

DISCOVERY 23 Independent Television Programmes for Schools Spring Term 1967

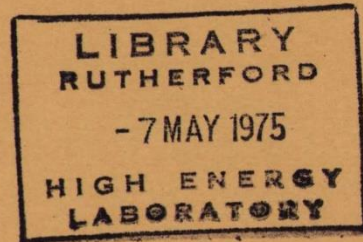
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Machines for a new age

Part one

The story of the Electronic Digital Computer

Part two

Nimrod: A machine to smash atoms

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DISCOVERY 23

Twenty-third series of Television Programmes for Science Sixth Forms

Machines for a new age

The story of the Electronic Digital Computer

Presented by Professor Stanley Gill

Nimrod: A machine to smash atoms

Presented by Dr. T. G. Pickavance

NOTES ON THE PROGRAMMES AND SPEAKERS

GRANADA TELEVISION *Manchester 1967*

Television programmes for schools are available in the areas indicated below.
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DISCOVERY: TRANSMISSION TIMES SPRING TERM 1967

MACHINES FOR A NEW AGE

THE PROGRAMMES	GRANADA	ALL OTHER REGIONS EXCEPT GRAMPIAN
<i>Part I: The Story of the Electronic Digital Computer</i>		
<i>Programme One</i>		<i>p.6</i>
The Speed Revolution	11.30 am Jan. 10 2.05 pm Jan. 11	2.05 pm Jan. 11
<i>Programme Two</i>		<i>p.7</i>
The Anatomy of Computers	11.30 am Jan. 17 2.05 pm Jan. 18	2.05 pm Jan. 18
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Programming	11.30 am Jan. 24 2.05 pm Jan. 25	2.05 pm Jan. 25
<i>Programme Four</i>		<i>p.10</i>
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What is a Proton Synchrotron?	11.30 am Feb. 21 2.05 pm Feb. 22	2.05 pm Feb. 22
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How was Nimrod designed and built?	11.30 am Feb. 28 2.05 pm March 1	2.05 pm March 1
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How is the research done?	11.30 am March 7 2.05 pm March 8	2.05 pm March 8
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The K7 Experiment	11.30 am March 14 2.05 pm March 15	2.05 pm March 15
Further Reading		<i>p.18</i>

This series of programmes has been approved by the Educational Advisory Council of the Independent Television Authority and the Educational Advisory Bodies of the Independent Television Companies. Additional copies of this booklet can be obtained through the Head of your school who has been supplied with an order form for this and other publications.

Introduction

This term, the twenty-third in the DISCOVERY series, the ten programmes presented are in two groups.

The first six programmes, presented by Professor Stanley Gill of Imperial College, University of London, tell the story of electronic digital computers.

Of the importance of electronic computers—not only in scientific research, but also in industrial and commercial fields many of which affect our lives—there can be no doubt.

MACHINES FOR A NEW AGE is a television primer on computers, providing an introduction to how they work and what they can do—for the future arts graduate who may train for business management as much as for the future scientist or engineer.

The last four programmes are presented by Dr. T. G. Pickavance, Director of the Rutherford High Energy Laboratory. The *Machine for a New Age* with which he deals is NIMROD, the 7 GeV Proton Synchrotron. Nimrod is the principal research instrument of the Science Research Council's Rutherford Laboratory, where resident physicists and visiting physicists from the universities conduct experiments in High Energy Physics to probe the fundamental laws of nature.

The summer 1967 term DISCOVERY programmes will look at some aspects of chemical technology.

PART ONE

The Story of the Electronic Digital Computer

The electronic computer was born out of World War II in the same laboratories that had developed radar. It was nurtured in the lean post-war years, and had a quiet beginning. A few stories about 'electronic brains' appeared in the press, and were quickly criticised by scientists as 'too sensational'. The scientists' own accounts, however, seemed complicated and dull, and the press finally gave up trying to make news of what seemed to be just another bit of expensive special equipment, like electron microscopes or linear accelerators. For about ten years, not much seemed to be happening.

But within the last few years computers have erupted into the news again, this time in a much more serious way. They are no longer pieces of scientific equipment; they are to be found in hundreds of business offices and in many other places, doing jobs that often seem far removed from what we usually think of as computing; jobs like scheduling work in a factory, or composing type for printing. Computers are now a matter for national policy. They have been described as the equivalent, in the second industrial revolution, of the steam engine in the first. No longer are they simply for scientists: they concern us all.

