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自然と産業における完璧さと不完全さ

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Perfection and Imperfection in Nature and Industry

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■略歴

1924	フランス、ヴォージュ県コルニモンに生まれる。
1945〜50	高等師範学校およびパリ大学で物理学を学ぶ。
1956	パリ大学 理学部教授となる。
1968〜73	フランス国立科学研究センター(CNRS)所長
1973〜76	科学・技術研究庁長官
1976〜84	フランス国立宇宙研究センター所長
1979〜84	ヨーロッパ科学財団会長
1981〜84	ヨーロッパ宇宙機構評議会議長
1983	国際宇宙飛行学アカデミー副会長
1983〜85	フランス国立航空・宇宙アカデミー会長
1984〜86, 1988〜93	フランス政府 ファビウス内閣、ロカール内閣およびクレッソン内閣での科学・技術大臣
1992〜93	国際宇宙年の宇宙機構フォーラム(SAFISY)議長
1994〜96	欧州共同原子核研究機構評議会(CERN)会長
1994〜97	アカデミア・ユーロペア会長

■受賞歴

レジオンドヌール2等勲章
大英帝国勲爵士、他

■会員

フランス科学アカデミー会員

●主な著書：

「ユベール・キュリアン：国際科学方針のために」

■Personal History

1924	Born in Cornimont, France
1945〜50	Educated in physics at the Ecole Normale Supérieure and the University of Paris
1956	Professor of Paris University
1968〜73	General Director of National Research Center, France
1973〜76	General Delegate for Research and Technology
1976〜84	President of the French National Center for Space Studies
1979〜84	Chairman of the European Science Foundation
1981〜84	Chairman of the Council European Space Agency
1983	Vice President of the International Academy of Astronautics
1983〜85	Chairman of the French National Space Academy
1984〜86 and 1988〜93	Minister of Research and Technology, Government of France
1992〜93	Chairman of SAFISY (Space Agencies Forum for the International Space Year)
1994〜96	Chairman of the Council of CERN
1994〜97	President of Academia Europaea

■Awards

Grand-Officier Legion d' honneur, France
Commander of several foreign orders.
Knight of British Empire.

■Memberships

the French Academy of Sciences

●Major publications

"Hubert Curien : for an International Science Policy"

Perfection and Imperfection in Nature and Industry

Commemorative Lecture at the conferring ceremony of Honda Prize
on the 17th of November 1998 in Tokyo
Professor Hubert Curien
University of Pierre et Marie Curie, Paris VI

My first words will be to express my deep thanks to the Honda Foundation. I feel very honoured with the Honda Prize 1998. I am very grateful to the members of the jury for this award, and, of course, to the Honda Foundation which is so generous and cordial. The list of the former laureates is quite impressive and it is intimidating to step into such a distinguished cenacle.

If I did propose as a title for my lecture "Perfection and Imperfection in Nature and Industry", it is indeed to be in harmony with the Honda Foundation's main orientation, ecotechnology, but also to propose some consideration about the ideas of perfection and imperfection of natural objects or man-made productions.

Every one keeps in mind Soichiro Honda's motto: "There is no limit for quality"(1). Meeting this requirement made the outstanding success of the Honda company and more generally of the Japanese industry in the world. Quality of manufactured articles means in great part quality of life.

But, in some instances, such as material processing, the quality surprisingly arises from specific types of irregularities, one can even say imperfections, which are purposely introduced and perfectly monitored.

Crystalline defects.

I started my scientist's career as a physicist, more exactly as a crystallographer. That was at a time when X-rays diffraction had already given quite a turn to the determination of crystal structures based on the perfect periodicity of the atomic ordering. The mood was more to go further in the knowledge of the "real" crystals, looking at the possible defects in periodic lattices.

One kind of such defects is in any case unavoidable: the spontaneous thermal motion of atoms. It has been well described by Max Born(2) and a bit later Jean Lavel (3) indicated the way of its experimental investigation by X-rays diffusion. Being a Laval's student, I have been lucky to be able to give for the first time a complete description of the phonons in a crystal of iron (4). The phonons are the quanta of energy carried by the waves in which the thermal atomic motion in a crystal can be resolved. The interaction of these phonons with electrons gives rise to electric resistance in solids.

A new incentive to study the crystalline defects was the spread of atomic energy reactors. It was necessary to foresee the kind of damage that radiation of any kind may cause in solid matters. Point defects (atomic vacancies of intersticial atoms) in lattices are formed on the traject of energetic particulates. The presence of theses defects change more or less severely the mechanical, optical and electrical properties of the matter. Heat treatments may restore the initial non disturbed state (cf. for example the description of the case LIF in (5)). There has been a lot of research performed on the radiation damage in crystals, as well as on the point defects of several other origins (namely impurities).

