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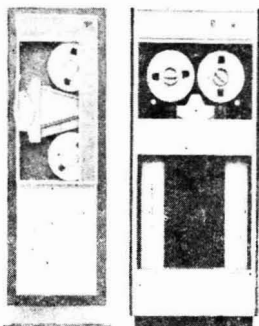
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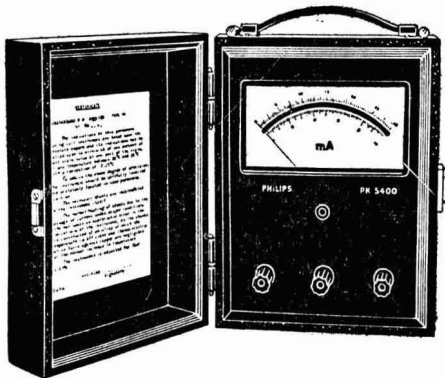
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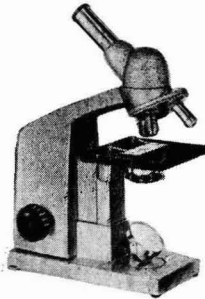
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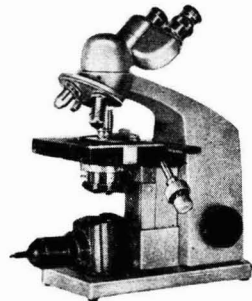


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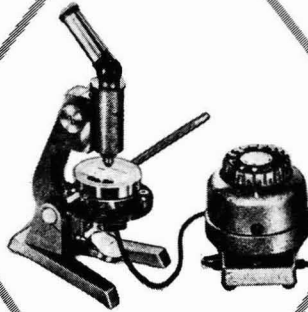
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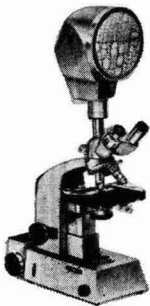
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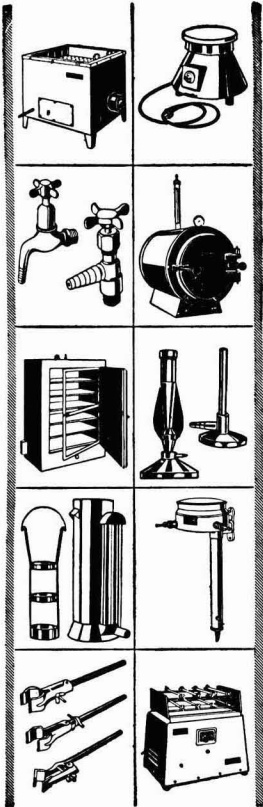
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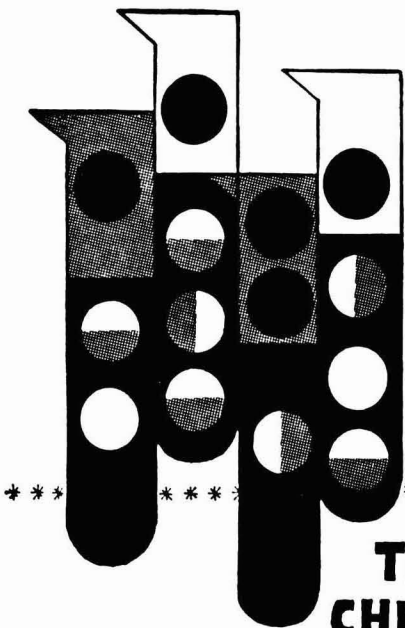
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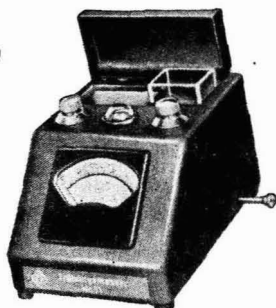
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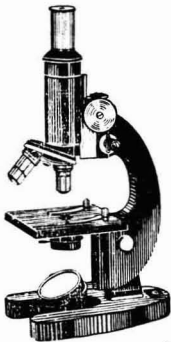
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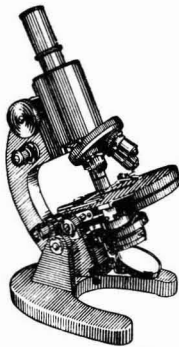