But what are we to make of them? What determines how far they can be used? What must we do to exploit them properly? How can the non-specialist begin to understand what they can do? Questions like these are being asked by everyone, from cabinet ministers down; and not the least in schools, for it seems likely that the pupil of today, whatever career he chooses, will find it shaped largely by computers.

PROGRAMME ONE

The Speed Revolution

Most of the basic ideas in the electronic computer had been thought of before—many of them a hundred years before, by the mathematician Charles Babbage. To make an automatic computer, you find some tangible way of representing numbers, e.g. by the positions of wheels or levers. Then you arrange that these control some device which is designed to produce the representation of another number. This other number is the sum, or difference, or product, of two given numbers started with. This much is, of course, achieved by many small machines, like cash registers.

The advantage of using electronics is simply one of speed. By using a purely electrical representation of numbers, and using electronic devices to combine these signals so as to mimic the operations of arithmetic, the arithmetic can be done faster, because there are no moving parts. But there are disadvantages too; since the electrical signals cannot be seen, some means have to be provided of making the results visible.

However, the speed advantage is so enormous that it completely outweighs all the disadvantages. Modern computers are about a million times faster than their mechanical predecessors. Now, a long multiplication can be done in a few millionths of a second! As soon as it was shown that electronic computers were a practical proposition, their exploitation began in earnest.

Much of the story of computers is concerned with the ways in which their designers have arranged for numbers to be represented. There is one basic choice facing the designer, which has nothing to do with whether the machine is to be electronic or not. This is the question of whether a number which may vary smoothly and continuously is to be represented by something which itself changes smoothly and continuously; or is it to be represented by a set of digits which can only change in jumps? The former method is used, for example, in the slide rule, in which the cursor moves smoothly and can be brought to rest in any position. Machines working in this way are called *analogue computers*; they are comparatively cheap and simple to use, and many types of them exist. More exciting, however, are the *digital* machines, because they are enormously more versatile. Digital computers have attracted nearly all the publicity of recent years, and it is with them that these programmes are concerned.

The mechanical machines used the scale of ten, as we do ourselves, and each decimal digit was usually represented by a wheel, which could come to rest in any of ten positions labelled from 0 to 9. The first electronic computer, the ENIAC built in Philadelphia in 1945, used the same idea. Instead of wheels it had rings of electronic circuits, so arranged that only one circuit in each ring could be switched 'on' at any moment. Thus each ring could 'remember' a decimal digit, and it could also accept pulses that would step the digit on, so that addition could be performed as in a cash register. The connections between the electronic registers, and the sequencing of operations, had to be set up on a vast plugboard before each calculation could start.

It was immediately realised that this kind of design was quite inappropriate for an electronic machine, and later electronic digital computers all followed a quite different pattern. New ideas had to be introduced—new, that is, to electronic computers, although Babbage had used them before.

One idea was to have a separate part of the machine simply for 'remembering' or 'storing' numbers, which couldn't itself do any arithmetic. To make effective use of an automatic computer, and especially one working at electronic speeds, the machine must be able to retain several numbers that it is working on, and refer to any of them whenever they may be wanted for the calculation. Nowadays we need storage for several thousands of numbers, and it would be quite impractical to use rings of circuits as in ENIAC. Instead, special storage devices have been developed, based on various physical principles. So far as the engineering of computers is concerned, the rest of the story centres mainly on the development of these storage devices.

PROGRAMME TWO

The Anatomy of Computers

The circuits in a digital computer deal with electrical pulses, which at a particular moment may be either present, or absent. Information, such as numbers, must be coded as a pattern of pulses, just as letters in the Morse Code appear as a pattern of dots and dashes. In a computer the pulses may be arranged either serially, i.e. at successive moments of time, on the same piece of wire, or in parallel, i.e. simultaneously on several wires; the distinction is not a fundamental one, and pulse patterns are often converted from one form to the other, as they travel around inside the computer.

One of the first ways of storing numbers was to 'write' the pulse pattern as a pattern of electric

charges on the inside face of a cathode ray (television) tube. A way was found of 'reading' them off again and transmitting them back to the rest of the computer as required. Also every number had to be read and then rewritten at regular intervals (of less than a second), otherwise the charges would leak away—the numbers would be 'forgotten'.

Another way was to send the pulses, serially, through a 'delay line', which is simply a device that delays them for a considerable time—perhaps for as long as a thousandth of a second. The pulses might be occurring as frequently as one every millionth of a second, so that a thousand new pulses could be sent into the delay line before the first one emerged again. Then as pulses emerged they were fed into the entrance again, and so continued to circulate through the line so long as the circuit was not interrupted.

