## ALBERT VAN HELDEN

# INTRODUCTION

The title of our book would lead the reader to believe that in speaking of the changing image of the *sciences*, we are taking for granted the multiplicity of sciences, as these are practiced, for instance, in modern universities. That was, of course, not always the case. Although we can point to some subjects, for instance mathematical astronomy, as being demarcated to some extent from other subjects as far back as Antiquity, the current division into individual sciences can hardly be traced back further than the nineteenth century. Moreover, the further we go back in history, the more we must subsume science under general knowledge or scholarship: *scientia*. Some of the earliest images of *episteme* or *scientia*, are those of forbidden knowledge – often related to technology – on the one hand, and the absent-minded scholar on the other. These are powerful metaphors – in word as well as image – that have been appropriated in various ages for different purposes.

The Greeks gave Western society its first images of the power of knowledge and those who produced it. Prometheus ridiculed the gods, stole their fire, and brought it down to Earth. For this, Zeus had him chained to a rock on Mount Caucasus, where a vulture fed on his liver during the day, while it grew back at night. He was finally freed by Heracles. From the perspective of humanity, Prometheus was a great benefactor: besides giving mankind fire, he taught it the cultivation and uses of plants and how to tame horses. Indeed, after he was freed, he joined the gods on Mount Olympus. Right from the beginning, we see here the two-edged sword of technical knowledge: on the one hand forbidden knowledge and on the other a great boon to mankind. For the later aspects he was especially celebrated among the English Romantics.

In European history, the image of forbidden knowledge was expressed strongly in the story of Faust, which began as a German folk tale (about a real scholar), first printed by J. Spies as *Volksbuch von Dr. Faust* in 1587, and made well-known by Marlowe into *The Tragical History of the Life and Death of Dr. Faustus* a few years later. Related is the Jewish legend of the Golem, an artificial man created from dust by rabbi Löw in Prague by means of Cabbalistic magic. Initially, the Golem helped the community solve its problem, but when his services were misused he turned on it. The themes of Faust and the Golem, of mankind's eternal quest for

*I.H. Stamhuis, T. Koetsier, C. de Pater and A. van Helden (eds), The Changing Image of the Sciences,* 1–7.

Figure 1. Atlas, carrying the heavens, watches a vulture pecking at the liver of Prometheus. 6th century B.C. Vatican Museum. Permission of the Vatican Museum.

Figure 2. Dr. Faustus conjuring the earth-ghost. Title image of Christopher Marlowe: Dr. Faustus, 1636. Permission of the Mary Evans Picture Library.

(forbidden) knowledge crop up time and again in Western culture, from Goethe's Faust and Mary Shelley's Frankenstein to J. Robert Oppenheimer's citation of the Bagava Gita upon the first successful test of the atomic bomb. The power that comes with knowledge is always a two-edged sword: the motives are often pure, but the results are frequently disastrous.

The second theme, that of the absentminded professor, also has its origin in Antiquity, although the images were contradictory. Of Thales of Miletus (sixth century B.C.E.) it is said that on the one hand he correctly predicted a bountiful harvest of olives, obtained a monopoly on olive presses, and made a fortune when the harvest turned out to be in fact bountiful. It is related about him on the other hand that he was so intent on looking up at the heavens as he was walking, that he fell into a ditch. Archimedes (third century B.C.E.) helped defend the city of Syracuse from the