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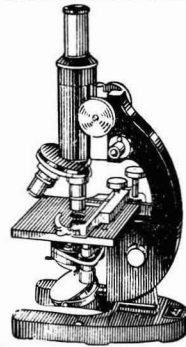
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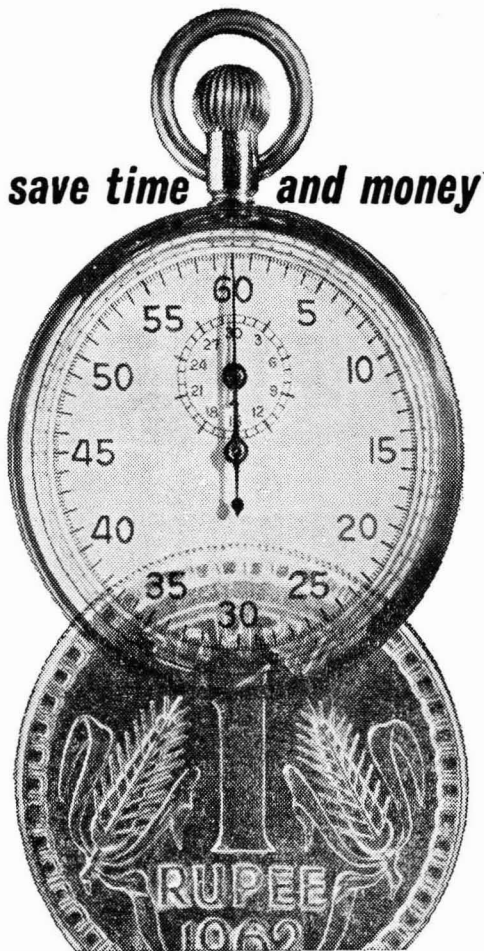
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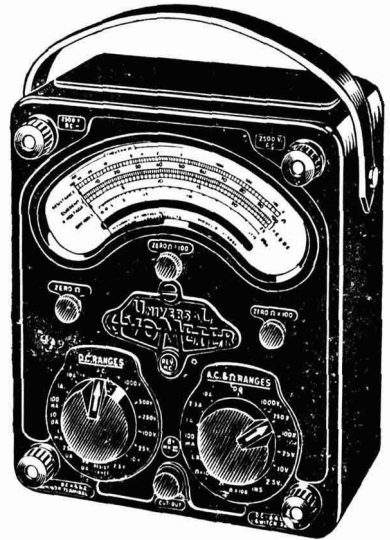
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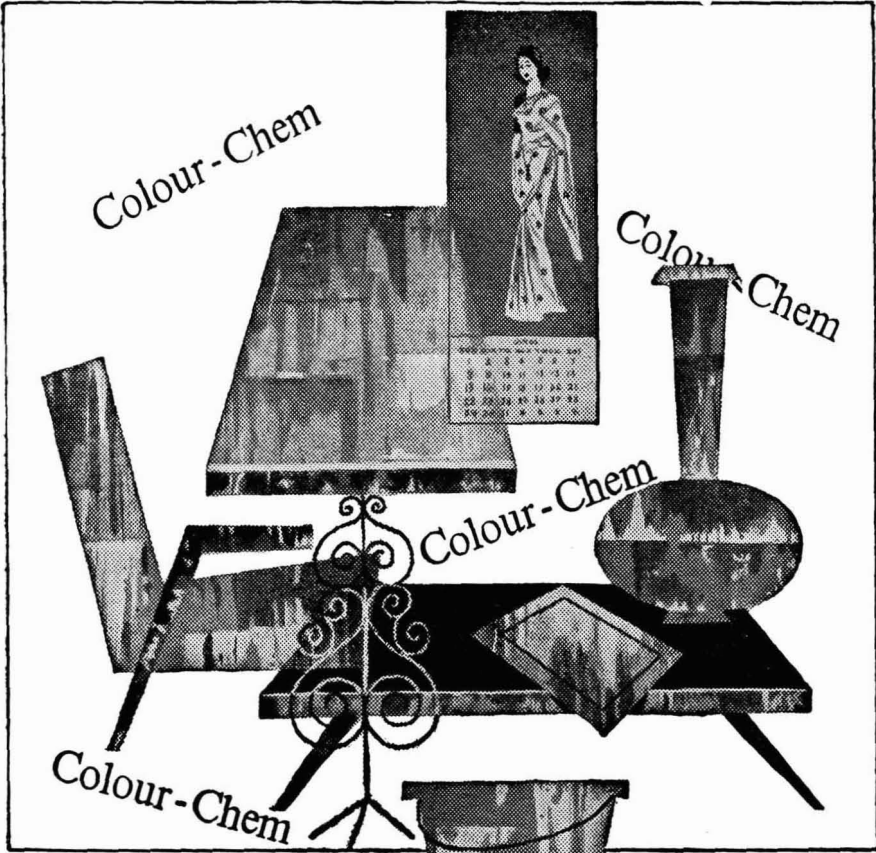
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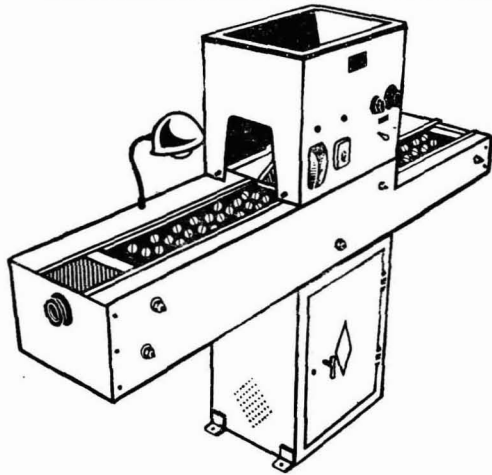
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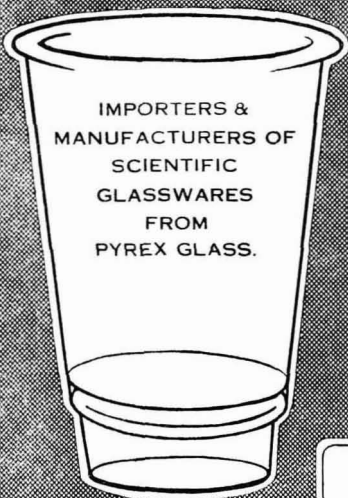