Nowadays the commonest store is made of magnetic 'cores'. These are little rings of magnetic material, which can be magnetised either clockwise or anti-clockwise. Many thousands, or even millions, of these cores are threaded on a mesh of wires, so arranged that by driving pulses of electric current through some of the wires, any core can be magnetized in a chosen direction. Alternatively, the direction in which it was last magnetised can be determined. Thus a pattern of pulses can be 'remembered' in the form of directions of magnetisation of a row of cores, and can be reconstituted later when required.

The two major parts of a computer are its store and its arithmetical unit. It is in the latter that new pulse patterns are formed, representing new numbers which are the results of doing arithmetic on other (given) numbers. Some particular code for representing numbers must be assumed, of course. We can use the ordinary decimal scale, and invent a distinctive pulse pattern to represent each decimal digit, but many computers use the *binary scale* instead. A binary digit can have only two possible values, 0 and 1, and so can be represented by either the absence or the presence of an electrical pulse.

Most of the traffic inside a computer, amounting to many hundreds of thousands of numbers a second, flows between the store and the arithmetical unit. Numbers required for arithmetic are extracted from the store and sent to the arithmetical unit, and the results are sent back to the store again, to be 'remembered' for some future arithmetical operation. Occasionally, however a result is formed which is not merely required to be kept for some later stage in the calculation, but is one of the final results of the whole job. It may be sent to an electrically-controlled printer attached to the computer, or to some other kind of 'output' device. Here it is recorded on magnetic tape, or punched in a suitable code on punched cards or punched tape, so that it can be used for various purposes later.

Similarly, before a calculation can begin, the initial data must be fed in through some kind of 'input' device, and converted into a pulse pattern. It is possible to have a keyboard with electric contacts, directly attached to the computer, but it saves time to have the data already prepared on punched cards or tape, and to let the computer 'read' it by means of machines which can detect the holes in the paper at high speed.

Thus we have all that is needed to enable numbers to be fed rapidly into the computer, enormously long calculations to be done inside, and the results to be put out in visible form. One thing remains—to direct the computer to perform the right sequence of operations for a given calculation. This is where another 'new' idea, adapted from the earlier work of Babbage, was introduced into the machines that followed the ENIAC.

The idea was to list all the possible operations that could be performed inside the computer, including all the necessary transfers of numbers from place to place, and to describe each one by means of a concise '*instruction*'. A calculation then became a long series of operations, each specified by an instruction, and the instructions could all be prepared in advance and given to the computer as it needed them. A part of the machine called the 'control unit' deciphered each instruction and sent control signals to all the other parts of the machine, telling them what to do.

One innovation was needed, however, which Babbage had not foreseen. His machine was planned to read each instruction off a punched card as it was needed. We now have very fast card readers capable of reading a dozen or more cards every second, but even this is much too slow to keep place with the operations of an electronic computer. The innovation was simple: the instructions were to be read, not directly from cards, but from the computer's own store. A code had to be established (called the 'instruction code') whereby each instruction could be represented, like a number, as a pulse pattern; and a pathway had to be provided from the store to the control unit.

This method of working was immediately seen to have tremendous potentialities, giving the user freedom to call for some extremely complicated calculations. It is now used almost universally. The task of preparing the instructions, or '*programming*' the computer, has now grown into a widespread occupation.

PROGRAMME THREE

Programming

Programming can be illustrated by some simple examples of short calculations involving only a few numbers. Other features of programming can then be introduced which enable more complex activities to be performed.

The first of these is the 'jump' instruction which prevents the computer from continuing to obey the following instructions consecutively as they are written and held in the store. It switches attention suddenly to another point in the programme. Most significant is the 'conditional' jump instruction, of which there may be several versions, causing a jump only under certain conditions. The conditions are framed in terms of one or more of the numbers on which the computer is currently operating. For example, the computer may be told to choose one of two possible courses of action depending on whether a number which it has just computed is positive or negative.

A jump instruction may switch the computer back to a previous point in its programme, so that it repeats some operations that it has already done. It may do this several times in succession before proceeding to another part of the programme, so that a comparatively few instructions suffice to keep the machine busy for a relatively long time. The route followed by the computer as it works its way through a programme may indeed be very devious.

