, caused the chains to cross-link, and came up with the first good man-made rubber in 1928.

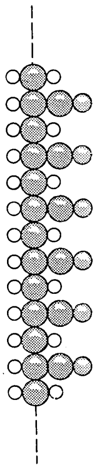
Germany was not slow to exploit this invention. By the time of the Allied blockade during the Second World War they were producing 100,000 tons of this 'Buna-S' rubber annually, which was plenty for all their needs. Indeed when Japan captured the rubber plantations of S. E. Asia it was Britain and America who suffered most.

MAKING FABRICS

Back in the 1920s the American laboratories of Du Pont had also begun fundamental research and they appointed an outstanding applied scientist, Wallace H. Carothers, to lead the team. At first he studied the *polyesters* made by linking together long chains of molecules whose alternate units were from an organic acid and from an alcohol. These were soft, low melting plastics of no commercial interest until a chance happening occurred. One of the chemists found that a long fibre could be drawn out of the molten polymer and that, even after it was cold, the fibre could be still further elongated which actually *increased* its strength and elasticity. What could have happened?

X-ray diffraction showed that these fibres were almost crystalline; the long polymer molecules had all been aligned by the drawing out so that they now lay side by side, linked together by close hydrogen bonds between the molecules. It was almost like vulcanisation between straight chains; no wonder the fibres were strong.

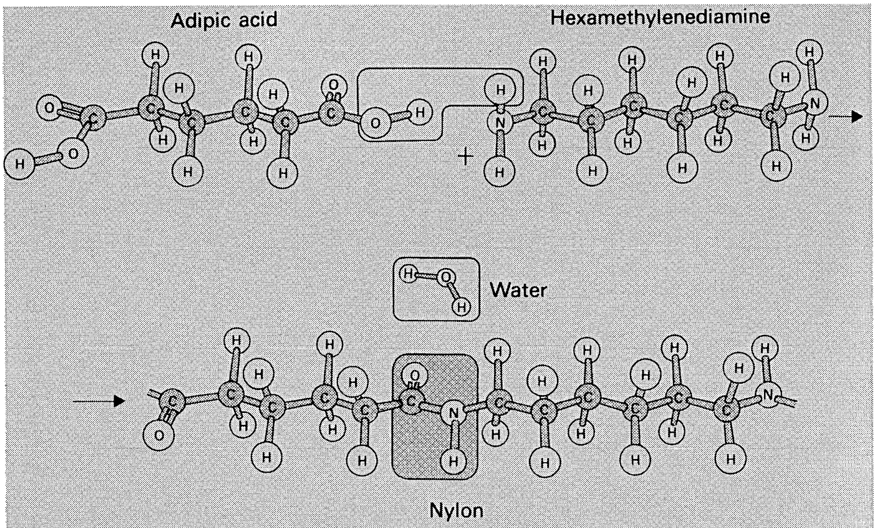
The polyesters Carothers had made were of no practical use because they softened at too low a temperature and for a few months he gave up the whole project. Urged to continue, Carothers led his team to investigate similar kinds of polymerisations and after four more years the project was crowned with success. The first thread of *nylon* was drawn out from the polymer melt of an acid and amine in 1934. Experiments with nylon are not difficult to perform in the laboratory.



Synthetic fibres are plastics because they are made up of similar long chain polymers.

1 *Hot and cold drawing*

Hold a postage stamp sized piece of nylon fabric in tongs near enough to a flame for it to shrink and melt. With a pair of forceps pull out the melt. At first the thread seems floppy, but go on, even after it is cool. You may be able to pull it the length of the laboratory. Examine a section of this filament, now finer than a spider's thread, under a microscope.



2 *Making nylon*

Pour adipic acid into a beaker to a depth of 1 cm (*Take care: this substance is caustic on the skin and poisonous if you drink it*). Carefully add 1 cm depth of diamino-hexane on top of the adipic acid. Look at the layer between the two liquids. This is a film of *nylon* polymer. With a pair of tweezers pull out this film at a slow and steady rate. Why does it go on forming? (*Wash the nylon in water before handling*).

During three years Du Pont had tried out hundreds of different types of nylon before this one, 'Nylon 6.6', was chosen as the best. The whole enterprise cost Du Pont about 1 million dollars in research and 21 million dollars for the development of factories and new machinery. In 1940 the whole output, 4 million pairs of stockings, was bought up within four days!

Do nylon tights and stockings really justify all that research?
What are the other uses of nylon?

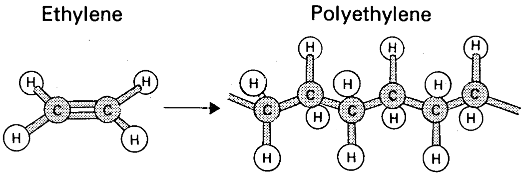
In 1925 the chemists at Du Pont began research on rubber using some preliminary work done by a Belgian monk, Father Niewland, on acetylene. They paid royalties to his religious order and set about building polymer chains from the gas. Eventually Carother's team succeeded; not only did they form a rubber, but one that spontaneously linked together like vulcanised natural rubber. This became known as Neoprene, it was first produced commercially in 1932 and was found to be actually superior to natural rubber both in its resistance to wear and to acids. Unfortunately America did not have the foresight to produce Neoprene on a large scale so that shortage of rubber during the Second World War hit their industry badly until production got going.

THE EXPLOSION OF POLYTHENE

In the British chemical laboratories at ICI the lesson that scientific research could produce commercial rewards was also being learnt. In 1929 a high pressure compressor was ordered from Holland for a new scheme in which coal was to be 'hydrogenated' making petrol and aviation spirit. Unfortunately the great economic depression hit ICI just at this time and forced the scheme to close down. Meanwhile the new high-pressure apparatus and the special laboratory built to house it remained almost unused. What research could be done with it?

By 1931 the decision had been taken to examine the effects of high pressure – between 1,000 and 3,000 atmospheres – on the polymerisation of liquids and gases. The work was dogged by trouble. As early as November 1932 the gases carbon monoxide and ethene were put in the compression chamber and heated to 160°C at a pressure of 3,000 atmospheres. When it was opened, some hours later, a strange white powder was found. No one yet knew what it was. A few weeks later, during the same reaction, there was a dangerous explosion, and hot oil was sprayed round the laboratory!

Two decisions were made; the first was to rehouse the apparatus in special brick cubicles and the second to study only gas-liquid mixtures. In March 1933 the apparatus was mended and filled with a mixture of ethene and benzaldehyde, raised to a pressure of 2,000 atmospheres and left over the weekend. By Monday morning it was obvious that a leak had developed, all the liquid benzaldehyde had been blown out of the reaction tube. The chemists dismantled the apparatus and only found that the end of one of the gas tubes looked as though it had been dipped in wax.



This research continued to be very troublesome. Again and again there were explosions with the ethene just decomposing into soot and hydrogen. Sometimes the apparatus was badly damaged. In May and July a little more of the waxy white solid was obtained but the largest yield was little over 0.2 grams. It was thought to be a polymer of ethene but of what use was such a soft material which could only be drawn into flimsy thread or film? Would you have advised continuing with such an unpromising, dangerous experiment?