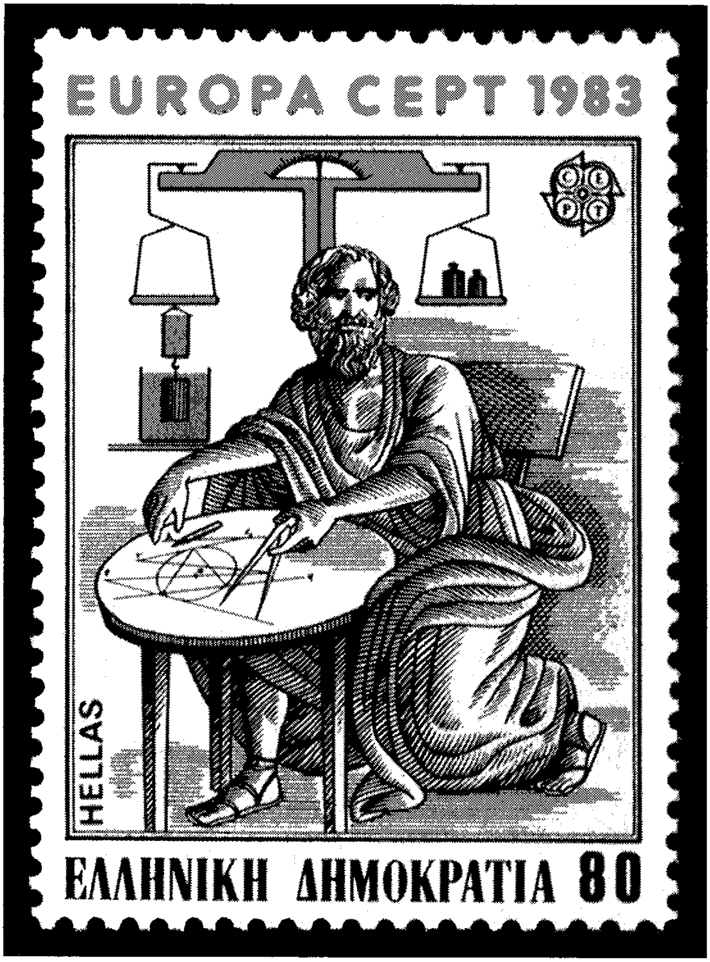

Figure 3. Greek stamp issued April 28, 1983. The illustration of Archimedes is adapted from a well-known Renaissance mosaic depicting his death. Source: Chris Rorres' website on Archimedes, *http://www.mcs.drexel.edu/~crorres/Archimedes/contents.html*

Roman forces with his war machines, but it is said that he really only cared about abstract mathematics, and when the city fell and a Roman soldier entered his house, Archimedes was working on a mathematical problem and did not wish to be disturbed: the soldier killed him.

In more recent times, these images become mixed with that of the pursuit of useless knowledge. Early in the seventeenth century, Francis Bacon wrote:

> Men have entered into a desire of learning and knowledge, sometimes upon a natural curiosity and inquisitive appetite; sometimes to entertain their minds with variety and delight; sometimes for ornament and reputation; and sometimes to

> enable them to victory of wit and contradiction; and most times for lucre and profession; and seldom sincerely to give a true account of their gift of reason, to the benefit and use of men.[1]

The Royal Society of London set itself a Baconian program, but their work was often satirized. When in his *Micrographia* of 1665 Robert Hooke praised the progress made in the improvement of the telescope and spoke of a day when perhaps animals might be seen on the Moon, Samuel Butler published a poem, *The Elephant in the Moon*, in which "A learned society of late, / The glory of a foreign state, / Agreed upon a summer's night, / To search the Moon by her own light; / To make an inventory of all, / Her real estate and personal . . . ." Needless to say, the gentlemen found all manner of human affairs going on on the Moon. Indeed, they were observing a war, in which a large elephant had broken loose. "It is a large one, far more great / Than e'er was bred in Africa yet; / From which we boldly may infer, / The Moon is much the fruitfuller."[2]

Some of the other activities of the Royal Society also raised the hackles of the satirists. In his *Travels in Several Remote Nations of the World* (1726) Jonathan Swift

Figure 4. The Golem from the film "Der Golem" by Paul Wegener (1914). Source: *http://www.davkamusic.com/images/golem.jpeg*

reported that the gentlemen of the Academy of Lagado carried out research into "extracting Sun-beams out of Cucumbers," "to reduce human Excrement into its original Food," and "softening Marble for Pillows and Pincushions."[3] That sort of criticism of the pursuit of useless knowledge, often with a serious purpose, has not ceased. It was not so many years ago that the American Senator William Proxmire, a watchdog of governmental spending on science, published a monthly "Golden Fleece Award," in which he singled out such apparently nonsensical scientific research projects as finding out why people fall in love.[4] The image was very much that of scholars who had lost touch with reality and were fleecing the public.

The papers in this volume pursue some of these themes in the modern period. The first group pursued the theme in individual sciences. Michael Mahoney chooses as his subject a device, the computer, and the new science it has generated over the past half century. We now see the computer as the basic ingredient in an emerging new electronic medium that is as different from its predecessors, as many now say, as print was from manuscript. But as Mahoney points out, the image of the computer began very differently, and it has gone through several changes since then. Half a century ago the machine itself was the central icon, associated with cleanliness, temperature control, and an almost priestly class of initiates. Today the central image is that of a network in which the computer itself is all but invisible, and when we do see it, it is as a small decentralized home- or office-appliance, soon to be merged with our telephones and televisions.