Another trick which the programmer may use is to tell the computer, by means of some of the instructions in the programme, to alter one or more of the instructions in another part of the programme. This it can do because the instructions and the numbers are all coded in the same form and held in the same store, so that it is just as easy for the computer to operate on its instructions as on the numbers that are given to it. So common is this trick that special arrangements are usually made in the design of computers to enable it to be done quickly and simply.

Using all these tricks, some very big and elaborate programmes can be written. To speed up the job of writing them, a number of techniques have been developed. One is to break the calculation down into parts, programme each part separately, and then fit the parts together. The parts of the programme are called 'subroutines'. Sometimes the same piece of calculation crops up frequently in a number of different programmes, and the same subroutine can be used each time; a collection of standard subroutines is kept for this reason. By taking a few standard subroutines from the 'library' and weaving them together with a few fresh instructions, quite a big programme can be assembled quickly for a new job.

The programme illustrates the computer programmer's approach to two simple problems.

Computers are Useful

Because electronic computers were invented in research laboratories, mostly in universities, they were first applied to scientific research. There were other reasons for this, too. The early machines were not equipped with very good input and output devices, and could not handle the masses of data which are found, for example, in business offices. Also the art of programming had yet to be learnt, and it was only in the concise mathematical equations by which scientific principles were expressed that worthwhile computations, which could be defined by simple programmes, were to be found.

Most of the early uses of these machines were therefore in testing scientific theories—in following through all the consequences of hypotheses, to see whether they agreed with the observed facts.

Soon it was seen that they could be equally useful in engineering design. To work out the consequences of designing a building, or a bridge, or a power station, in a particular way, was only a little more complicated than testing a scientific hypothesis. The speed of computers allowed many more alternative designs to be examined than had ever been possible before, so that small but significant improvements could be made over previous designs.

Then came improvements in the computers themselves: more input and output equipment, bigger stores, enabling longer programmes to be accommodated, and so on. These provided the key to the use of computers in business offices. During the second half of the nineteen-fifties they were adopted as essential equipment for every large business firm.

The first business uses were different in nature from the early scientific and engineering uses. The scientists and engineers were studying hypothetical situations, often many thousands of them, using data that was mostly generated inside the computer itself. The businessmen had real data to deal with, actual transactions that had taken place and had to be recorded, checked, summarised, and so on. More recently, however, scientists and businessmen have been adopting each others' ways. Scientists have used computers to analyse very large amounts of real data gathered from experiments (one of the biggest computing loads today comes from the physicists who are studying the fundamental particles, and who have to analyse millions of photographs in the search for new phenomena). Conversely, business managers have found that it sometimes pays to make hypothetical studies of their businesses, to seek out the best way of running them. It is true that businesses do not follow simple mathematical laws, but nevertheless there are some business problems that can be described sufficiently closely in mathematical terms for a computer to help in studying them.

What computers have done, in fact, is to alter the economic balance between calculation and intuition. Calculation has now become very much cheaper, while human intuition can still cost as much as before! Hence, where there is a possibility that guesswork might be replaced by calculation, computers are likely to make this change economically attractive. The search for such situations continues, and is creating a great demand for mathematicians who can devise suitable computations.

The practical uses of computers are now being extended by arranging for their input and output signals to be sent long distances over wires, so that data can be gathered and results displayed at many places, perhaps many miles apart. Already, a computer at the Massachusetts Institute of Technology has been demonstrated to audiences in this country, via the international Telex (teleprinter) network. Computers can also be linked directly to chemical plant, controlling it without human intervention.

Of less immediate practical interest, but perhaps of greater interest in the long run, are investigations into the programming of much more sophisticated tasks such as translating languages,

or seeking proofs of theorems by computer. This work has proceeded alongside the development of more powerful ways of writing programmes.

PROGRAMME FIVE

More about Programming

Translating between languages such as English and French is something that has not yet been achieved by computer, and is not likely to be achieved for a very long time, except in an imperfect way. This is because the rules have not been explicitly stated; you have to learn them by example, which is something that the human mind is capable of doing without being aware of how it does it. Computers—so far, at any rate—need explicit rules to tell them what to do.

The instruction code of a computer is a kind of language. Moreover its meaning is quite explicit; it is embodied in the design of the computer, which is there for any engineer to see. It ought therefore to be possible to invent other programming languages, also explicitly defined, and to work out explicit rules for translating programmes from one to another.

This has been done, and there are now a number of programming languages in use which are much more convenient for most purposes than the order code of the computer itself. Moreover some of them can be translated into the order codes of several different computers, so the same programme can be used in many places. One of the best known is called 'Algol'.