> July 1933
> A quantity of the waxy polymer of ethylene (ethene) has been prepared and work with this reaction has now ceased.'
>
> (Monthly report by the two
> chemists Fawcett and Gibson)

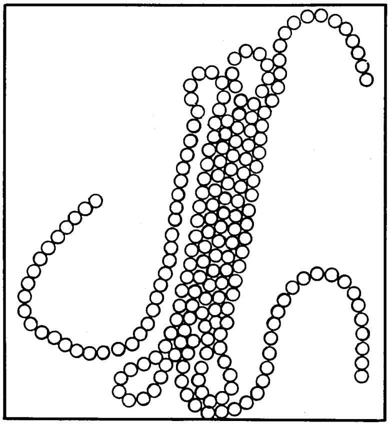
Two years later when the original chemists were at work on other projects two other scientists decided to brave the firm's edict on experimenting with ethene. The compression chamber had been slightly improved and the researchers, Perin and Manning, discreetly set up the experiment after normal working hours. They used a lower pressure but when they opened the chamber they were delighted to find it full of white powder. Fortunately for them their next experiment was also a success although it was followed by others which ended in explosions. Now, however, there was enough material to mould and test properly and this time a new property of 'polythene' came to light; it was an excellent electrical insulator. ICI filed applications for patents.

The rest of the story is easy to imagine. Careful tests proved that traces of oxygen had caused the explosions. Gradually larger scale compressors were designed and tested until commercial production was ready to begin, on the very day that Germany invaded Poland, 31 August

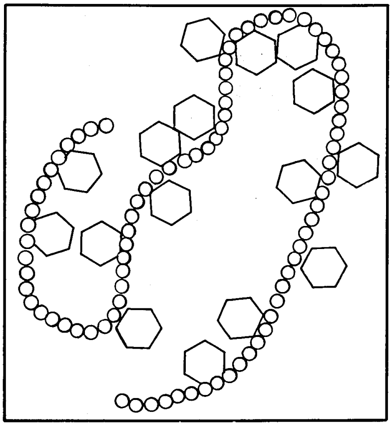
1939. There was added significance in this coincidence. It has often been said that the Battle of Britain was won just as much by the chain of radar stations round our coasts, which gave early warning of German air attacks, as by the valiant 'few' of the RAF. Sir Robert Watson-Watt, the inventor of our radar defences, said of polythene and its superb electrical qualities that it 'transformed the task of the Allies in the field of radar from the impossible to the comfortably manageable'. It was the only available insulator for the very high frequencies used in radar.

PLASTICS EVERYWHERE

The long molecules in polythene are not cross-linked, they can easily be pulled along as the film is stretched except in regions where they fold tightly into little crystals. These make the film slightly cloudy. If you stretch a piece of transparent polythene you can see these white regions becoming more apparent as the loose branched chains move away. For food packaging polythene has the great advantage of being *impermeable* to air and water. To make it more flexible instead large molecules can be added so that the chains cannot align tightly. This kind of polythene softens below 100°C and is not rigid, even when it has been cast into a solid object like a comb or a bowl.



Chains of polythene molecules.



Large molecules are added to the polythene chains to make it more flexible and less rigid.

In 1950 two chemists made quite independent discoveries of catalysts which caused ethene to polymerise without such high pressures. (Another example of multiple invention). This kind of polythene has unbranched chains so they fold up much more easily making a stronger denser but less transparent plastic. If you investigate the two kinds of food bags you can easily spot the differences. Even the rustling sounds of the materials betrays which one is the more crystalline. Each have their uses.

It is easy enough to look around a room or among one's personal possessions and to recognise the widespread use of plastics. Because they are cheap, strong and lightweight we find them everywhere as wrappings and containers of every sort; we wear them in clothes and shoes; we use them to stick things together with new ease and enormous strength; they are coloured to add brightness to the common articles of the household. Even in engineering new plastics are used to make improved paints, smooth hard bearings and heat resistant nose cones for rockets. Their uses seem endless but it is not enough just to list them one after another. Such an important new industry is bound to affect our lives in ways which are more complex and unforeseen. There will be risks as well as benefits, challenges and choices to be made now, as well as exciting possibilities for the future.

PLASTICS AND THE NATURAL ENVIRONMENT

You will remember that the market pull, which was the incentive to produce the first plastics, arose from a shortage of such natural materials as ivory, shellac and rubber. More recently plastics have been made for articles which would previously have been made from wood, paper or even metal. The raw materials for plastics are organic chemicals usually derived from petroleum oil; these were cheaper than the alternative natural materials and still are, even though the price of oil has risen so sharply since 1973.

In what ways does the use of plastics conserve the natural environment?

Occupations closely associated with the environment such as fishing and agriculture have also benefited from these new materials. In arid countries where the evaporation of water from the soil is a problem, sheets of plastics stretched over simple low frames provide a valuable substitute for expensive glass houses. In southern Spain it is commonplace to see whole fields growing fruit or vegetable crops under shimmering sheets of polythene.

On the debit side it is only too obvious that plastics, thoughtlessly discarded in roads and fields, easily become an eyesore. They do not rot away as do wood, potato peelings or paper. Indeed so widespread is this problem that even remote regions of the great oceans have not escaped. A few years ago marine biologists working in the North Pacific Ocean counted 53 man-made objects floating in 12½ square kilometres of sea. Two thirds of these were plastic. The total area of the Pacific is over 100 million square kilometres; the total of this plastic flotsam must be huge!

In our towns the problem of plastic litter has become more severe. It takes a great deal of labour to collect the increasing amounts of rubbish which include large quantities of throwaway plastic packaging materials. They cannot be composted, sorting out for recycling is not feasible and dumping sites are becoming hard to find. Worse still these light materials float, blow about in the wind and even tend to rise to the surface after topsoil has been laid over them. Most will not burn without the addition of precious fuels and some, like PVC, produce dangerous fumes when they burn. No wonder then that research is going on to produce cheap plastics which will begin to break down under the action of sunlight so that bacteria can attack them and degrade them into natural organic products.

Other ways of tackling the litter involve our social behaviour:

Do you think that stronger anti-litter laws should be introduced?
How far has packaging become a selling gimmick?
What are the arguments for and against the throwaway milk carton?

PLASTICS FOR MEDICINE

One exciting feature of plastics is their use in medicine. Plastics can be designed to be used as implants in the human body. Already high density polythene has been used to make replacement hip sockets, acrylic is used for corneas, cellophane for the permeable membrane in kidney machines and dacron in heart valves. There is even a plastic for bone grafts to which the living bone tissue will bond and a silicone rubber, silastic, which can be used to replace cartilage in the nose or joints in the fingers. This is only the beginning.

The hands of a rheumatoid arthritis sufferer. The hand on the left has had all the knuckle joints replaced by silastic prostheses.

What advantages and disadvantages do plastic implants have over human transplants?

Unfortunately there are also considerable hazards to health in the case of some workers in the plastics industry. Polymers made from phenols probably involve the worst danger since this substance has been proved to be a potent cancer-causing agent. Sadly, such risks are not new to the chemical industry; the most dangerous case is probably the manufacturing of asbestos where the lung disease, asbestosis, due to the inhaling of fragments in the air, has caused numerous cases of chronic illness and premature death. Examine for yourselves how the responsibility for the health and safety of the workers is shared by government health inspectors, research chemists, Trade Unions, factory managers and the whole community which uses these products.

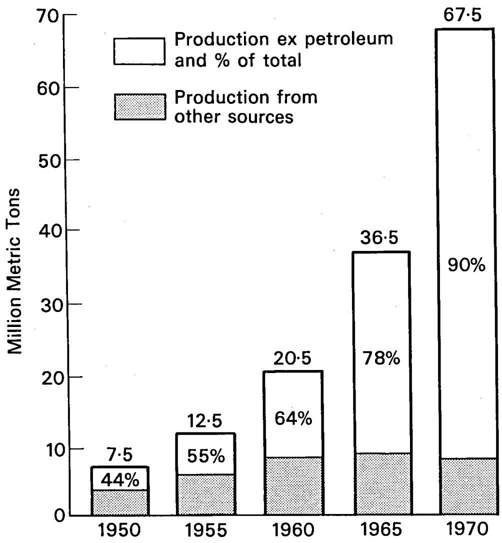
Plastics are used in the construction of even the most conventional seeming houses. They have largely replaced metals for pipes and guttering, they provide sheathing for electrical cables as well as foam for injecting into cavity walls to insulate against heat loss. The plastic foam which is used in modern upholstered furniture can become a fire hazard, but the fire-resistant finishes that have been developed to cope with this danger are also made from new polymers. A simple sheet of polythene provides a damp course under a concrete floor and office blocks are often clad with weather-resistant plastic. Buildings of the future may well be prefabricated out of moulded plastic, to be transported to the required site almost ready-made. On our roads resin-bonded fibre-glass cars and safer, nylon reinforced tyres are already with us.