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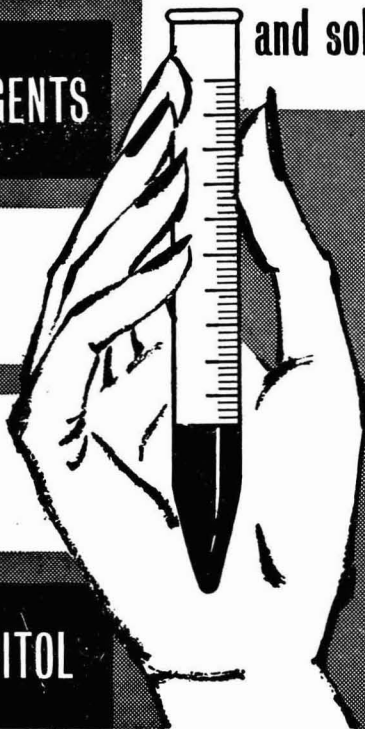
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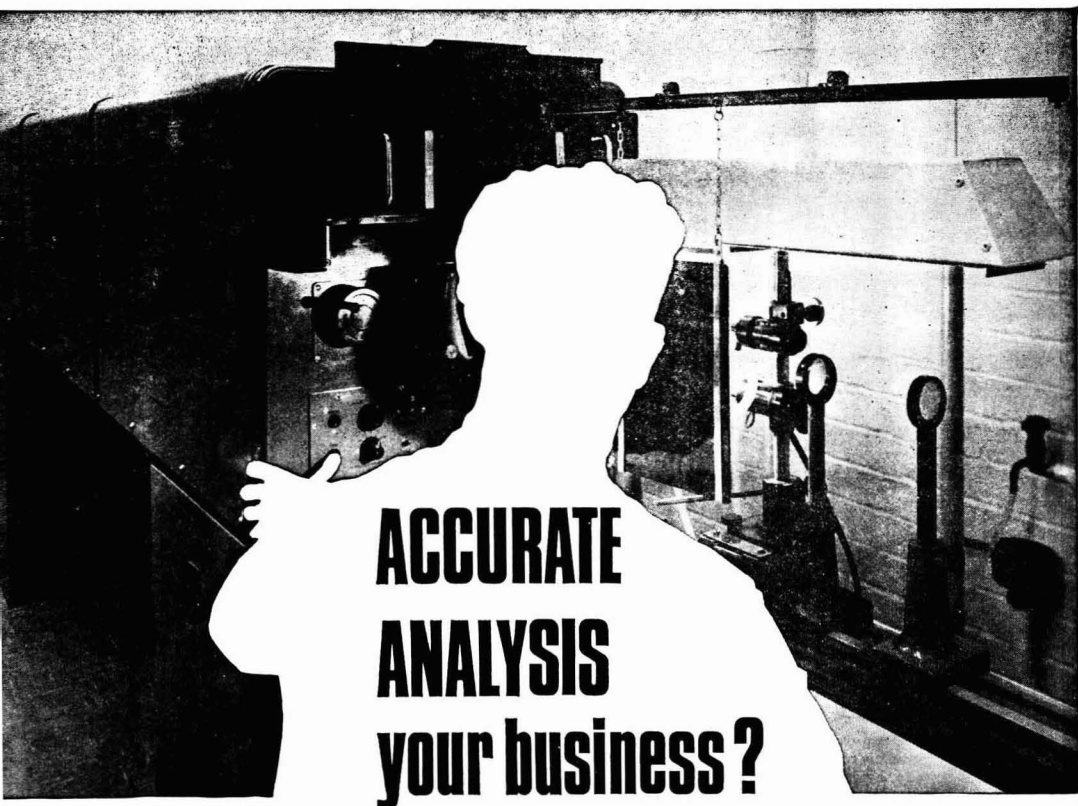
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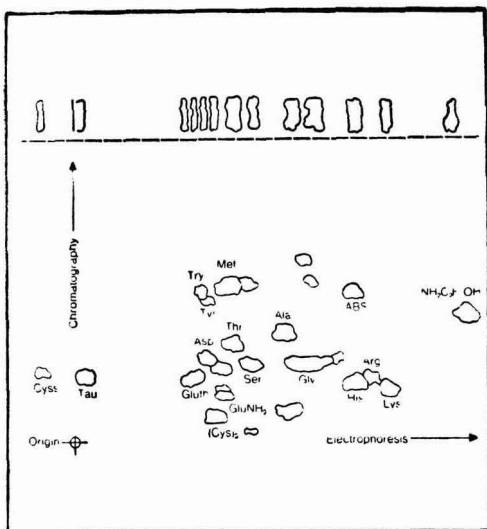
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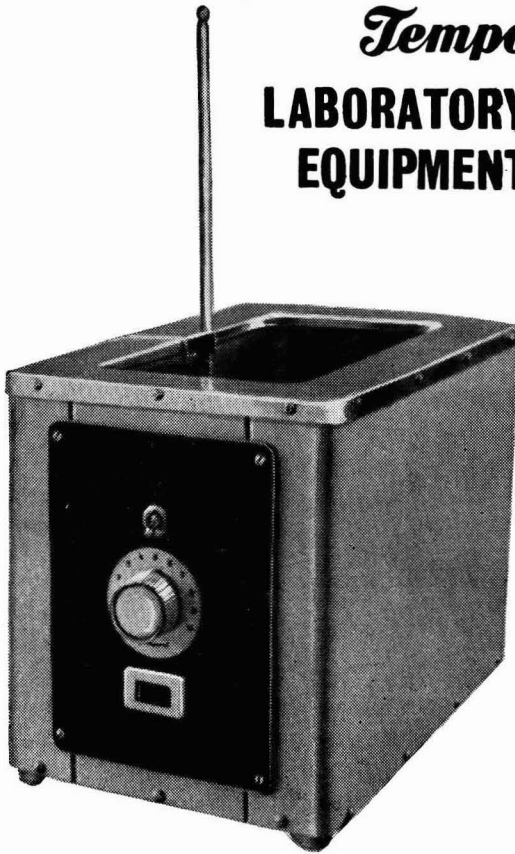
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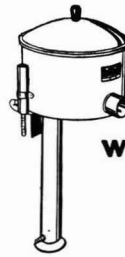
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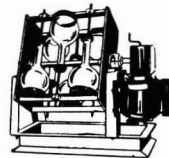
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Science in India—Some Aspects*