But computers have also changed the way science is often done. The awesome calculating power of even small computers means that models can be built in which one can change the initial parameters and see the results. Increasingly, problems involving complexity that could never be solved before the computer can now be calculated by models and algorithms. Computers have given rise to a middle area between experimental and theoretical/mathematical science that has in effect become a new branch of science.

Bernadette Bensaude-Vincent's paper is about the problem one level down from biology, and very much related to Allen's paper. The chemists (and Bensaude-Vincent focuses precisely on *synthetic* chemistry) are seen as being historically in competition with Nature itself. Here we are not talking about describing, imaging, nature so much as competing with nature's creative aspects. In its modern form, this competition goes back to Wöhler's supposed synthesis of urea from "inorganic" substances. Regardless of the fact that Wöhler did not exactly start with inorganic reagents, the synthetic chemist was increasingly seen, and saw him/herself, as a benevolent creator of useful substances for mankind: better living through chemistry. Obviously, this image has become hopelessly fractured since Hiroshima and *Silent Spring*. Yet, in the pharmaceutical laboratories, in spite of all the arguments about the costs of new medicines, increasingly effective new medicines are created every year. We have had to learn to live with the Janus face of synthetic chemistry.

It is interesting to see, in Bensaude's paper, how the normative use of the notion of *nature* in the popular mind often clashes with the chemist's notion. Where *natural* on the packaging in the supermarket stands for *pure*, to the chemist reagents found in nature are anything but pure, so that for him/her *natural* often stands for *impure*. Each generation of (synthetic) chemists has to (re)construct the image of its

MICHAEL S. MAHONEY

# IN OUR OWN IMAGE: CREATING THE COMPUTER

## FROM "GIANT BRAIN" TO INFORMATION APPLIANCE

In the years following World War II, the world appeared to be entering a new age, the Atomic Age, portrayed as an era of prosperity fueled by energy "too cheap to meter". Automobiles, trains, planes, homes, industry would all draw their power from nuclear reactors of various sizes and formats, and society would assume new forms around the possibilities of ubiquitous, unlimited energy.[1] Some of those visions became reality, some turned into nightmares. Fifty years later we draw on atomic power, but the phrase "atomic age" is more likely than not to evoke images of a nuclear winter of desolation.

Instead, we speak now of the "Information Age", or the "Computer Age". It too is a product of World War II, but the potential of the electronic digital computer for social transformation was not immediately evident. Costing upward of a million dollars, weighing several tons, drawing a hundred kilowatts of power, it seemed at first destined for limited scientific use. Several subsequent and unforeseen developments had to occur before the possibilities became clear. The "computer age" of which people spoke in the 1960s referred to large mainframes in the scientific laboratory, the government agency, the military command center, or the corporation.[2] The computer was the agent of automation, the tool of Big Brother. "I am a human being," protesters of the late '60s exclaimed, taking their cue from the then common IBM punch card, "do not fold, spindle, or mutilate" (Figures 1–3).

Few at the time foresaw, or even imagined, computers with many times the capacity of those mainframes sitting on people's desks or indeed on their laps, serving as agents for personal business and as tools of Little Brothers seeking not to exercise control over society but to wreak havoc on it. In the 1950s, the computer was an object of wonder, viewed through plate glass windows and tended by technicians. It was a visible statement of corporate and governmental power. Today, at least in the developed world, it has become a common appliance, an instrument of personal power as much a part of daily life as television and the telephone. Indeed, it is on the verge of combining with television and the telephone to form a single information/communication/entertainment device, in stationary and portable format (Figure 4).

*I.H. Stamhuis, T. Koetsier, C. de Pater and A. van Helden (eds), The Changing Image of the Sciences*, 9–27.

Figure 1. Early mainframe UNIVAC.

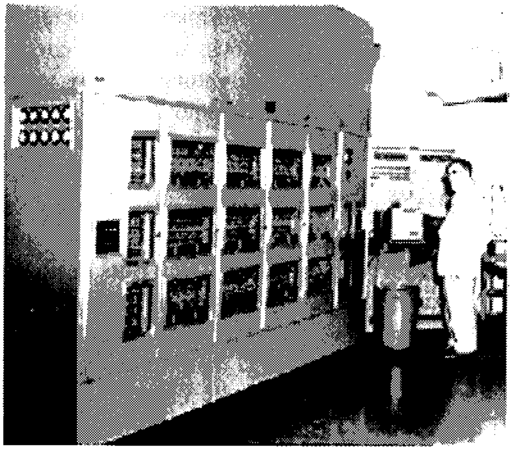

Figure 2. Early mainframe ILLIAC.