What advantages do fibre-glass car bodies have over those made of steel?

Once again there are also problems connected with this expanding industry. More and more raw materials are required by the firms producing the wide variety of new plastics. Many of these chemicals are produced by the giant oil distillery plants and need to be transported by road or rail to the plastic manufacturers and stored ready for use.

A large proportion of these are either dangerous if leaked or very inflammable. You can readily understand the anxiety of those who live near the chemical works or the roads along which the huge tankers carry these chemicals. At best these tankers must contribute to road congestion and pollution, at worst they cause disastrously explosive accidents. Statistics show four times as many deaths per mile among heavy freight drivers as among a comparable group of bus and coach drivers.

Suggested solutions to this risk situation include using freight trains instead of road transport and the siting of plastics firms far away from residential districts. What advantages and disadvantages do you see in each of these suggestions?



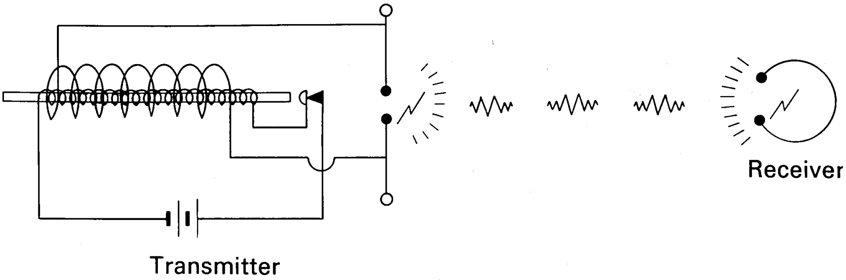
Production of organic chemicals from petroleum, 1950–1970. With the growing shortage and expense of oil this whole industry is gravely threatened. It may be possible to generate some of these oil-based chemicals by biomass techniques. Some have suggested that our dwindling resources of oil should be earmarked for the chemical industry while we look elsewhere for fuels.

4 Case Study of Microelectronics

WAVES WITHOUT WIRES

The best place to begin the story of this new industrial invention is back at the very beginnings of radio.

In 1887 a German professor of physics, Heinrich Hertz, had transmitted and received radio waves for the very first time. He generated them by sparks from a shocking coil and proved that they had travelled the length of his laboratory by picking up smaller sparks in his receiving circuit.



Hertz's experiment.

It does not sound a very useful experiment and indeed Hertz did not think of it as such. Scientifically, however, it was a breakthrough, showing that these 'electric waves', which travelled at the speed of light, did exist – as had been predicted in theory. It was to be eight more years before anyone realised that they might be of commercial use. Hertz took out no patents.

Guglielmo Marconi was only 20 years old in 1894 and still a student when he began experimenting with these waves. At first he repeated Hertz's experiment but then, because he had the idea of communicating by means of these waves, he adapted the receiving circuit to include an electric bell to make sounds (radio waves are of course inaudible), so that he could then send messages by Morse Code. At this time telephone communication was already some 20 years old and expanding rapidly. Networks of wires and cables were being laid down in countries on both sides of the Atlantic. From the beginning Marconi was convinced that his invention of radio communication would rival and surpass the telegraph and telephone. The very name used, 'wireless waves', emphasised the advantage that Marconi believed they had.

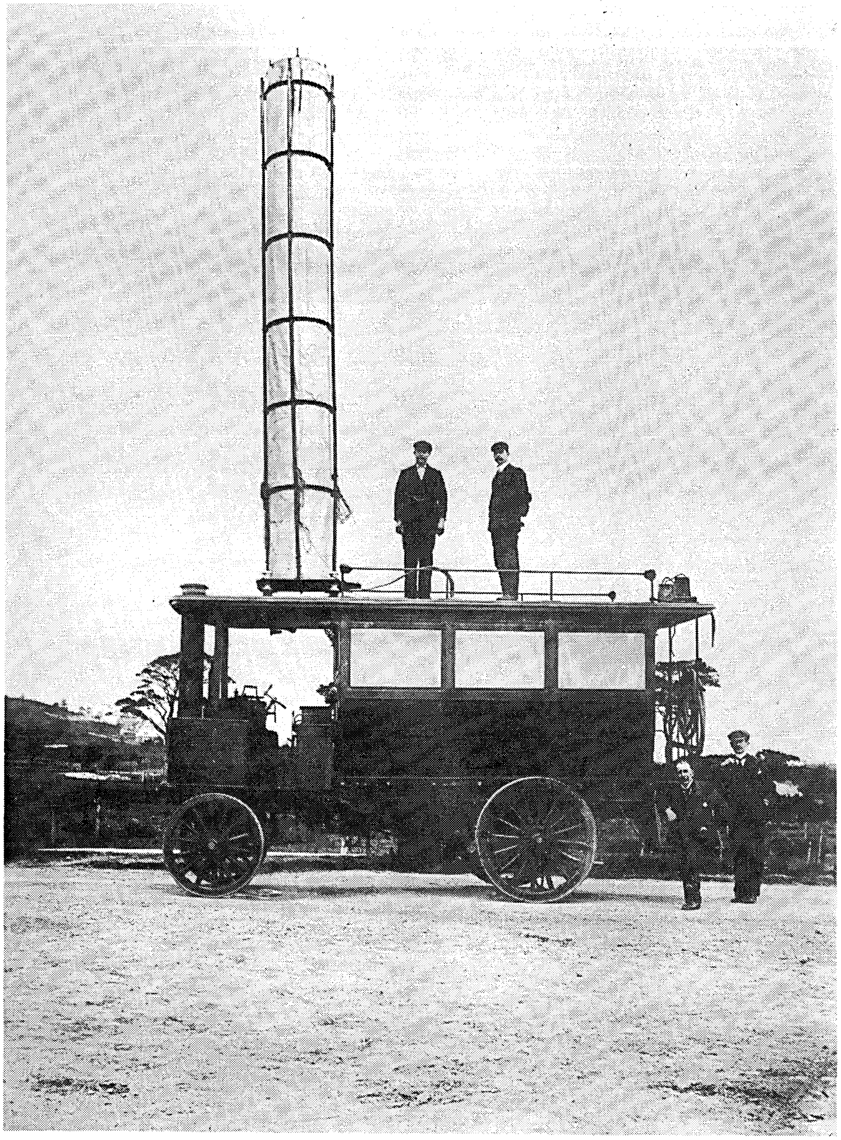
In 1896 the young Marconi offered his invention to the Italian government as a cheaper alternative to the telephone. They turned it down. Undaunted, he then set out for London to demonstrate his system to the Chief Engineer of the Post Office which, then as now, had a countrywide monopoly on telegraphic communications. This was a success and excited a lot of interest.

From then on events moved fast for Marconi, though perhaps not quite in the direction that he had intended. He took out patents on his design and in the following year he was able to set up his own firm, 'The Marconi Wireless Telegraph Company Limited', complete with a research laboratory and workshop.