Role of Science in a Developing Country

WE are meeting at a time when science is on the threshold of a very exciting era. Last year, for the first time, the opaque atmosphere of Venus was pierced and man-made instruments were landed on it. This achievement is indeed exhilarating and the Indian scientists will no doubt join me in congratulating the fellow scientists responsible for this historic achievement. This, however, strikingly reminds us that whereas the problem in the advanced countries is how to land man on the moon, the problem in the developing countries is how to make man walk well on earth.

Why did Nehru give so much importance to science in India? Why are we making substantial investment in scientific and technological research? And why are we encouraging more and more scientific endeavours? In short, what are the objectives in our support to science?

The consideration of these questions brings two aspects to the fore; firstly, the value of science in developing rational thinking and widening knowledge so essential for a society in transition; and secondly, its economic and social significance. Science and technology, which is sustained by industry and agriculture, give us knowledge and ability to improve communications, endow us with better health through eradication of disease and, in short, give us a better standard of living. Science in the contemporary world is an important tool of human well-being even as capital, labour and enterprise were in the world of yesterday. Never before had man so much knowledge and technique at his command for his well-being. It is this promise which science holds for the people that makes it important. Indian scientists, therefore, have the inalienable responsibility to contribute to the good of the community. What else could be the function of scientists in a developing society? The question we should ask ourselves is, "How near are we to our people, and how relevant is our work to their hopes and aspirations?"

Our research and development should be closely linked and contribute to economic growth. Prof. P. M. S. Blackett, President, Royal Society, London, in his recent Nehru Memorial Lecture has very appropriately said, "The present poverty is so great and the task of dealing with a rapidly rising population is so formidable that almost everything must be sacrificed to economic growth. Economic growth is not everything; but today in India, it is almost everything." I am in full agreement with this view. In this context, the test for research and

development is the extent to which it is put to use in productive enterprise. In India, where research and development is mostly confined to government-sponsored establishments and utilization of results has to be in industry in public or private sectors, there is a hiatus. This is understandable as even when both are under the same auspices, there is usually resistance to innovation from the shopfloor. This dichotomy of research and production is a weakness. The best disposition is research by industry in industry. In spite of tax incentives to industry to undertake its own research and CSIR's offer to contribute towards industrial research associations on cooperative basis, research by industry has not been growing sufficiently fast. In this year's budget, the Deputy Prime Minister, Shri Morarji Desai, has enhanced the concessions on taxation on money spent for research by industry. I hope, industry will take full advantage of these opportunities. It will help them as well as the country. Research not only in our national laboratories and other research institutions but also in our universities should desirably be relevant to the country's needs. For, as Sir Francis Bacon pointed out, "The true and lawful goal of science is that human life be endowed with new powers and inventions and be operative to the betterment of man's life".

For centuries, technology and science remained and developed independent of each other. Technology, known as industrial arts, was essentially empirical and provided little interest to the intellectual classes who generally looked down upon it. As an offshoot of organized human thought, science appealed to the intellectual classes and remained their preserve and pastime. It was only about the middle of the nineteenth century that science and technology came closer to each other and it was realized that each stimulated the growth of the other. With the progress of organized knowledge in many areas, science and technology have lost much of their distinctiveness. Technology is now more science-based than ever before.

I think, it will be of some benefit to us in this country to appreciate the distinct roles of science and technology. Though in a well-developed economy this distinction is not of great significance, in the present stage of our nation's growth, it is important. For, it is on this distinction that we have to base our strategy of development of science as well as technology. Our present need calls for greater emphasis on technology.

As today's science may lead to tomorrow's technology, we must promote and sustain science in all its aspects. Those with vocation for pure science must be able to pursue it. To apply science, one must first know it. Hence, pursuit of pure science must be encouraged in all its varied branches.

*Based on the General Presidential Address of Dr Atma Ram, D.Sc., F.N.I., Fifty-fifth Session of the Indian Science Congress Association, Varanasi, 3 January 1968.

But, in doing so, the highest international standards should be observed. It is essential to have healthy growth of basic science and research should be conducted at the very frontiers of knowledge. For this reason, the universities which are the principal centres of basic work must be strengthened. One of our primary aims in this regard should be the development of what I would term 'scientific capabilities'.

In passing, I wish to mention that the experimental aspect is not sufficiently emphasized in our science teaching. Cultivation of experimental ability need not solely depend upon sophisticated equipment or ready-made apparatus. Improvisation is what should be encouraged; it is this which leads to innovation and often to discoveries. In any case, it develops skills and machine sense. This will also help in orienting our education system to production.

Our country has had a great tradition of intellectual activity; in many fields of science our forefathers made some great contributions to the growth of knowledge. But such knowledge mostly remained unrelated to social needs. Later, in science, as in many other fields of creativity, a stasis set in. Several historical forces made us, along with other oriental peoples, backward. Science and technology became almost foreign to us. The Indian renaissance in the latter half of the nineteenth century, which began with the pioneering efforts of Raja Ram Mohan Roy, caused a literary and cultural upsurge in the country motivated by the desire of a subject nation to attain intellectual equality with their masters. This movement which reached its height in Rabindranath Tagore also re-established the scientific tradition in India throwing up many distinguished scientists, pure and applied, around whom centres of excellence grew. This gave the lie to the view, popular in the West, that the eastern mind was essentially metaphysical and unsuited to science and technology. With independence, public support was ensured for rapid institutional growth and heavy investments were made by the government whose policy in relation to science was most ably put forward in the famous Scientific Policy Resolution of 1958.

While we have a Scientific Policy Resolution, is there a national resolve of dedication to science? How is it that the fire and enthusiasm, which produced outstanding men who could walk shoulder to shoulder with their compeers elsewhere, have dampened? Before independence, we had a goal. What is the goal now? Are we now resting on our past laurels? How is it when insignificant sums of money were available compared to what we get now, we did so well?

At a juncture when emphasis is on technology, we do not have a clear statement of technological policy as we have of science and industrial policies. A technological policy statement which will link our science and industrial policy is vitally necessary. This will give practical shape to many aspects of our scientific policy and provide guidelines for our industrial policy. Such a statement would have to consider, among other things, the following:

(a) Modern technology is capital intensive and labour saving. Conditions in India are just the

opposite; capital short, labour affluent. She is particularly short of foreign exchange. The question would be, what technology should be selected? The test should be suitability to our needs rather than superiority, so as to avoid create social imbalances and unemployment. In adapting technologies considerations of prestige should have no place. Contrary to general belief, Japan has shown that non-automatic technologies are not necessarily primitive nor that sophistication need necessarily be automatic.