The programme that tells the computer how to translate from a language like Algol into the machine's own order code, is called a *compiler*. In a compiler, the computer is of course dealing not with numbers but with instructions, and with the strings of characters that make them up. The processes which it performs are therefore not so much the ordinary ones of arithmetic, but simply the processes of comparing, sorting and replacing characters and other symbols. These, however, can equally well be included in the repertoire of the computer's 'arithmetical unit', and can be called for within a programme.

So much thought has been devoted to the problems of automatically translating languages, both natural and artificial, that a formal mathematical theory of language structure has emerged. The syntax of a language—at least, of a strictly defined one like a programming language—can be expressed in a few concise statements. Many compilers are now planned so that these statements stand apart from the rest of the compiler, which tells the computer how to apply these syntax definitions in order to do the actual translation. Thus it is a simple matter to change the syntax of the language being translated, without having to rewrite the whole compiler.

So much programming is being done nowadays, that it is important to have compilers that provide a good translation, i.e. a programme that makes efficient use of the computer and does not waste its time doing needless operations. The compilers themselves can be very big, and contain tens of thousands of instructions; they are themselves written in a language which has to be compiled into the computer's own language.

The compilers must do other things besides the actual translation. They must make the computer print out diagnostic information to help the user to locate any mistakes he may have made in his programme. For it is almost impossible to get a big programme right first time, and most programmes have to go through a lengthy period of testing before they are fit for use.

In addition to compilers, most modern computers need a programme, sometimes called a 'supervisor' or 'monitor' programme, which takes charge of the computer between jobs and arranges for the work to be fed through the machine as expeditiously as possible. Often, in a big machine, there are several things going on at once; one programme may be on its way into the

machine while the previous one is being worked on, and some results from a previous one are being printed. The computer switches its attention from one thing to another as necessary.

In this programme, the working out of a chess problem is illustrated in terms of the computer language, *Algol*.

PROGRAMME SIX

What Next?

The number of computers in the world has been almost doubling every year for the last fifteen years, and there are now about 50,000 of them. More computing is now done by machines than by men. Most large organisations use them for their clerical work and for planning their operations, and will use them more and more in the years ahead. When we deal with a big firm we will in most cases be dealing with a computer, which will process our enquiries, meet our orders and make out our bills. Transactions between firms will largely be carried out by the computers themselves, the human controllers seeing little of the individual items.

Documents will be located by computers when required; perhaps even the information in the documents will be filed in computer stores and used by computers to answer direct questions.

What, then, will be left for men to do?

For those who understand the machines, and who direct their operation through great volumes of programmes, there will be plenty to do. Our imagination has already outrun our ability to provide the detailed programmes for the computers we have. It is easy enough to picture a machine that will play a nearly faultless game of chess, or will translate flawlessly from Russian into English; and there is no doubt that some of the computers already built are adequate for these tasks. But no-one, as yet, has written the programmes. Doing so will probably exercise the ingenuity of some of our ablest minds for many decades to come.

When the daily transactions of business and government are carried on by computers, it is the programmers who will have a great indirect effect on our lives. Ministers and managers may decree the policies, but the programmers will interpret them into actions, which the computers will faithfully perform. The programmers must exercise foresight and humanity; for it would be a tragedy if, in lifting the burden of clerical drudgery from men's shoulders, we were to subject the same men to a harsh and inflexible administration.

In a world of machines, we should prize the essential human qualities more highly than before. Kindness, cheerfulness and compassion are qualities of men, not of machines, and if a man cannot show them, he might as well be a machine. The highly respected positions will be those in which a man can show his personality by offering a personal service, either as an individual or as the representative of an organisation.

If we can learn to live with machines, we may yet find that our lives are enriched with their aid. Leisure interests and hobbies will take great strides when the thirst for knowledge can be amply satisfied by consulting an automatic library. Music of greater beauty than ever before might result when the ingenuity of a mathematical machine is harnessed to the musical inspiration of a man.

Already machines have played draughts with men, composed music for men, and helped men to design buildings and machines. If we only understand them fully, machines will make the new age a richer one for all men.

This final programme—the first education programme to use Early Bird—illustrates some of the powers of modern computer systems, in particular 'project MAC' at the Massachusetts Institute of Technology.

BINARY NOTATION

DECIMAL	BINARY
1	I
2	IO
3	II
4	IOO
5	IOI
6	IIO
7	III
8	IOOO
9	IOOI
10	IOIO
11	IOII
12	IIOO
13	IIOI
14	IIIO
15	IIII
16	IOOOO

etc.