Right at the start Marconi had shown his radio transmitting set to the Army and Navy. To his delight he found that messages could be sent across water. With an eye to publicity he organised demonstrations of his wireless waves and even Queen Victoria used his new system to communicate with her son when he was ill on the Isle of Wight. Gradually Marconi extended the range of his transmissions until, in 1901, he proved that they could span the Atlantic Ocean. This feat caught the imagination of the world but it did *not* bring the commercial success that he had expected; telephone and telegraph remained cheaper and more effective over all distances.

Only in the field of naval signalling, from ship to ship or from ship to land, did Marconi score an immediate triumph. As early as 1899 wireless telegraphy was used to save lives at sea. In 1910 the murderer Dr Crippen was arrested with the help of a radio message sent from the ship on which he was attempting to escape. In 1912 when the ill-fated Titanic went down the only survivors were rescued by a passing ship equipped to pick up radio distress calls. By 1914 a law had been passed in Britain making it compulsory for all ships to carry radio receivers.

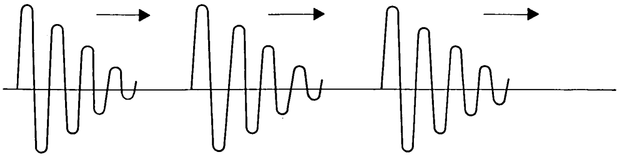
Some scientists were intrigued by transatlantic transmission, and although Marconi was content with the simple explanation that his waves bent round to follow the curvature of the earth, research soon showed that they were bouncing back off an unsuspected layer of



Marconi (extreme right) used this steam wagon to make experiments in wireless telegraphy in 1901.

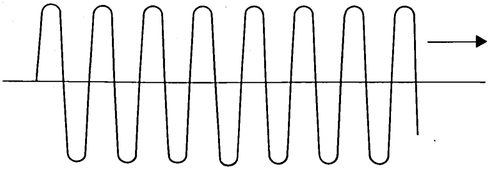
ionised gas high up in the atmosphere. Radio waves were to prove a vital new tool for science. The increasing use of radio also produced a drive for new electronic components – something which is more important for our study.

Marconi, like Hertz, began by using sparks to make his radio waves. These gave bursts of radio noise which could be used for signalling by dots and dashes using the Morse code, but were no good for transmitting speech or music.

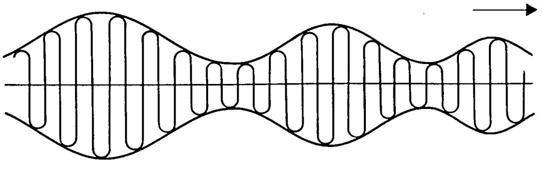


Radio waves are much higher in frequency than the sound waves that we can hear, so, before sounds could be transmitted important advances had to be made in radio technology. Radio waves had first to be transmitted continuously, not in short impulses.

1 Continuous radio waves transmitted. These are called the carrier waves.



2 Sound waves superimposed on to the radio carrier waves. A microphone is placed in the transmitter to change the amplitude of the carrier waves. The radio wave frequency remains unaltered.

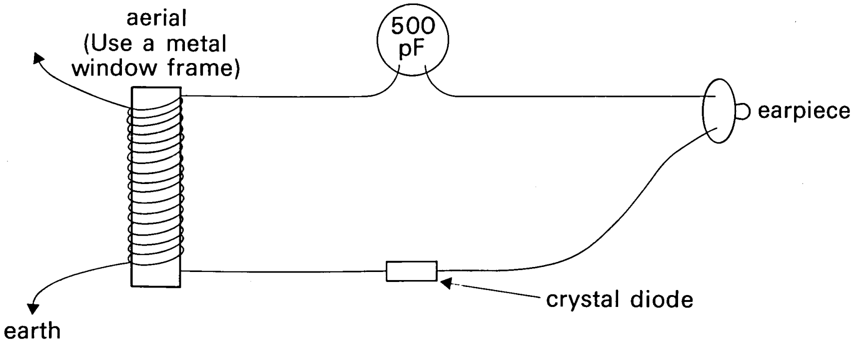


3 Sound waves separated from carrier waves. In the receiver the aerial picks up the radio carrier waves and converts them into electric currents. The *top part of these* is fed into the loudspeaker which only responds to the changing profile of the wave; that is, to the sound frequency which we want to hear.

For the purpose of this case study only the last of these technological developments is important.

Some years earlier the surprising discovery had been made that a crystal of galena (lead sulphide), if touched in one of its sensitive places by a fine wire, would conduct current *in only one direction.* This meant it would just pass the top parts of the currents in the receiver. In the year 1901 the newly formed Telefunken Company in Germany was the first to use and market a device like this. The moveable wire became known affectionately as the 'cat's whisker', and was used by radio amateurs for the next twenty years. In America it was soon discovered that both carborundum and silicon had the same useful property. These materials, together with germanium and a few others

It is very easy to make one of these crystal radios. Today you can buy a *germanium contact diode* sealed in a glass capsule with the cat's whisker firmly in place. They are called OA79 or OA91 and a microscope will show you how they are made. You will also need to wind a coil of about 100 turns of thin enamelled copper wire on a piece of iron (ferrite rod). Then connect them to a 500pF tantalum capacitor and a high impedance earpiece.

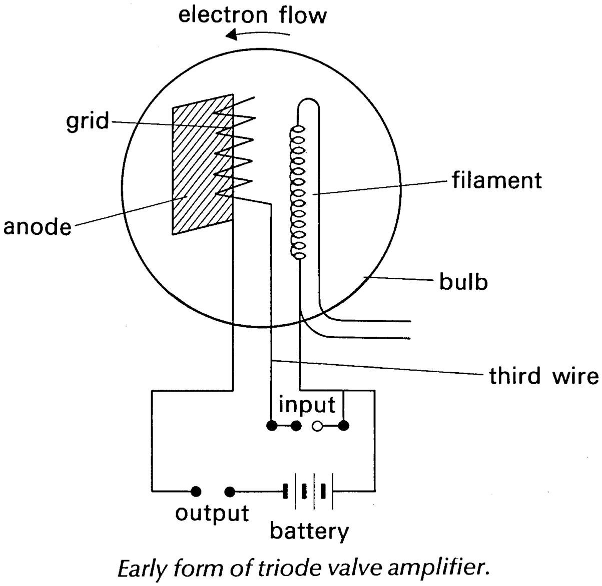


were later to become known as *semi-conductors* (they did not conduct electricity nearly as well as metals do) and eventually these were to form the basis of the great micro-electronic revolution of the 1960s and 1970s.

If you do make a crystal radio you will notice that reception is not very good but it is just audible. This set needs no power; it works by simple resonance picking up radio waves in the same way as a tuned bottle half full of water responds to the sounds from a tuning fork. It can be improved a little by having a larger aerial (see illustration) or by altering the coil, but it lacks amplification. The output is not powerful enough to work a loudspeaker.

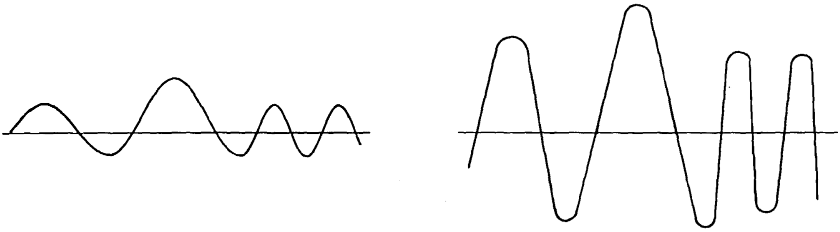
TRIUMPH OF THE VALVES

In 1904 the first thermionic valve was invented by Ambrose Fleming who was then a scientific consultant to Marconi's company which acquired and held the patent rights. The device looked similar to a light bulb; it had a hot filament and a cold metal plate (anode). Like the crystal diode it let the current flow only one way but in the beginning it was so little improvement on the crystal and its cat's whisker that Marconi did nothing to develop the invention.