(b) In what fields should the country seek and obtain know-how? And what are those which our institutes could be assigned the task of developing know-how and processes? In obtaining know-how there are many aspects which are interrelated and which need careful consideration. For producing consumer goods, we should rely more on labour-intensive technologies.

(c) What should be the degree of sophistication in relation to our needs? In certain fields, such as steel making, basic chemicals, defence and health, we must have the very best, and economy of scale must be ensured.

(d) The relation of technological policy with the availability of raw materials is important. In international commerce, we should identify those items where we can enjoy competitive advantage and in such cases we should use the best techniques. For instance, we should have given concentrated attention to research related to jute, tea and textile industries which have been our major foreign exchange earners.

There may be other similar questions. These should be carefully considered and should form part of a statement of technological policy. There has been some thinking on these issues and policy decisions have been taken in regard to some of them. But a look at the problem in its entirety is needed to bring them together within the ambit of an integrated national policy statement on technology.

Importance of Development of Human Resources

The Scientific Policy Resolution is a well-drafted statement of intentions. We are yet to work out a strategy of development. One often hears the description of India as a poor rich country; we are rich in our resources and potentials but our people are poor. A developmental strategy for India would consist of three essential elements: comprehensive survey of our physical resources and their exploitation; encouragement of capital formation and enterprise; and development of human resources. It is simultaneous progress in all these three fields which can make our country really rich.

Of these, the development of human resources is pivotal. Economic growth needs capital, technological and economic know-how, managerial ability, modern industrial skills and the will to work hard. Except capital, all these relate to human resources. We know of countries with inadequate capital having made remarkable progress on the strength of their human resources. No country in the world can be self-sufficient in its physical resources. History provides instances where unwise human

activities have rendered otherwise prosperous countries barren.

The development of our country can only come the hard way. Inflow of capital and assistance from abroad in various forms can at best be a catalyst. Unless forces are generated within the country based on scientific and technical skills, entrepreneurial talents and forward-looking social attitudes, we will not be able to have the proper infrastructure of development. How are these growth forces to be generated? Obviously, by developing human resources. If investment in physical resources pays off, investment in human resources pays off many times over. Human resources development is not merely education, though education plays an important part. Education provides the base on which we have to build a superstructure of skills and capabilities which transform physical resources into wealth. The training of scientists, technologists and engineers, technicians and craftsmen, managerial and administrative personnel and a host of professional and non-professional men of skills is essential for the growth of the nation. Have we adequately tackled the problem of development of skills, competence and capabilities which produce wealth?

While dealing with skills, I would like to mention the continuing neglect of technicians in our country. More sophisticated the production, the more its dependence on technicians and scientifically trained workers. Industrial production, which is becoming increasingly mechanized and elaborate, needs a highly skilled work-force to operate, maintain and repair equipment, test and inspect raw materials and products, design and construct new machines and develop new products. These highly technical tasks of industry need men with wide and deep technical training. Our society has not given the technicians the recognition they deserve. Their contribution to economic and social progress is as significant as that made by other professional groups of the community.

Planning and Organization of Science

Since we began to organize and expand science in a big way, problems relating to organization and planning of science have held our attention. These are: How should science be organized? What is the position of individual scientists in such an organization?

A certain minimum organization is necessary in any human effort. In applied science directed towards the solution of specific problems which need large resources of men and material, organization is inevitable. But organization of work alone does not always lead to creativeness. Great discoveries are as unexpected as unplanned. Development which has very specific objectives should be as fully organized as possible. Applied research laboratories fall between these two extremes and organization of their research does not conform to a fixed pattern. It varies from laboratory to laboratory depending upon to which end of the spectrum it is close.

In modern research laboratories, management is considered an important aspect. There are no

well-recognized or standard methods of organizing or managing industrial research. Yet, industrial research has been a great success and has progressed very far. There is a view that the relatively unsuccessful attempts to work out satisfactory formulae for organization of industrial research have, ironically, contributed to its success. We should, nevertheless, be aware of our problems and constantly endeavour to improve our methods of organizing research. But to think of straight jacket methods and to expect to find solutions made to order will be expecting too much. While books, seminars and symposia will continue to pour out thoughts and theories on the management of research, the very dynamism of science makes its management a continuing problem. All methods evolved have to be tentative and tested in the crucible of experience. In any case, in our country we should spend less time organizing and more time doing research.

The next question is — "What should be the place of the individual scientist in this age of team-work?" The popular belief is that modern research is a team-work and the days of individual accomplishments are over. Whether it is a team or a committee that functions, ideation is essentially the result of individual intelligence. It is the sudden gleam in the laboratory of the human mind that generates ideas which lead to basic contributions. Committees did not discover penicillin or invent jet engine. The emphasis on team-work and committee work inevitably leads to overall organization and planning. It is doubtful if one who is busy organizing and planning has the time to think science. A team of scientists can be guided and inspired only by an active scientist intimately in touch with and participating in the work at the bench. These views may not be to the liking of science planners who are deeply worried to find the ideal way of organizing effort, avoiding overlapping, preventing duplication and similar other problems.

After completing my university career under the affectionate guidance of Prof. N. R. Dhar, I came under the spell of Prof. Meghnad Saha. I was privileged to collaborate with him in the work of the National Planning Committee. In recent years, Dr Shanti Swarup Bhatnagar planned and organized science in a big way and I was associated with him for fifteen years. Later, I came in contact with Prof. P. C. Mahalanobis in matters of planning. My experience has made me a strong believer in the essentiality of planning for development. After having spent 36 years of my life in research I have been a recruit to Delhi for about a year. I have watched and participated in numerous meetings and committees. If one kept a record of the terminology used in many of these discussions, one would come across phrases like long term, short term, phased programme, feed-back, crash programme, spill over, and infrastructure. But where do they lead us to?