PART TWO

Nimrod: A Machine to Smash Atoms

Nimrod is a 7 GeV (7,000 million electron volts) particle accelerator, and is the principal research instrument of the Rutherford Laboratory, Chilton, Berkshire. The Rutherford Laboratory serves as a base where universities can carry out fundamental research in the physics of elementary particles, side by side with the Laboratory's own research staff whom they outnumber. The work at Nimrod and with the associated apparatus needs the services of about 1,200 people, not including the visiting research workers, and costs £6 million a year. In these four programmes, Dr. Pickavance explains why it is necessary to work on such a large scale, and with such expensive instruments, in one specialised branch of physics, and gives his own account of how Nimrod was designed and built, and how the physicists go about using it in their research.

PROGRAMME SEVEN

What is a Proton Synchrotron?

A particle accelerator is an electrical machine which accelerates charged particles to high speeds, in a vacuum, through electric fields produced by high voltage apparatus. Nimrod is a proton synchrotron, and accelerates protons, held in closed orbits by a ring-shaped electromagnet 150 feet in diameter and 7,000 tons in weight, through 7,000 volts on each orbit. The protons are injected into the ring by a linear accelerator, at 15 million electron volts, and make 10^6 orbits, a total distance of 80,000 miles, to reach 7 GeV in 0.7 second. The magnetic field strength is steadily increased during this time, to keep the protons in the ring, with the help of two very large motor generators and a bank of 96 rectifiers connected to the magnet coils. The magnetic field is returned to zero again, ready for the next pulse of protons to be accelerated, by reversing the voltage on the magnet coils—again in 0.7 second. The process is repeated 28 times per minute. The machine is enclosed in heavy concrete and earth shielding, to protect its operators from dangerous radiation, and therefore has to be remotely controlled.

To understand why physicists need such enormous machines, it is helpful to consider the history of research in elementary particles. The ancient Greeks believed that matter was made up from atoms, but the chemists proved it scientifically only in the nineteenth century. Later, J. J. Thomson discovered the electron, and later still Rutherford and Bohr showed that atoms have a small, heavy, positively charged nucleus surrounded by a cloud of orbiting electrons. By 1932, Chadwick's discovery of the neutron showed that the nuclei are composed of protons and neutrons. What was missing was an explanation of how the protons and neutrons stick together in a nucleus, against the disruptive forces between the electric charges on the protons. Yukawa showed that

these forces can, in principle, be explained by the exchange of another particle, a meson, between protons and neutrons—a particle heavier than the electron but lighter than the proton or neutron. Mesons of Yukawa-type were discovered by Powell in 1947, coming from collisions between cosmic ray particles and the atomic nuclei in photographic emulsion. But shortly afterwards other, and unexpected, particles were discovered—some of them heavier than protons. By the use of powerful accelerators, over a hundred different particles have now been observed. The search for the elementary constituents of matter has led into the interior of the proton, and regularities and symmetries can be seen, as yet dimly, in the large families of so-called elementary particles now known. The situation is reminiscent of that when Mendeleef produced his periodic table of the elements. To unravel this mystery, which lies at the root of the nature of the physical world requires more and more detailed experiments and theoretical study of the results. The experiments require the huge machines, because the elementary sub-nuclear objects can be produced for quantitative study only by bombarding matter with intense beams of high energy particles.

PROGRAMME EIGHT

How was Nimrod designed and built?

The choice of a 7 GeV proton synchrotron as a British national accelerator was made after lengthy consultations between nuclear physicists and accelerator specialists in 1956. A design target of 10^{11} protons per second was laid down. A team of 100 physicists and engineers at the A.E.R.E., Harwell, made a design study and prepared outline specifications of the main components and cost estimates for the complete machine and its buildings. The project was authorised in 1957.

The design study team was enlarged and organised as a project team; eventually 400 physicists, engineers and assistants were employed by the Laboratory on this work, and many more were engaged in industry on the manufacture of equipment. Many components had to be developed in the Laboratory, in experiments with models aided by calculations with computers, before engineering design could be done. The physicists and engineers had to solve problems in many fields of technology—for example radiofrequency phenomena, high voltages, high vacuum, magnetic fields, electronics, heavy current engineering, plastics technology, before the designs could be completed and the equipment ordered.