Early form of triode valve amplifier.

Then a truly important advance was made and the valve became an *amplifier.* A third wire had been connected to a metal grid inside the bulb just where the stream of electrons had to pass. Quite *small* variations in its voltage could make *large* variations in the main output circuit.



A quiet signal (left) could now be amplified into a larger signal (right).

Power from the battery had to be supplied (you cannot get extra electrical power without expending power) and it was also needed to heat the filament. This triode valve was of vital importance to radio development and you will not be surprised to learn that it was another example of multiple invention.

With the incentive to produce better reception technical advances were rapid. All the radio firms competed and by 1916 the vacuum inside the valves was much more complete, the filaments lasted longer and the performance had grown reliable. It was clear that the crystal, with its tricky cat's whisker, was fast becoming obsolete. Valves, which look so old fashioned to us now, had won the day.

By the help of these valves the first electronic revolution was launched. In 1922 the BBC began regular broadcasts, television came along in the 1930s, oscilloscopes came into use and even some early types of computers were constructed. Of course these valves had their disadvantages; they were slow to warm up, were rather bulky and needed frequent replacement since their filaments wore out in the same way as do those in our light bulbs. For controlling and amplifying the current, however, they had no rival for nearly fifty years.

In what countries and places did radio have the most effect on (a) medical services, (b) education?

The scientists still had no explanation for how the semi-conductors used in radios worked. From 1920 to 1940 very few university science departments even bothered to research the problem. It seemed to have little commercial importance and there were plenty of other more popular fields of research such as atomic or nuclear physics. During these years at least two hopeful inventors did try inserting a third wire into the crystal to act like the grid in a valve and so produce amplification but they failed.

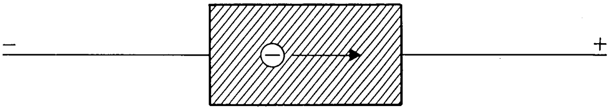
One trouble was that semi-conductors were exceptionally difficult materials to work with: they were ultra sensitive to crystal imperfections, to traces of impurities, to heat and to light.

The only firm which had sufficient funds and foresight to allow such an unpromising line of inquiry to go ahead at their expense was the giant Bell Laboratory, the research wing of the American Telephone and Telegraph Group which ran that country's telephone system. The majority of their scientific workers concentrated on the triumphant valve technology but a few studied the electrical properties of semi-conductors. One particularly far-sighted research manager even suggested that these might one day replace the cumbersome mechanisms of the telephone switchboard but in the 1930s this must have seemed a very long shot indeed.

Eventually some basic knowledge about the behaviour of these materials emerged:

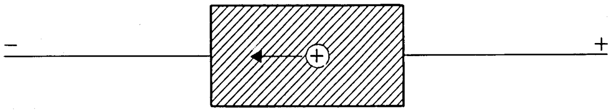
1 Unlike ordinary metals these semi-conductors possessed very few free moving electrons for carrying electric current – less than a thousandth of those in copper for example. Introducing the merest trace of impurity had a dramatic effect on the number of these. This was called 'doping'.

2 If the impurity were arsenic or phosphorus it boosted the number of electrons. Since these carry *negative* charge such 'doped' material was called *n-type*.



⊖ electron
N-TYPE

3 If either aluminium or gallium were the impurity it seemed to produce tiny electrical 'holes' in the semi-conductor, into which neighbouring electrons could move, so producing an apparent progress of the hole in the opposite direction (rather like the motion of the gap in the teeth of a comb as you run your finger along it). Since this was the equivalent to movement of *positive* charges such semi-conductors were called *p-type.*



⊕ positively charged 'hole'
P-TYPE

4 Junctions between n- and p-type material in the same crystal were peculiarly sensitive to heat and to light.

In 1939 two men at the Bell Laboratory whose names were to become famous in the post-war transistor revolution made yet another attempt to build a semi-conductor amplifier. They were William Shockley and Walter Brattain. Once again the attempt was a failure.

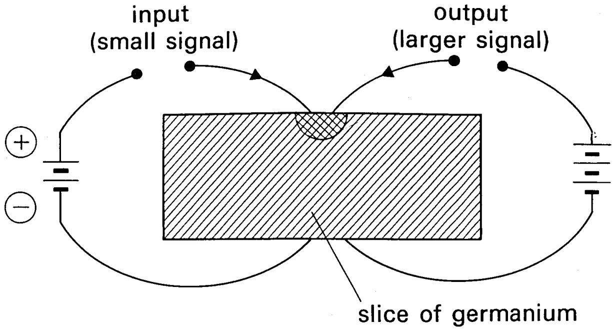
Give *two* general reasons why progress in microelectronics was so slow (use the ideas at the beginning of this book).

RADAR NEEDS MICROELECTRONICS

The outbreak of the Second World War had a significant effect on this field of research by a rather roundabout route. Both Britain and Germany had invented radar systems (Radio Detection And Ranging) for locating enemy ships and aeroplanes. At first there were land-based stations equipped with large aerials and great dish-shaped radio 'mirrors' to focus the reflected waves. Once air forces began making night raids it became important to equip fighting planes with mobile sets to act as their eyes during combat. These could only carry small aerials and receivers, so much shorter radio waves with very high frequency (about 3 billion cycles per second) had to be used. The British invented the necessary fast oscillator to produce these waves, a top secret type of valve which they demonstrated and tested at the Bell Laboratories in 1940. Such tremendously high frequency also needed an extremely fast type of rectifier. Tube valves could not work at that speed, and so interest in the old type of crystal diode using silicon or germanium was reawakened.

When America entered the war a renewed effort was made to understand the action of these point-contact diodes. Several university research departments were directed into this work to help the war effort and some more progress was made. Purer silicon and germanium were produced and the diodes became better. When the war was over most of this research was abandoned and it left the scientists at Bell Laboratories virtually on their own to use what new expertise there was.

In 1945 this small team was joined by another brilliant physicist, John Bardeen, who had a new theory about how the old point-contact diode worked. He and Brattain showed that there was a tiny sensitive region in the crystal just round the tip of the contact wire. By placing another wire on the surface of the crystal within half a millimetre of the main contact they succeeded in modifying the through-current. A small change in the input current produced a large change in the output current. This meant that, at last *amplification* was possible and the first prototype *transistor* was made and tested in 1947.



The first transistor amplifier (highly magnified).

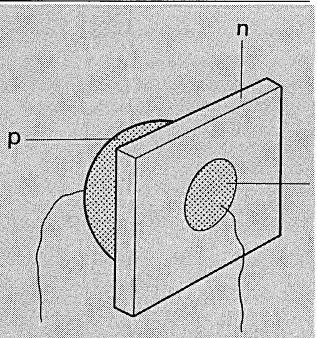
The scientists were jubilant, but the public and the market were unimpressed. The leading American newspaper, the New York Times, reported the discovery in about three inches of small print near the bottom of the page which gave the day's radio programmes. It is not really so surprising that the journalistic world showed such a lack of interest; the transistor, like any other invention, still had many technical hurdles to cross before it could become a real power for electronic progress.

What reasons can you think of for the final success of transistors?

TINY, PURE, AND VERY DIFFICULT TO MAKE

This transistor with its two 'cat's whisker' type contacts proved to be rather unpredictable in practice and only capable of handling the smallest amounts of current. Meanwhile William Shockley was working on another type of transistor where the amplifying action would take place inside the crystal across a double p-n-p junction. This kind of transistor is like the ones we use today but, as we shall see, it proved extremely difficult to make. Shockley announced this invention in 1948 but it was not until 1951 that the first prototype could be made to work, even in a laboratory.