In those aspects of science where planning is important we have hardly begun. We have not yet evolved a method of working out priorities or a system for the allocation of funds. At present, work programmes are formulated by institutions

and a collection of such programmes becomes a plan. There is no scientific body to determine the priorities or to lay emphasis on various areas of research or to frame guidelines for allocation of funds. It is important that some mechanism should be established to ensure that the total amount of money invested in scientific research in our country is so laid out as to yield the maximum benefit to the country. This will ensure that money is not diverted to prestigious projects or to projects of lesser social and economic importance at the expense of some vital needs of the country.

The increasing tendency in laboratories to 'democratization' is a direct outcome of and reaction to the concept of planning and organization. Each worker in a laboratory wants to have a say in decision-making. What is the extent to which democratic process can be applied to the functioning of a laboratory? It is in inverse proportion to the stature and respect the leader commands among his fellow scientific workers. Various democratic departmental procedures have been evolved in many laboratories. Any number of committees and panels are appointed for every conceivable purpose; for library, for workshop, for stores, for purchase and even for space allotment. Various forms and proforma are devised and scientists at the bench have to spend time filling them in. Excessive departmental democracy can be time-consuming and may, in effect, impede research. What is needed really is an intelligent appreciation of the views and needs of the research worker at the bench. In all our discussions on organizational problems of scientific research in India, the point of view of the research worker at the bench is sadly neglected. All other points of view are amply and vociferously put forward, particularly the point of view of the men at the top.

Before I take a different tack, I may refer to the relation of administration and science. It has been taken for granted, it appears, that scientists and administrators lack sympathy for each other's point of view. Our present administrative system was devised by a ruling class for a subject people. Since independence, this system has undergone some changes but not radical enough to satisfy the yearnings of an independent people. But the system has permeated deep. A rapid change will not be free from pangs. I think what ultimately matters is not so much the system of administration but the man behind it. In the hands of an enlightened and competent administrator, even an inadequate system can work to advantage. Impediments cannot deter one who wants to accomplish. No administrative manual can shape the behaviour or skill of an administrator. Under an indifferent administration wrongs can persist as procedurally correct. In the hands of the incompetent, the right can go under. I, therefore, attach far more importance to the choice of proper men in administration. As days go by, the generalist administrator will be replaced by technocrats; a new system and a new relationship are bound to emerge and with them new stresses and strains.

Often, the question of autonomy in scientific institutions is raised. The stress has generally been

on autonomy for spending. But, I would prefer to emphasize intellectual autonomy, and it is this autonomy that I would like scientists to be assured of. Throughout my career starting as a research assistant, I have not had any interference in the operational freedom to handle scientific problems as I liked to. This is what I would consider intellectual autonomy. Autonomy particularly in the mission-oriented institutes has to be viewed in the context of the objectives of the institutes and the country's needs. It also does not mean that he is free from accountability for the financial and other resources placed at his disposal. On the contrary, scientists should be paradigms of discipline and accountability. Administrative rules, regulations and procedures are man-made and can be changed; genuine difficulties in the way of pursuit of scientific research should be removed. So long as finances are derived from public funds, the scientist is as responsible as anyone else spending public funds to account for them.

The problem of autonomy has a twin brother, i.e. the hierarchy. Here again, I think, there is considerable misunderstanding. Science recognizes no intellectual hierarchy. Wherever it exists it must be completely inhumed. But in a research laboratory where a few hundred scientists make the staff, there will be a sort of disorder if all of them begin to feel that they are not answerable to anyone. In such a situation, indiscipline and irresponsibility would breed. Have we taken care that this does not arise?

The Need for Healthy Attitudes—Role of Scientific Societies

The emergence and development of scientific organizations on a large scale in the wake of independence have also widened the scope of and opportunities for scientific careers. A number of problems have arisen, the most noteworthy of which is the growth of careerism in science. From savants scientists have now become 'scientific personnel'. Before independence, only those interested in scientific work took to it; a few made a comfortable living out of it; but, by and large, scientific career did not offer much in terms of money and material acquisitions. But science now offers a career and social position too.

Careerism in science brings mixed results. On the one hand, scientists as a group have developed greater social awareness. On the other, science-for-career attitude is apt to make a scientist emotional or subjective in his approach to scientific work and life. Quite a few scientists nurture the feeling that the very fact of their being scientists entitles them to special rights and privileges in society. A new class-consciousness reminiscent of the privileged priestly class of medieval India is discernible. One viewpoint is that because science helps improve material life, it is loftier than other forms of knowledge. Nothing can be more erroneous than the belief that a particular kind of knowledge is superior to others. Knowledge is varied and integral to progress. A balanced blend of human talents is what ultimately makes a healthy society. Unless scientists are tempered with

humility and with the knowledge that they are but one of the many who contribute to the growth of society, they are likely to fail to make an impact on society and earn its confidence.

Learned societies and professional bodies should provide leadership to the scientific community and create and mould public opinion by example and precept. With such a lead, possibilities of unhealthy tendencies in the body politic of Indian science can be curbed or at least contained. With diversification and growth of Indian scientific institutions, there is a growing number of young men and women engaged in scientific careers. They are easily susceptible to influence due partly to economic reasons and partly to the lack of proper understanding and appreciation of the true role of science. They are likely to become easy victims of shibboleths and slogans and their careeristic attitude may sometimes lead them into wrong thinking and action. The spectacle of a large body of such talented people adrift should be a matter of concern. I appeal to the learned societies to give serious consideration to this problem. Societies should provide leadership to the large body of impressionable young minds.