All the major components of Nimrod, and many smaller items, were ordered from industrial firms against detailed specifications prepared in the Laboratory. Some very special items were ordered against full engineering drawings. Many firms were engaged. Often there were several specialist suppliers of items designed by the Laboratory in a single assembly. Co-ordination of manufacture and installation was therefore a major task for the Laboratory staff. Many physicists and engineers were engaged in quality control of the materials and the manufacturing processes for critical items, and others in development work, in collaboration with their opposite numbers in industry. Equipment started to arrive on site in 1958, and continued with increasing tempo until 1963. Throughout this time physicists and engineers were busy testing, adjusting and in many cases developing the installed equipment until, in August 1963, commissioning of the complete accelerator could start. Almost immediately it reached its full design energy of 7 GeV, and by the end of 1963 it reached the design intensity of 10^{11} protons per second. It had taken six years and had cost £10 million.

PROGRAMME NINE

How is the Research Done?

Now the accelerator was working, after six years' work, and everyone's job had to change. This was just the beginning for the high energy physicists, but it was not the end for the engineers and applied physicists who created the machine. They had to learn how to operate and maintain Nimrod; and keep it going round the clock with only rare interruptions for maintenance or development. They must improve its performance as new development becomes possible with the advance of technology, and adapt it for the changing needs of research as expressed in the demands of the high energy physicists. But what is even more important, and perhaps less obvious, is that they must devise and produce a continuing supply of elaborate research apparatus for the experiments—beam selection and transport systems to handle different kinds of elementary particles produced at targets in Nimrod, particle detection equipment, data collection and data reduction equipment. The range of technology is even wider than that embodied in Nimrod itself.

The high energy physicist has first to decide what experiment he wants to do. He cannot work by himself in a field with such complicated techniques, and teams of twenty or so, including research students and assistants, are usual. As in other research work, part of his time is spent in studying the literature, exchanging ideas with other physicists, giving and attending colloquia—and finding out what other research groups are doing and are planning to do. At Nimrod the first positive step is to lecture to other physicists on a proposed experiment; the second, to examine the technical (and financial) feasibility with the engineers and applied physicists. The survivors of this process are submitted to a small panel of senior physicists, as detailed proposals supported by facts and figures, for a searching examination. The successful candidates are awarded a block of machine time, the man in charge of Nimrod fits them into his schedule, and the teams start to build their apparatus in collaboration with the engineers and applied physicists.

Twenty teams of physicists, using various experimental techniques, keep Nimrod fully loaded. Each team will spend one to two years from conceiving the idea for the experiment to the final calculation of results. There are several experiments on the floor simultaneously, in various stages of progress. One current experiment, coded K7, on scattering of π and K mesons from a target containing polarized protons, is presented as an illustration by the team-leader, Dr. J. J. Thresher, and the programme ends with the start-up of Nimrod and the experimental apparatus for this experiment.

PROGRAMME TEN

The K7 Experiment

The data-recording apparatus for the K7 experiment is being operated, connected 'on line' to a small computer which makes simple calculations on the angles through which detected particles have been scattered from the target. The computer is programmed to take account of the positions of all the particle detectors in the experiment, and the known kinematics of the particle collisions. It rejects those events whose kinematics show that the scattering was from a nucleus other than hydrogen, in the substance from which the target is made, and allows the genuine candidates to be recorded. After some hundreds of hours of operation, sufficient data has been collected on the numbers, angles and momenta of scattered particles to enable a reliable result to be calculated. These calculations are made in a large computer.

In a previous stage of the same experiment, the final calculations established previously unknown

properties of two short-lived particles generated in the scattering process. A small but important detail of Nature was thus discovered, to add a piece to the jig-saw puzzle.

About half of the Nimrod research is based on an important particle detector called the bubble chamber, in which a liquid, brought temporarily above its boiling point by a sudden expansion becomes sensitive to the passage of charged particles. The ions, left behind by collisions of the charged particles with molecules of the liquid, act as centres of boiling and rows of fine bubbles form along the particle tracks. A flash of light and a stereoscopic camera produce a permanent record of the tracks, and the liquid is recompressed before the bubbles grow too large and boiling becomes general. The details of elementary particle phenomena can be studied by examining the photographs, if necessary far from the accelerator and long after the original exposure. The bubble chamber has its own magnet, so that particle momenta may be determined by measuring the curvature of the tracks. Many collisions or other events must be measured in most experiments, in order to obtain statistically significant results, and therefore complicated automatic machines have been devised to speed the measurement of the tracks. Some are already used 'on line' to fast computers which apply kinematical tests (similar to those used in the K7 experiment) to select events for detailed computation and to perform preliminary calculations on those selected. Nimrod is currently taking two million bubble chamber photographs a year.