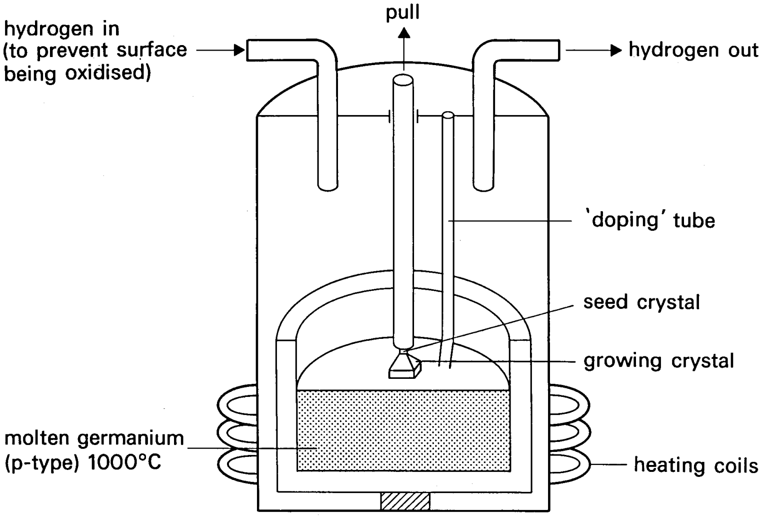
This early junction transistor was like a miniature cheese-roll made out of germanium. A small change in the current to the thin slice of n-type causes a large change in the through-current between the two pieces of p-type. You can easily obtain a modern version, the OC 71 for example; carefully snip the top off its black casing, clean out a little of the protective jelly and examine its structure. If you look closely you will see how it resembles the diagram, but you may need a magnifying glass!



Now if you can get some help to put this freshly opened transistor into a simple circuit, you can show that

1. it amplifies the current input;
2. it is sensitive to the light (try covering it with your hand, or holding a lighted match near it);
3. it is unstable if it gets heated by too much current – the current goes up and up.

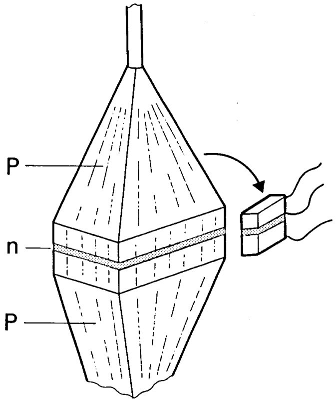
This transistor does work quite satisfactorily if kept inside its case and used with care, but it took many years to develop. Just imagine trying to start a new industry which would have to turn out small *perfect crystals* of the *highest purity* material doped with impurity to about one part in a million including a *junction region* (the sandwich region) of only one thousandth of an inch thick. Worse still, should the crystal have any imperfections, should it be contaminated to the extent of one part in a hundred million, or should the thickness of the junction vary, the final transistor will either misbehave or be quite useless. What a challenge! The basic scientific research had been done but the remaining problems for the manufacturing process and development were every bit as difficult.



Crystal-pulling for making transistors in the early 1950s.

You may remember from your own early attempts at growing crystals (copper sulphate, was it?) that you had to start by hanging up a small 'seed' crystal, and also that the process was very slow. Examine the diagram above and you should be able to tell how the early designers set about making their crystals. As the seed was slowly pulled upwards from the p-type melt, a tiny pellet of arsenic was added to dope the material and make it n-type. This became included in the next horizontal layer of crystal growth. Then another doping material, gallium this time, was dropped down the tube to change the melt back to p-type.

When the crystal had been removed the vital junction region was carefully sliced out and, with the finest diamond saws, cut into hundeds of tiny bars. To each of these, three terminals had to be attached using



Slicing the crystal: the junction region is sliced out and cut into tiny bars. Three terminals are attached to these.

minute soldering irons under a microscope. Such intricate work needed a very delicate touch and even as late as 1960 about 80 per cent of the workers in this new transistor industry were women.

The final testing stage could be very disappointing. Each transistor had to be graded and the results were unpredictable. A typical batch might yield the following:

20%	20%	40%	20%
Very good quality. Work at highest frequency. Worth £2.00 each.	Good quality. Work at high frequency. Worth 80p each.	Fair quality. Can only be used at low frequency. Worth 50p each.	WORTHLESS

It was rather like just throwing a net, blindfold, into the sea, and counting the lucky catch afterwards!

Even today, after years of production research, the semi-conductor industry still has problems. A few of every batch of transistors and chips may be faulty. Worse than that, the new and better semi-conductor, *gallium arsenide*, has been in development for more than fifteen years while production researchers struggle to make pure and perfect crystals of it. Fortunuately in the late 1950s new techniques and a better material than germanium were found.

THE ARRIVAL OF THE SILICON CHIP

The new technical advances included:

1 A new way of purifying germanium and silicon to a standard of one part in a hundred million!
2 A method of diffusing hot atoms of the required doping material directly on to a thin layer of crystalline silicon.

The wafer thin chip of silicon, including its p-n-p junction, was then cut up to make separate transistors. If you open the top of a used BC109 you can see for yourself the thinness of the chip with its gold-bonded surface.

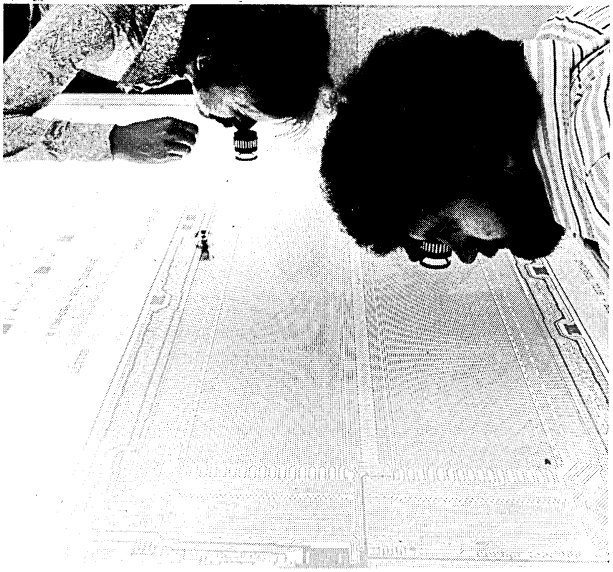
Then it was realised how wasteful this cutting up was, since the transistors all had to be reconnected again into a circuit. Why not print the whole array of transistors and interconnections straight on to the chip? This brought further advances:

3 The use of a mask (stencil), like that used in silk-screen printing, to control the areas on to which the different impurities had to be laid.
4 A photographic method of miniaturising the masks and aligning them, one after the other, to print metal connections and insulating layers as well.

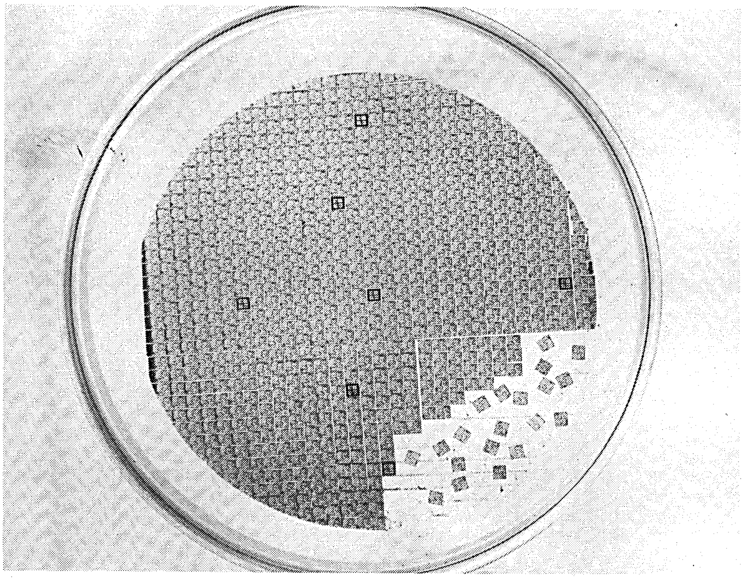
Thus, by 1960, the first *integrated circuits* were made and the age of the IC *silicon chip* had arrived.