The technology of semi-conductors, which is one of the most eminent innovation of the present century, proceeds from the mastership of introducing foreign atoms (donors or acceptors of electrons) in perfect or almost perfect crystalline (most often silicon) matrices. There is no room here to go into details concerning this fascinating field of physics and technology.

Order-disorder transitions are another illustration of the same category of phenomena. Consider an alloy A B. In many cases, you can find it in two kinds of configurations. One is ordered: the A and B atoms are regularly distributed with well-defined surroundings of B around A and reciprocally. The other is disordered with exchanges at random between A and B in the structure. The order-disorder phenomena found a lot of applications, not only in the metallurgy, but also in magnetism and electricity.

One of the most fruitful tracks in decoding the crystal imperfections was the discovery of dislocations (6). These defects are mono-dimensional (fig. 1) and they can be displayed by X-ray imagery, due to the fact that they disturb the crystalline periodicity in their proximity (fig. 1 and 2). The dislocations can move when the crystal sample is stressed, causing the plastic deformation. In the course of their motion the dislocations interact among themselves or with other defects, namely point defects. These interactions may lock up the motions. The material becomes harder. This phenomenon is called " work hardening ". In some metals, namely aluminum, it is usual to introduce a small quantity of other metallic elements. These "foreign" atoms are segregating in limited zones in the crystalline matrix (Guinier-Preston zones) which hinder the movements of the dislocations and the materials are much harder as if it were pure.

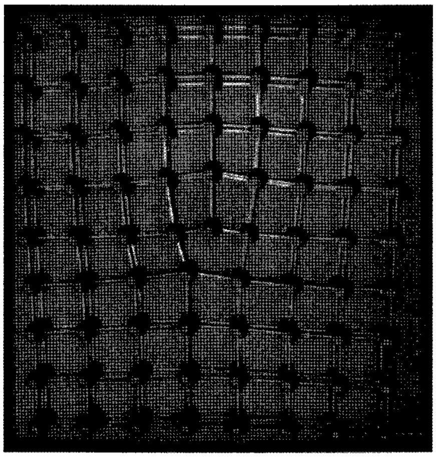

Fig.1 Atomic model of dislocation in a cubic crystal.

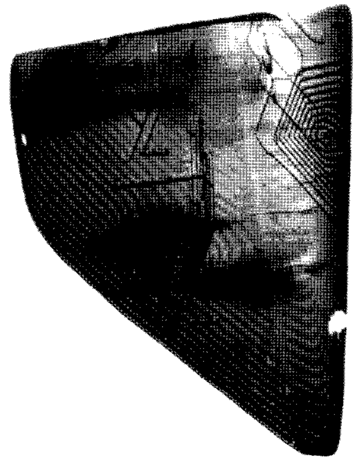

Fig.2 An Image of a dislocation in a silicon crystal obtained by Lang topography method (A. Authier, Univerisité Paris VI)

Dislocations also permit a correct explanation of crystal growth. Going through the surface of a growing crystal, a dislocation forms a step which favors the deposit of new atoms. The presence of dislocations increases enormously the growing velocity.

Teaching crystallography nowadays aims at a double target. First, to show the magnificent virtues of the periodicity of atomic ordering, which is indeed the expression of homogeneity at atomic scale in condensed matter. Second to show that a small and even very small quantity of defects can govern the most important properties of the crystalline matter and may be adjusted to get wonderful applications.

Mastering perfection in condensed matter means also to be able to introduce irregularities in a perfectly controlled manner.

Process Engineering

Let us now leave the materials and look at the processes which are used to make up objects from the raw matter. A revolution deeply changed the face of industry in the recent past when processes were elaborated as entirely integrated operations, starting from the raw matter and going up to the final products, and by-products. All the consequences of the process are studied and weighed, as well as the interactions between the tools and the workers. The search for innocuity of the process is placed at the same level as the quality of the final product. This is especially evident in chemical industry, but it is also true in any kind of manufacturing activity.

A general principle has been edicted and called "caution principle". It states that no action can be undertaken unless one is not sure to master all the outcomes. It looks safe and helps to limit the dealings of irresponsible or dishonest actors. It is quite natural to use the caution principle as a guarantee for the future of our planet and its inhabitants. There is nevertheless a danger in complying to the principle without the lightest touch of humour. Applied in a too strict way, it would amount forego any innovative programme. How could we be sure to foresee all the consequences of a really original venture ? This is, in fact, a question of honesty. The main point is never to hide nor forget about consequences which are doubtful.