Figure 3. Early mainframe IBM 704.

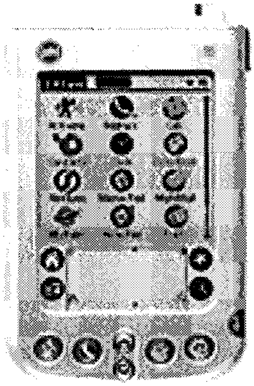

Figure 4. Palm™ i705. Courtesy of Palm Inc.

Our image of the computer is evolving along with it. As it becomes more common, we grow less conscious of its presence. Yet, at the same time, it increasingly shapes our view of the world. We think of the computer as a machine, as a thing. Indeed, we speak of *the* computer, as if it were a single, generic device. But there is no computer, only computers. Or rather, *the* computer is an abstract scheme, first devised by Alan M. Turing in 1936 and then articulated by John von Neumann and others in 1945. In a paper addressed to a recondite problem in mathematical logic, Turing sought to capture what it meant to speak of a number as "computable". "According to my definition," he wrote, "a number is computable if its decimal can be written down by a machine".[3] But what kind of machine? Turing imagined a device that shifted among a finite number of predefined states in response to symbols read from and written to a potentially infinite tape. He showed how any logical function could be expressed in terms of the operations of such a device, that is, could be defined as a Turing machine. Moreover, since the states and operations themselves can be denoted by symbols, it was possible to define a Universal Turing Machine that would first read the description of a particular computation and then carry it out. The purpose of the exercise was not to design an actual machine or to do computations, but rather to show that some functions cannot be computed and, more important, that there is no function for deciding whether any given function can be computed or not (Figure 5).

The "First Draft of a Report on the EDVAC", published in July 1945, bears only John von Neumann's name, but it was the outcome of his collaboration with John Mauchly and Presper Eckert, the designers of the ENIAC.[4] Its significance lies in transforming Turing's abstract scheme into a general design for a physical device. The finite state machine became the control and arithmetic units, the tape became memory. In keeping with Turing's central insight of a universal machine, von Neumann's report placed data and instructions in the same memory, thus allowing the device to modify the instructions as it proceeded (Figure 6).

This scheme has remained the basic structure of the vast majority of computers. The processors have become faster and logically more complex, the memory (both primary

BERNADETTE BENSAUDE-VINCENT

# CHANGING IMAGES OF CHEMISTRY

## INTRODUCTION

The tensions between chemistry and medicine (or life science) are as old as chemistry itself. They were caused by enthusiastic alchemists who vied with nature or were accused of doing so. The promise of creating a living creature through laboratory operations survived the collapse of the alchemical tradition and profoundly shaped the public image of chemistry. The dichotomy between the laboratory and Nature as the creator of life was still at the center of literary images of chemists in the early nineteenth century. In her popular 1817 novel *Frankenstein*, Mary Shelley revived the Promethean image of an all-powerful chemist. This image, which has created an association of chemistry with witchcraft, magic and charlatanism has persisted through the centuries in spite of the many successful and useful products that have issued from the chemist's laboratory. As early as the eighteenth century, chemists began to substitute artificial, man-made products such as ammonia, oil of vitriol (sulphuric acid), and what they called "facticious" (that is, *artificial*) soda (sodium carbonate) for products formerly extracted from vegetable- or animal-matter. By the end of the eighteenth century chemistry was, therefore, celebrated as a useful science, contributing to public welfare and the wealth of nations. Chemists were no longer perceived as dangerous people. Rather they had become respectable professionals enjoying social recognition and, often, political responsibilities.

In the mid-nineteenth century, however, the development of synthetic chemistry revived the competition between chemistry and life. One purpose of this paper is to contribute to an understanding of how and why the term "synthetic" became a synonym of "chemical" and the antonym of "natural" or "organic" in popular language. I will also discuss to what extent this common view has changed because of the most recent developments of chemistry.