Sections of the integrated circuit, much enlarged, can be checked on a visual display unit.

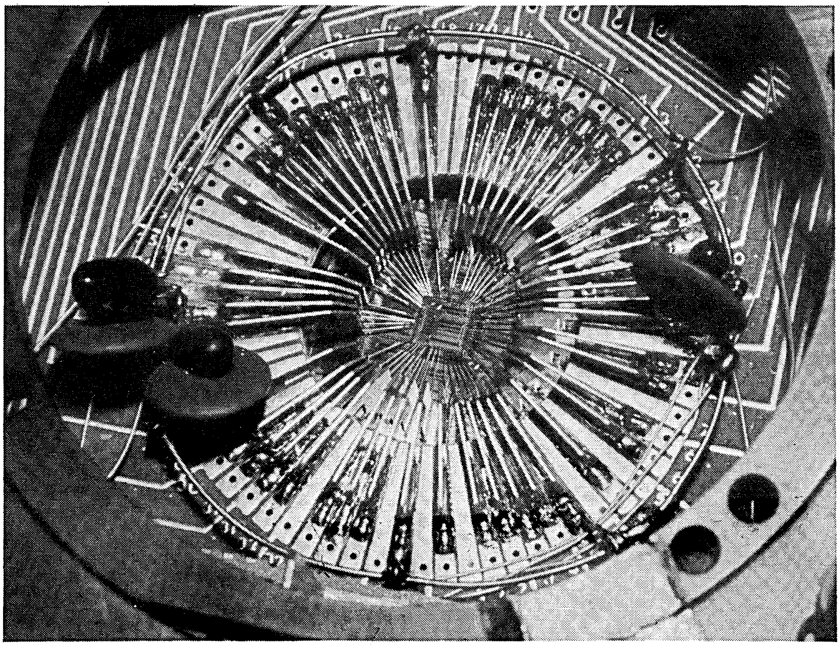
You will remember that, originally, the transistor had been developed to replace the valve. At first, however, they could handle only the smallest currents and they were *not* as reliable as the valve.



The chip layout is thoroughly checked on a light table. The blow up is 500 times normal size.



Each of these tiny squares contains a complete large-scale integrated circuit.



The chips are individually tested prior to packaging. The long contact needles are directed on to probe pads whilst being viewed through a microscope.

In which of the following would you expect the transistor to have scored its first successes:

> hi-fi music reproduction; portable radios; telephone switchboards; hearing aids; car radios; public address systems?

In one of these cases the use of the transistor was so successful that its name became used instead of the item. What do most people think a 'tranny' is? Why was the transistor such an improvement on the valve for this item?

THE SPACE RACE

From the beginning the American military showed keen interest in the new industry and its products; they provided about half of the large amount of money needed for commercial R and D programmes. Transistors were tested for military use in communications and weapon-guiding systems; many proved unsuitable but the wastage did not seem to matter if the final component worked. The military had an almost total disregard for cost. 1957 was a particularly significant year; this was when the first satellite, Sputnik, was launched by the Russians. It was hardly bigger than a football but it carried a powerful radio transmitter. US technical pride suffered a terrible blow. It was even worse when their own first efforts to launch a satellite met with humiliating failure; so that from then onwards they were eager to back every attempt to produce electronic miniaturisation. Such superiority in the 'space race' also suggested a more frightening superiority in missile control systems. As one technical innovator has put it: 'All you had to do was wave the Russian threat and you could get money!'

CHIPS FOR COMPUTERS

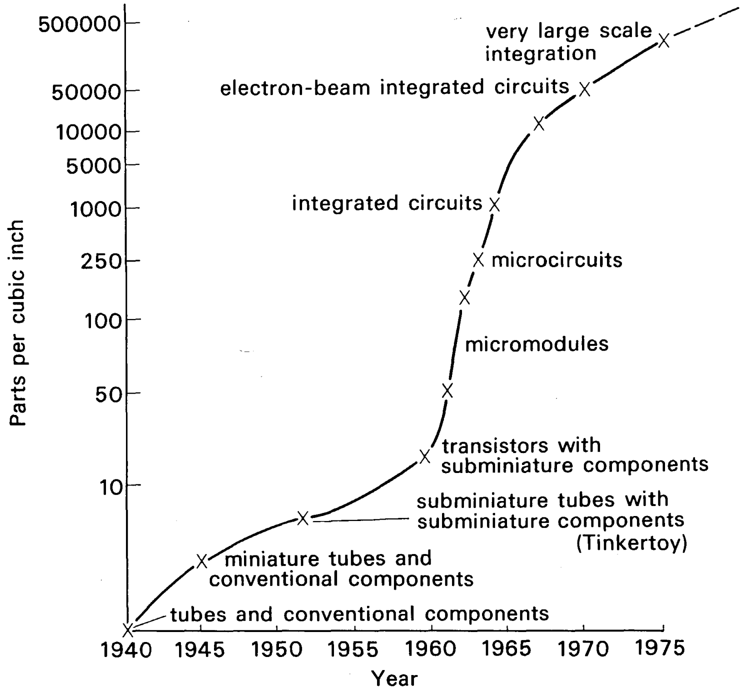
Sales of US transistors in 1963 (millions of dollars)

Military		**Industry**		**Domestic**	
Space	33.0	Computers	41.6	Car radios	20.6
Aircraft	22.8	Communications	16.0	Portable radios	12.6
Missiles	20.3	Testing	11.7	Hearing aids and organs	7.3
Communications	16.8	Others	23.0	Television	0.3
Others	26.3				

You will see that the largest single item on these lists was the fast-growing *computer industry*. Just after the war the first generation of electronic computers had been built using valves (as many as a thousand to each instrument) but they had not been very satisfactory. Each valve had only a limited lifetime since its hot filament was bound to burn out eventually. They also used an enormous amount of power. Indeed valve computers generated so much heat that it was said that you could cook your dinner on them while they were working!

Transistors, of course, had no such hot filaments but they also possessed another advantage: they could handle pulses of current *without any amplification* being needed. As we shall see, transistors and IC chips could act as special kinds of switches to open and close electronic 'gates' in the circuit using hardly any power at all. There was now no need to limit the number of components in any new computer. Even in 1963, it was possible to see in which way the new microelectronic revolution was going.

Both the space programme and the computer industry wanted more and smaller parts at just about the time when integrated circuits were becoming cheaper to make than the equivalent number of transistors.



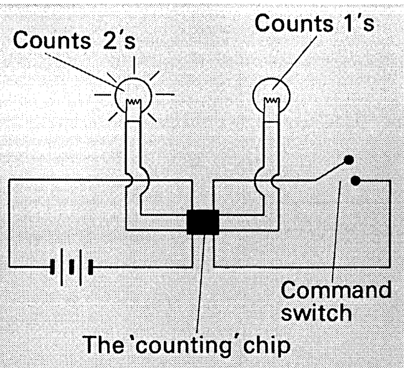
The increase in the use of small parts in computers. Note the scale on the vertical axis.

The small size of the IC chips brings more advantage than just convenience or economical production; it also means *quicker* control of the flowing pulses of current. Hardly has the stream of electrons or holes advanced a tenth of a millimeter than it is halted, stored, divided or amplified. *Smaller* size makes for *faster* operation.

You probably know that computers contain 'memory' chips. Information is fed into these by electric command currents and gets fixed into the chips for future use.