About by-products or pollution which can be detrimental, an important point is the definition of the threshold of acceptability, namely for the very small doses. A general tendency is to make a confusion between the limits of detectability and of acceptability. The chemical instrumentation makes wonderful progress. It is now possible to detect and even titrate incredibly small amounts of impurities in solids, liquids or gases. This is also true for radioactive atoms. The caution principle may lead in absence of scientific or practical basis to decree that as soon as possibly detrimental substance can be detected it is to be suppressed. The assessment of the tolerance limits for nuclear matters are sometimes adjusted this way, the result being that the threshold imposed on industrial products is sometimes more drastic as that which results of the spontaneous emission from natural ambient rocks. After all, why not ?

In industrial engineering the interactions between the tools and men play a crucial role. What would be the use of perfect tools if they are conducted by imperfectly competent or unreliable actors ? Much of the recent industrial catastrophes in the domains of chemical or atomic plants are due to human deficiencies. The modern machines are more and more "self-correcting" and can rectify their own mistakes and refuse inadequate orders coming from outside. But, at Tchernobyl, the reactor was not able to refuse orders which made him a very dangerous device ! The man-machine relations form in itself a research domain not only in technology, but also in psychology and sociology.

It is sometimes admitted in technology that linearity can often be accepted as a rule in reasonable limits. This means that, as long as you know how to build a nuclear reactors of a certain capacity, you can build another one on the same model but with twice more power. The same for a rocket, a satellite, or more commonly any kind of technical product or device. This can lead to serious mishap. The perfection obtained at a given scale is not evidently kept when the dimensions or power are changed. In the domain of nuclear reactors, French engineers were quite happy with the behavior of Phenix, an experimental fast neutron breeder. When they erected a reactor of the same type but five times more powerful, Superphenix, they had to face and solve a series of new problems.

The same can be said about rockets. It happens that I have been directly involved in Space activities as chairman of the French Space Agency (CNES) and of the European Space Agency (ESA). We have built successive series of "Ariane" rockets, from Ariane I to Ariane V (fig. 3). At each step we did increase the power of the launcher and not one of these steps have been a kind of routine process, even if no drastic innovation had been put in the new model of the rocket. To be more precise, we did not introduce drastic novelties in the models II,III and IV compared to model I; On the contrary model V is quite innovative. The failure we suffered at the first test of Ariane V was essentially due to the software of the guidance system of the first stage. This software worked perfectly in the former models. It was deficient in the new one. It has been indeed duly corrected !

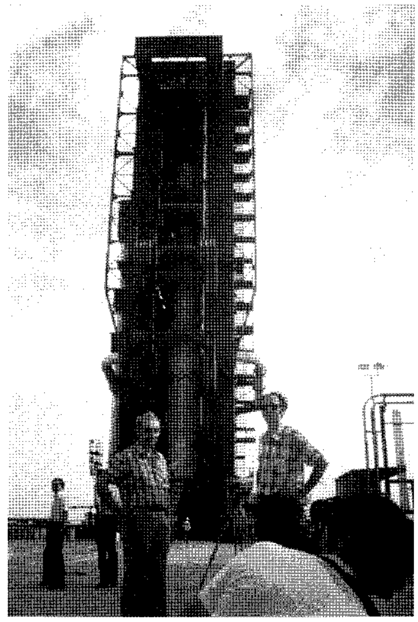

Fig. 3 The very first specimen of " Ariane" in the assembling phase (February 1979) at Kourou (French Guyana).
On the left : Prof. Hubert Curien, chairman of the French Space Agency in charge of the program.
On the right : Frédéric d'Allest, director of Lauchers Dpt in the Agency.

Natural phenomena

Looking at natural phenomena the nations of perfection and imperfection are no longer adequate. As in the first part of this paper dedicated to the crystalline states, it is probably more useful to speak of regularity and irregularity. The number of parameters is generally high. The case of meteorology is quite obvious. To built efficient models, it is necessary not only to have a correct inventory of the significant parameters, but also a precise measure of their value at a given time. The prominent progress made in weather forecast is due to two main factors : the improvement of the computing facilities and the collection of any kind of data by observation satellites.

Space Technology opened a new area in many fields : telecommunication, weather forecast, deep space exploration and many others. Concerning meteorology, it is interesting to note that watching the oceans is as important as observing the atmosphere. The exchanges between oceans and atmosphere are the key process. The satellites allow regular monitoring of any place on Earth with a perfect time regularity. If you ask a meteorologist about his dream for the coming century, he will certainly answer : multiply by a factor ten or even hundred the quantity and the quality of satellite observation data. No doubt that in the same time the power of computers will still make substantial progresses.

Everybody agrees to say that meteorology made tremendous progress in the last half-century. But one should be happy to say that climatology is also rapidly improving. Forecasting the general trends of the climatic changes in the coming centuries is quite a challenge. But it is crucial indeed if we want to restrict or orient the human activities in order to avoid undesirable influences. The caution principle plays here a key role.