The government has a vital stake in this matter. It should encourage scientific societies and consult them on matters of moment. The Government of India has long been thinking of setting up a single national academy of science for the country. I might mention that as early as 1945, the government had declared the National Institute of Sciences of India as the premier scientific society in the country. There are well-organized professional societies in most branches of science and technology whom the government could call upon for advice. What is needed is for the government to cultivate the habit of consulting such societies.

Science and Social Forces

Another important duty of the learned societies is to bring about greater understanding between scientists and society. The scientific point of view alone can neither explain nor deal with the dynamics of society. Such a view would presume social forces to be simple, which they are not. Even in highly developed industrialized societies based on science and technology complex social forces are at work. Some intellectuals feel that a deep cultural crisis has overtaken humanity and that individual freedom and human dignity are at stake. Others stress the need to re-establish spiritual values. While scientists may claim to be the new humanists, there are others who feel that the changes brought about by the scientific orientation of life and the industrialization of societies are not all for the good.

Science and technology are only a part, though an important part, of a complex set of forces moulding society. While science and technology should become an essential and integral part of our culture, we cannot ignore other aspects. It is naive to assume that because it contributes a great deal to material well-being and physical comfort, scientific and technological progress automatically results in human progress. Behavioural sciences as

applied to human and social functioning are still in their early stages of development. Perhaps, with the development of these sciences, we may have a deeper understanding of the individual and society. I am no expert in social sciences. The point I wish to make is that an industrialized society based on science and technology is not an unmixed blessing. For, how else can the mental stresses, strains and ailments caused by them in highly industrialized western societies be explained?

The limitations of science are better appreciated today than ever before. Seemingly, great truths of science pale off both at the macrocosmic and microcosmic levels. The principle of uncertainty shows that science is confined to the limits of observation. Relativity, on the other hand, has established that what a scientist deals with are not actual events but observations of the events and, thus, is subjective. The philosophical import of these two discoveries has been stupendous both on scientific and non-scientific thought. The true scientist is humble enough to realize this situation.

Acharya Vinoba Bhave has been saying that science and spirituality have taken the place of politics and religion in the modern world. It is a profound statement. Nehru saw its implications in a society such as ours. One often hears it expressed as the viewpoint of scientists and also the scientific viewpoint that religion has acted as a drag on the advancement of the country; it is also said that religion in Indian society has acted as a counterweight against rationalism, as a force against the spirit of science. It is advocated by some that unless religion is relegated we are not likely to make much progress.

When we refer to religion, what do we have in mind — dogmas or spirituality? If by religion we mean dogmas, superstitions and obscurantism, we should shed it off most determinedly. The Indian mind has the subtlety to distinguish between spirituality and religion. Some spiritual content in human life is essential for its sustenance. The basic irrational forces at work in man and society cannot be easily explained. Sigmund Freud proved in a systematic manner how profoundly irrational forces and hidden motives shape human behaviour. These forces should not be allowed to take better of us humans but should be reined in and channelized. Perhaps, religion has been aiding man achieve this essential task. It has also satisfied the urge in man for social cohesion. Science is yet to prove its value as a cohesive force in society. Spirituality perhaps has a greater potential in this regard. Science has not discovered a chemotherapeutic agent which can induce virtues in man nor has it produced an antibiotic which can fight bigotry. Religion without the temper of science is superstitious. Science untempered by spirituality can be dangerous.

Human society is basically conservative — slow to change and evolve. Science, on the other hand, is basically revolutionary and upsets *status quo* by making unknown known. Modern technology which is continuously changing the material and social conditions of man intensifies the challenge of science to society. It would seem that there is

an inherent conflict between science and society. Older the society the more conservative it tends to be. Ours is a society with centuries of history behind it and so are our people steeped in tradition. In dealing with the problems of an ancient society such as ours, we come across innumerable difficulties. But our approach to the problems should be pragmatic. Let us avoid the futile exercise of finding faults. Instead, we should demonstrate by constructive endeavours the positive benefits of science and technology. The vast masses of our people take succour in fatalistic beliefs, and religion appeals to them for the promised better things in the next life. Mahatma Gandhi used to say, "To the poor, God can only appear as bread or a bowl of rice". Before we expect people to break away from traditions and develop a scientific attitude, we might as well ask ourselves, whether we have provided them even the elementary benefits of science—food, shelter and clothing; in short, economic security. Instead of giving our people more science and the accruing material benefits, are we justified in giving them ideology and the conflicts attendant to it?

Some Problems of Scientific Talent and Manpower

We frequently hear of our difficult manpower position, particularly about the shortage of able people and the problem cryptically described as 'brain drain'. It may be conceded that there is a shortage of able people. This bad situation is made worse due to two reasons. One's reputation, prestige and influence are determined by one's ability to move in the right circles and to have the right contacts. It is often difficult to withstand temptations and stay on in a laboratory to struggle with one's problems. The lure of opportunities does not always have healthy influence. The size of our country adds to the difficulty. It is not easy to know all the talented individuals spread over 70 universities and nearly two hundred scientific and academic institutions scattered over an area of above three million square kilometres. This results in two consequences. The few who are identified are sought after again and again. They soon lose their bearings in the area of science which once was their force. As a result, a few individuals tend to feel disproportionate importance in the community and develop tendencies akin to 'mathadhipatis'. Others, many of them young, remain unrecognized. Since they are unable to enjoy the opportunities that frequent the fortunate few, they become disenchanting, critical and even cynical. Often this cleavage assumes the controversial tinge of young versus old. In absolute terms, I do not think the nation is short of talent. Rather, the fault seems to lie, first, in the defective methods of locating talent and, secondly, in the overuse and diffusion of talent. Government's method of consultation should not unduly distract scientists from creative pursuits, nor should they be neglected.