If this sounds odd to you it may be a good idea to set up a very simple counting chip to see how it works. Counting involves memory because you need to remember what number you got to last time.

1 Press the switch briefly to get a pulse of current.
2 One light goes on – and stays on – so remembering what you did. Count '1'.
3 Press the switch again briefly.
4 The first light goes off and the second light goes on, and stays on. Count '10' in binary, that is 2.



Of course this is very simple. It is now possible to buy chips so complex that they will remember and store 64,000 bits of information.

NEW DEVELOPMENTS

During the early 1960s the transistor industry showed signs of going into a recession; production had outstripped demand. The market for radios seemed to be saturated. What other transistor product would the public buy? It was a challenge to 'invention push' and the answer was an item for which no one previously had ever felt the need – the *pocket calculator*. It was a huge success, not only in terms of profit but also in technical 'spin-off'.

The first calculators were made from several transistors or chips which had to be assembled and connected by hand. Many were made in Japan from American components. Gradually they became more integrated until, by 1975, it was possible to obtain the whole of the electronics on a single chip. Manufacturers only needed to add a case and a battery. The *microprocessor* had arrived.

Prices of calculators (in £s)

	Simple	Scientific	Business
1974	13	40	85
1975	11	30	29
1976	9	24	22
1977	7	19	17
1978	5.50	15	13

What are the main reasons for this drop in price?
When did the prices drop most sharply?
What type of calculator has shown the largest percentage drop in price?
Why is this?

You often hear criticism of this kind of commercial enterprise because it sets out to create a need where there was none before. It is said to make us both more greedy for material goods and more dependent on them. In particular it is said that calculators make children lazy so that they forget how to do arithmetic.

Do you think arithmetic is important? Should young children still be made to learn their multiplication tables?
How do you rate the calculator?
What about the digital (quartz) watch? Who benefits? Who suffers?

THE COMPUTER FUTURE AND ITS SOCIAL EFFECTS

Micro processors and giant 'memory' chips storing thousands of 'bits' of information on a few square millimeters of area launched the great innovation of the 1970s and 1980s – the cheap microcomputer costing as little as £500 (1980). Of course large computers for industry, banks and research organisations continue to be made and improved and they may cost millions of pounds. The whole range of instruments is likely to influence our lives in many ways.

1 *Industry*

Factories will become more automated. This will make goods cheaper and should provide the country with more wealth. It will also displace many people who do rather boring or routine jobs that a computer-controlled 'robot' could perform.

What human *problems*, as well as human *benefits*, do you foresee in this?
Would there be less unemployment if Britain's factories were *not* automated?

2 *Banks and Business*

Computers are ideally suited for storing information, analysing it and making it almost instantly available. Few people will be displaced since new uses, such as the cash and credit cards, give computers jobs which had *not* previously existed. There has been some criticism about the amount of information, of a personal kind, which is potentially available to those with access to the computer programme.

What advantages do the credit-card systems possess?

Are computers free from human error?

Can computers be an invasion of personal privacy? How would the school office use *your* data in such a computer?

3 *View-data Systems*

You can already buy a system for seeing the information that you want displayed on your ordinary TV set. This could be anything from a weather forecast, the latest Stock Market prices or the cost of goods for sale in the local shops. In principle you would then be able to select the 'best buy', dial, order and pay for it, all without going out of your house.

Does such a method of shopping appeal to you?

What social advantages and disadvantages would this have for working or home-bound women?

4 *Medicine*

Some remarkable new diagnostic machines have been invented recently for scanning the whole body, inside and out, to locate trouble spots. At the moment these, and their computers, are very expensive. Electronic implants, like the famous pace-maker, are becoming more common. No doubt doctors will also soon be using computers to store our medical records and to prescribe treatment.

Will there still be room for human skill, and, if so, in what special fields of medicine?

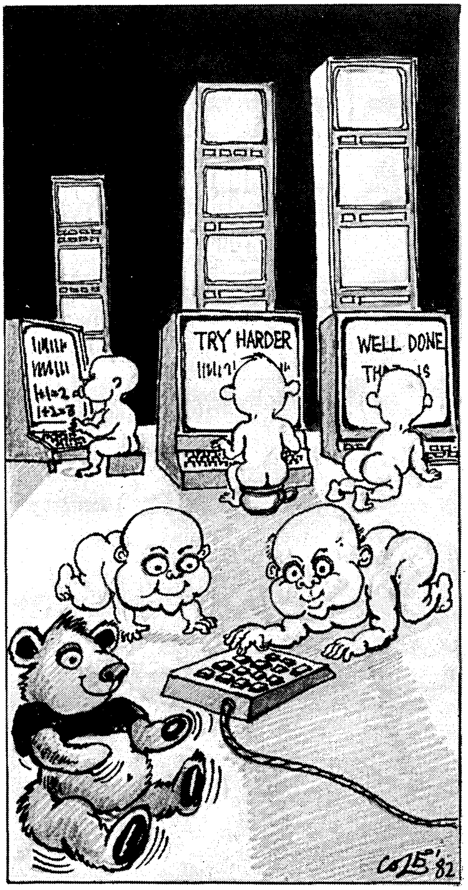
5 *Education*

Teaching machines, rather like the view-data systems, could become available. They could print or speak information, test you, mark and store your results. Maybe each pupil will have his or her own pocket computer packed with as much information as the whole school library.

What difference would this make to lessons?
What would still be essential in education?
What skills do computers teach?

Many schools now have microcomputers for the pupils to use. They are even beginning to go into primary schools, in order to start young children early in computer skills.

Can you use a microcomputer like an extension of your brain, to think with?
Should education be completely changed – or should computers?



'To prepare children for life in a society in which devices and systems based on microelectronics are commonplace and pervasive.'

Suggested Reading

Wealth from Knowledge Langrish, Gibbons, Evans, Jevons (Macmillan)

A study of technical innovation in modern industry which includes the theoretical ideas touched upon in the first section. Authoritative but rather dry.

The Scientific Breakthrough Ronald Clark (Nelson)

Written for a popular audience and might well appeal to those over 16 years old. Contains accounts of inventions from many fields including plastics and communications.

Facts of Life R. Reddon (Macdonald Educational)

Based on a TV series this gives an elementary account of the connection between economics, political control, and developing industry. For those over 15 years old.

The Force of Knowledge J. Ziman (Cambridge University Press)

This was written for an undergraduate course but is fairly easy to read and very well illustrated. Many different examples to show the relation between science, technology and the Research and Development system.

Science and Decision-Making 'Patterns' W. Hall (Longman)

One of the readers for the SCISP course. Well-documented and illustrated stories of invention including plastics, oil, and high-rise flats.

Alfred Nobel Nicholas Halasz (Robert Hale)

A well-written biography which takes the story of explosives further, and contains plenty of social comment as well as personal history.

Giant Molecules H. F. Mark (Time-Life International)

A small book all about plastics. Plentifully illustrated in colour, easy to read stories from celluloid to the latest plastics. 15 years and over.

From Marconi to Telstar Norman Wymer (Longman)

A very simple introduction to the history of radio, broadcasting, television and radar. Not up-to-date on satellites. 12 years and over.

Revolution in Miniature E. Braun & S. MacDonald (Cambridge University Press)

Good for reference. This is an authoritative book on the development of semi-conductors, transistors and chips, with economic and scientific details.

Scientific American September 1977

This whole issue is devoted to Microelectronics. It is very well illustrated and particularly good on the technology of chip-making.

Science In a Social CONtext is a series of eight books based on the project SISCON-in-Schools. The books provide a new course in science and society for general studies at sixth-form level. The course has been specially designed to make scientific problems accessible to the non-scientist, as well as to explain the social aspects of science to the scientist.

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The Atomic Bomb
Energy: the Power to Work
Health, Food and Population
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