## CREATING LIFE

The public view of synthesis rests on a legend created and propagated by chemists such as Hermann Kolbe, Wilhelm August Hofmann and Marcellin Berthelot.[1] They

*I.H. Stamhuis, T. Koetsier, C. de Pater and A. van Helden (eds), The Changing Image of the Sciences,* 29–41.

pointed to Friedrich Wöhler's synthesis of urea, an organic compound, from inorganic material in 1828 as the death sentence of vital forces. The metaphysical belief in a vital force was supposedly destroyed by this experiment bridging the chasm between the inorganic and organic realms. Wöhler's synthesis was presented as an epoch-making discovery, the dawn of a new era, when chemists would be able to create organisms.

In reality, vital forces were not swept away by the synthesis of urea. As John Hedley Brooke has argued, this is a biased interpretation of this synthesis.[2] Urea is an organic substance but not an organism; it is a product of life but it was not synthesized through the same process as it is in the organism. It was thus easy for Claude Bernard to state that chemists could certainly imitate the products of life but could not imitate the ways of nature.[3] Thus the anti-metaphysical claim rests on a confusion between "organic" and "organized" and between product and process.

The claim is also unacceptable because Wöhler's synthesis was not a direct synthesis from elements, but rather a partial synthesis from a cyanate. This cyanate was itself not synthesized from its elements but by oxidation from a cyanide extracted from horns and hooves of animals. Therefore Wöhler's synthesis did not affect the belief of chemists such as Jöns Jakob Berzelius and Justus Liebig in the existence of a vital force, active in the formation of organized bodies.

The synthesis of urea as a crucial experiment overthrowing a metaphysical dogma is thus a myth, intended to exalt the power of chemical synthesis. If Wöhler's synthesis was an epoch-making discovery it was so not because it killed vital forces but because it revealed a strange phenomenon, later called "isomerism." Urea was obtained from the same components as potassium cyanate, although it did not present the same properties. Consequently, the belief that the properties of a compound were exclusively determined by the nature and proportion of its constituent elements was challenged. Wöhler's synthesis was thus a landmark because it drew the attention of chemists to the arrangement of atoms within the molecule. In the 1860s, the understanding of the structure of the benzene molecule by August Kekulé allowed the synthesis of many aromatic compounds, synthetic dyes, by the substitution of atoms within benzene's hexagonal structure.

Substitution of atoms or groups of atoms in a molecular edifice was the real practice of synthesis in the second half of the nineteenth century. However, the popular connection between "synthetic" and "artificial" does not rest on this practice. Rather it was rooted in Berthelot's view of synthesis as a creation. "Chemistry," he wrote, "creates its own object." This creative faculty, like that of art itself, distinguishes it fundamentally from the natural and historical sciences."[4] For Berthelot, who opposed all atomistic views, synthesis was like the construction of an edifice, starting from the ultimate elements – carbon, hydrogen, oxygen and nitrogen. Berthelot claimed he could build up carbohydrates, "which are so to speak the building blocks of the scientific edifice;" and he would then proceed to the synthesis of ternary compounds made of carbon, hydrogen and oxygen, such as alcohols; the next step would start from the alcohols and build up ethers, alkaloids or organic acids, which in turn would lead to amides such as ureas, at the threshold of living matter. Through progressive syntheses, chemistry could create anything. This ambitious program is described at length in Berthelot's popular book *La Synthèse chimique.*

Figure 1. Marcellin Berthelot. Reprinted with permission of the Agence Bridgeman Giraudon, Paris.

However, it remained a paper program. In fifty years, Berthelot realized only a small, insignificant part of his grand design. He synthesized wine alcohol from ethylene (not from the elements); formic acid by combining carbon and soda; and acetylene by directly combining carbon and hydrogen in an instrument named “the electric egg”, a name presumably reminiscent of alchemical instruments. The view of synthesis as an artificial creation, therefore, rests on no effective practice. Rather it was a fantasy, forged with the help of rhetoric and reminiscences.