The Rutherford Laboratory is exploiting advanced technology in many fields, to enable physicists from many universities to study the very small but very strange world inside the proton. This is pure research, but engineers and technologists work in a very similar way on very similar problems in many other environments which have nothing to do with high energy physics. Technological advance makes new research possible; history tells us that scientific discoveries lead to new technology.

Further Reading

COMPUTERS

- Computers in Education: Proceedings of a Conference on 'The Computing Laboratory in the Technical College'* edited by J. A. P. Hall, held at Hatfield College of Technology, September 1959, Pergamon, 1962.
- Proceedings of the Conference on Education and Training for Automation and Computation*, held at the College of Aeronautics, Cranfield, in March 1962. Published by the Institution of Mechanical Engineers.
- Faster than Thought* by B. V. Bowden, Pitman 1953.
- Programming for Digital Computers* by J. F. Davison, Business Publications and Batsford, 1961.
- Electronic Computers* by T. E. Ivall, Iliffe and Sons, 1956.
- An Introduction to Automatic Digital Computers* by R. K. Livesley, Cambridge University Press, 1957.
- Man and Automation* by L. Landon Goodman, Pelican Books, 1957.
- The Human Use of Human Beings* by Norbert Wiener, Eyre and Spottiswoode, 1955.
- Charles Babbage and his Calculating Engines*. Selected writing by Charles Babbage and others edited by Philip Morrison and Emily Morrison. Dover Publications Inc., New York.
- Contemporary School Mathematics Computers 1 and Computers 2* edited by T. B. Lovis. Edward Arnold (London).

NIMROD

- Elementary Particles*—a short history of some discoveries in atomic physics by C. N. Yang, Princeton University Press (1962).
- The 'elementary' particles* by D. H. Wilkinson. Science Journal, March 1966.
- The 7GeV Proton Synchrotron* by T. G. Pickavance, P. Bowles, G. W. Dixon and A. J. Entwistle. Nuclear Engineering, April 1959.

Biographies

Professor GILL

Stanley Gill was born in Worthing in 1926. He went to school there and later went to St. John's College, Cambridge, where he became a Fellow in 1952.

He entered the electronic computer field in 1947 at the National Physical Laboratory, where he joined the design team planning the Pilot model A.C.E. Later he studied programming and obtained a Ph.D. degree in 1953 for research into methods of applying the Cambridge computer, EDSAC, to problems in mathematics and physics. This work included the introduction of mistake diagnostic routines and the development of a particular form of the Runge-Kutta process for the solution of differential equations.

He spent eighteen months in the United States during 1953-54 where he held the position of Visiting Assistant Professor at the University of Illinois; he also lectured at Summer Session courses at the Massachusetts Institute of Technology, and has delivered occasional lectures at several other American universities.

From 1955 to 1964 he was employed in the Computer Department of Ferranti Ltd. (which was absorbed into I.C.T. Ltd. in 1963). In addition, he was appointed part-time Professor of Automatic Data Processing at the Manchester College of Science and Technology in April 1963. He gave up both of these appointments in October 1964 to become Professor of Computing Science at Imperial College, London, where he is also Director of the College Computer Unit.

He is one of the authors of *The Preparation of Programmes for an Electronic Digital Computer*, and is on the Council of the British Computer Society and of the International Federation for Information Processing.

Professor Gill is married and has three children.

Dr. PICKAVANCE

Thomas Gerald Pickavance was born at St. Helens in 1915, and was educated at Cowley School and Liverpool University. He obtained his Ph.D. in 1960 for research in nuclear physics and cosmic radiation, and worked on nuclear physics and mass spectrometry in the wartime nuclear energy project, under Sir James Chadwick. In 1946, when a lecturer in physics at Liverpool, he was appointed Head of the Cyclotron Group at the Atomic Energy Research Establishment, Harwell, where he and his colleagues built the 175 MeV synchrocyclotron and used it for research in high energy physics. He became Deputy Head of the General Physics Division at Harwell in 1955, and in 1957 was appointed Director of the Rutherford High Energy Laboratory. He was made a Commander of the Order of the British Empire in 1965.

Dr. Pickavance is married and has a daughter and two sons.

Machines for a new age

Part one

The story of the Electronic Digital Computer

Part two

Nimrod: A machine to smash atoms