Earthquake prediction and hopefully prevention is another field of research in which we can still hope for significant progress. A posteriori explanations are reasonably satisfactory. A priori reliable and precise previsions would of course bring more comfort.

Mathematical models of natural phenomena are becoming really useful only when they can be checked periodically with the real situation with the best possible precision. Earth scientific observation remains an imperious necessity for the management of our planet. It may be costly, but it is strict duty. The study of complexity is one of the main trends in modern sciences, in mathematics, physics as well as in biology. Earth is a fascinating object to deal with in this mood.

Transparency

The transmission of information about scientific and technical activities to the public is a domain where the perfection still remains to be found. Not so long ago, the scientists were sad no to be taken in due consideration by the journalists. Science was not a major topic in the radio and TV programmes. The newspapers did not dedicate regular headings to report on scientific activities. The present situation is quite improved, but it presents at least two types of imperfections. The first one is inherent to the journalistic style of life. The accent is put on the most emotional and not necessarily the most basic events. The second is due to dramatic reduction of the time delay which runs between a discovery and its public announcement. There is no time to check with care possible errors or make desirable verifications. This absence of any kind of "relaxation time" before publication leads sometimes to present as strictly reliable some results which are interesting but remain to be confirmed. If it happens afterwards that the so-called discovery was in fact a mistake, Science as a whole is brought into disrepute.

In the field of technology and industry the laudable attitude is indeed to be "transparent" concerning information about the processes and the management. But the idea of transparency merits some discussions. One can be passively or actively transparent. Being passively transparent is to publish all information with no restriction, but also with no hierarchy in importance. The active transparency consists in distribution of information with explanations and discussions leading to a confident dialogue in order to get from the journalists and the public the most interesting questions and to be in a position to give back the most relevant answers. To be transparent is not only to hide nothing but also to try to explain how and why the scientific and technical activities are running.
This is specially important in industries which can be a priori suspected of pollution and nuisances.

It is clear that total transparency may be contradictory with the protection of industrial property. This is an aspect which must be taken into account in the patent policy.

Imagery

The control of perfection and of mastered imperfection brings the most modern tools into play. One has to perform measures and also to get images at any scale. Imagery has certainly been one of the fields in which the contributions of recent scientific advances are the most remarkable. The matter is scrutinized at the molecular level as well as in the bulk.
It is particularly fruitful to combine several methods to look at the same object. Addressing the diverse intrinsic properties of the matter (magnetic, electric, optic) and using various types of phenomena

(transmission, reflexion, diffraction, radioactivity) one gets a complete knowledge of the object under examination. This object can be living as well as insert. The medical imagery plays a key role in diagnosis.

The interpretation of images is not the most easy task. The goal is not to get "just an image" but a "just image". Computing aids and modelisation have to be developed in order to draw useful information out of a mass of raw data. A quite obvious example is the interpretation of the maps transmitted by Earth observation satellites. The observations are made in visible, infrared or radar ranges. Their uses are in the fields of agriculture and fishery, desertification, prevention of catastrophes, meteorology, among others. Each user needs a personified interpretation.

On the other end of the dimension scale one can also cite the combined use of atomic models of molecules and molecular configurations deduced from X-rays diffration (fig. 4). This is now a routine in all the laboratories dealing with atomic]structure of the matter (6).

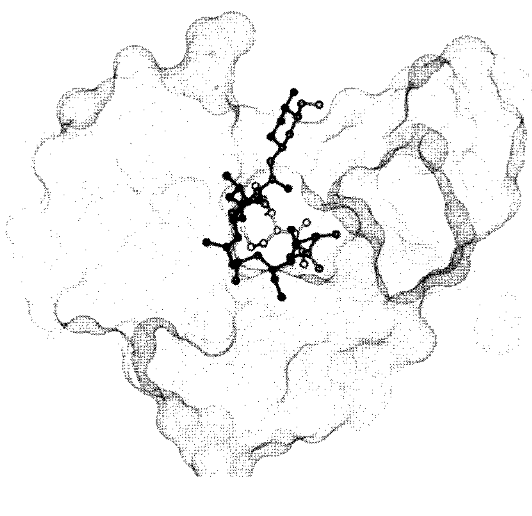

Fig.4 Molecular complex formed by a natural protein(FKBP) in stippled on the figure and drag(FK506) in line.
The structures are obtained by X-ray diffraction.
The immuno supprevie drug is used in order to avoid graft rejection. (J.-P. and I. Mornon, Université Paris VI)

Conclusion

Each of us, inhabitants of the planet, has or at least should have the concern to preserve the quality of life on Earth. Each of us, consumers of man-made products, is demanding more and more quality. The obvious consequence is a growing necessity of prudence well balanced with the natural and laudable taste for innovation (7). There is fortunately no basic incompatibility between "sagesse" and "hardiesse"!

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