Today the image of the chemist as a creator is in competition with another heroic image of the synthetic chemist put forward by the Nobel Laureate Roald Hoffmann in the 1980s. In contrast to the nineteenth century image of an all-powerful creator, manipulating the elements of nature, the modern synthetic chemist is portrayed as an

GARLAND E. ALLEN

# THE CHANGING IMAGE OF BIOLOGY IN THE TWENTIETH CENTURY

## INTRODUCTION

The changing image of the life sciences in the twentieth century can be charted as the conscious attempt to introduce rigorous experimental, analytical and reductionist methods from the physical to the biological sciences. This change brought biology from being a largely descriptive to an experimental science that included both the laboratory and field. Of all the natural sciences, biology underwent the most profound sequence of changes during the twentieth century. (Biology is defined here initially in the nineteenth-century sense, as the study of the structure and function – including aspects of general physiology – of living systems, excluding medicine and medically-related subjects such as pharmacology, epidemiology and public health.) During the first half of the nineteenth century biology was dominated largely by issues of natural history: taxonomy, new discoveries relating to geographic distribution, fossils and extinction, and of course comparative anatomy. Physiology was largely separate from Lamarck's general term of *Biologie* at the time, and was housed institutionally within medical schools and hospitals, as opposed to museums and botanical or zoological institutions. The connection of physiology to general biology was clearly recognized, but it shared a largely different intellectual and social base until at least the 1840s.

The "image" of biology at the turn of the century is captured in the illustrations shown in Figure 1. It is of biology as largely natural history, concerned with the life histories of organisms, with comparative anatomy and taxonomy among the major activities in which naturalists were engaged. Laboratories were largely given over to microscopical work or dissection, with observational skills and drawing ability often honed to a fine degree. Who, over the age of 50, does not associate biology with dissecting and drawing images of frogs, earthworms and flower parts? The tools of biology, right up to the period just before World War II, were also relatively descriptive and simple, not unusually expensive, and did not require highly developed analytical skills.

By the end of the century however, the images of biology had changed so dramatically they would have been unrecognizable to even the most advanced investigators

*I.H. Stamhuis, T. Koetsier, C. de Pater and A. van Helden (eds), The Changing Image of the Sciences,* 43–83.

Figure 1. As the century opened, the prevailing image of biology was that of natural history, concerned with describing and cataloging organisms in nature. As shown in this 1890s collecting trip at the Marine Biological Laboratory in Woods Hole, Massachusetts, biology was closely tied to field experience and most biologists knew a great deal about the structure and life histories of the organisms with which they worked. Woods Hole, MA: Courtesy, Special Collections, MBL/WHOI Library.

in 1900 or 1920 (Figure 2). Today's images include electrophoretic gels, x-ray diffraction patterns, high-resolution electron micrographs, sedimentation coefficients, and evolutionary lineages based on molecular rather than anatomical data. The modern biology research laboratory presents a totally different appearance – dominated by large and expensive equipment such as ultracentrifuges, confocal microscopes, spectrophotomers and an endless array of computers. The eye is no longer the major point of contact between the biological system and the investigator. What has brought about this profound change in the way biology "looks" in the course of the past century? How does this change reflect the way we think about living systems, how we depict them, manipulate them and understand their history?

The outcome of this widespread dissemination of experimental methods into biology, however successful in investigation of certain problems, was the failure to develop a sophisticated method of dealing with complex, interactive systems. By mid-century, certain areas of biology, notably general physiology and embryology, were struggling to find more holistic methods for investigating biological processes.

In this chapter I will trace the changing image of biology as driven by several dialectical imperatives: (1) Philosophically, between mechanistic and holistic (including

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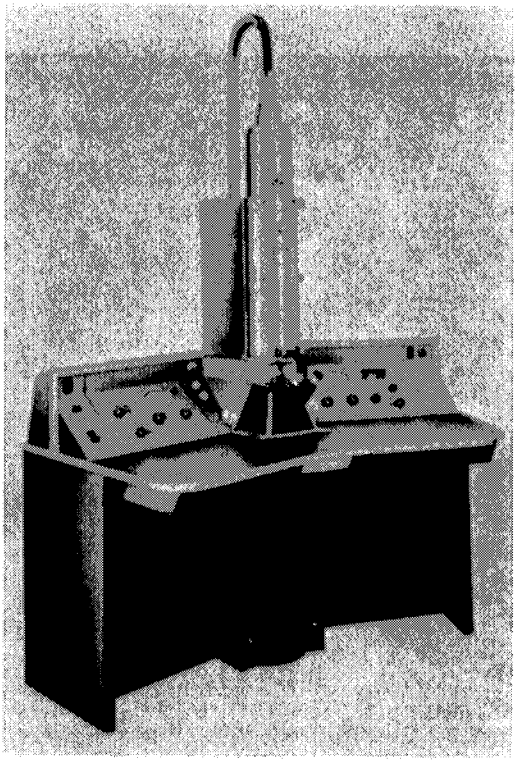

(a2)

Figure 2. *Cont.*