Another related topic which comes to my mind links creativity with age. In absolute terms, creativity has little to do with age. Relatively

speaking, however, at young age, the propensity to discovery is sharper. This is a statistical statement. Because the young mind is not loaded with knowledge and its sense of wonder is still keen, it proceeds unfettered by preconceived ideas. It is able to hazard hypotheses which may seem too bizarre to minds saddled heavily with preconceptions. Such strides of the young mind sometimes make significant discoveries. This theory is not peculiar to science alone. William Wordsworth seemed to feel that infants had spiritual knowledge and the shades of the prison house close upon the growing mind. When a young scientist makes a significant discovery, he becomes a celebrity and has to give of his time receiving awards, addressing meetings, discussing in committees and so on. Circumstances tear him away from creative scientific work. He may yet obtain plenty of equipment and money, acquire status and security, but he does not have the time or the moorings for creative work any more. May be, in this manner, we might have lost quite a few who might have blossomed to distinction.

The essentially statistical theory of creativity and age is often strained to extreme lengths. The theory bears relevance to discoveries and may, therefore, be applicable in the pure sciences. It is not of much value in the application of knowledge as in technology, engineering, industry, agriculture and medicine. In these spheres accumulated knowledge and experience weigh much. Competence is and should be the only test in any area of human endeavour.

While every one should warmly endorse the view that young should be encouraged, the temptation to make another generalization should be resisted. If one studies the lives of eminent Indian men of science, who may now be put in the category of the old, one will notice that most of them achieved distinctions while they were young. One might recall that during early days heads of several national laboratories were appointed in their thirties and forties. Old order changing and yielding place to new is but a natural process. The process thus goes on and will continue to operate for all times to come. Does this process which is obvious and inevitable really need a push? Although it is often said that the young are exploited by the old, I have yet to come across a single case of anybody being penalized for this. Specific cases of exploitation should be identified and the wrong-doer dealt with. It is most important to remember that in our enthusiasm to encourage the talented, we should not support mediocrity in the name of young.

Much is being said and written about 'brain drain'. There have been discussions on this problem all over the world. Many have described the phenomenon just as it has appeared to them; they have diagnosed the causes for what they consider a disease and have suggested various remedies. I have also made a little contribution to this discussion and quite a few interpretations to what I said have been tossed about. I must confess that some of these interpretations have amazed me. For, some people have even gone to the extent of

saying that I was closing down the Scientists' Pool. I must emphatically say that this is totally incorrect.

The problem of brain drain is not peculiar to India. No country in the world except perhaps the United States is free from it. In the so-called 'brain drain', the trek seems to be towards the United States. To some extent, the other developed countries in Europe serve as an interface between the developing countries of Asia and Africa and the United States; but the ultimate receiver is the United States.

I would like to deal mainly with two facets of the problem. The first is the fact of migration. Since the last World War, mobility of scientists and other skilled persons has considerably increased throughout the world. Apart from the fact that the language of science and technology is universal, the increasing use of English as the common medium of communication among scientists and technologists has made mobility easier. Skills always seek opportunities and the United States provides today those opportunities which give satisfaction, both ephemeral and real. It is difficult to stem the flow of scientists, but we should take more steps to lessen the number to ensure that it does not work to our disadvantage. But for the measures taken in this country to induce scientists to return or stay at home the outflow of scientific talent from India would have been much greater.

The second aspect of this problem is what precisely can be done to get the foreign-based Indian scientists and other qualified persons back to our country. Here again, we tend to become emotional and subjective in our approach and even forget those who are already in the country. Are we doing enough to recognize and satisfy the competent and the good who have chosen to stay home? A general call for return of scientists abroad is no remedy. The Scientists' Pool, the creation of supernumerary posts in government establishments and other palliatives barely touch the fringe of the problem. Unless the growth of our economy is such that it can absorb them fruitfully, the return of a large number of skilled and qualified men and women will only add to the prevalent atmosphere of frustration and resentment in our intellectual life. Those who can be absorbed in the growing economy should be encouraged to come back. They would find satisfaction for themselves and give satisfaction to the nation. Any other step unrelated to the needs of the country will not help, it may only worsen a problem already bad enough. Ultimately, the real solution lies in the economic growth of the country, on the basis of which industry will develop and wealth produced. This in turn would sustain the creation and growth of social institutions and generate multifarious other activities needing the services of qualified men of various types. The point becomes clearer by the fact that it is becoming increasingly difficult to provide employment even to engineering graduates. With the relatively meek economic growth compared to our progress in education, the exodus of scientifically and technically qualified young persons may increase. Most of them are patriots, but we cannot expect them to live by patriotism alone.

The Problem of Know-how and Foreign Collaboration

Foreign collaboration and import of 'know-how' is another subject on which strong views are often expressed. Whatever may be the views of scientists and technologists, let us not make any mistake about the general psychology influencing the policy of foreign collaboration and technical 'know-how'. Since 1947, our country has registered a fairly good economic growth. By and large, the growth is based on foreign collaboration and imported 'know-how'.

The government has adopted a fairly liberal policy towards foreign investment and remittance and repatriation by foreign investors. There is a feeling that foreign collaboration has been permitted even where 'know-how' was available in the country. Some say that laboratory scale operations are mistaken for technical 'know-how'. An investor invests for profit. Altruistic motives play little part in this matter. Unless we are able to give the investor the whole 'package offer' consisting of technical and economic 'know-how', plant and machinery, managerial and marketing techniques, technical 'know-how' alone will not interest him. The research scientist cannot offer the whole gamut of expertise and 'know-how' to make an industrial enterprise. Nowhere it is so. Lack of appreciation of the role of the research scientist can cause much wastage of time, effort and unnecessary recrimination.

Industrialization in the modern sense has brought with it new techniques of management of high sophistication. Such responsibilities as the following, which now devolve upon large industrial management, were mostly unknown before: (i) choice of product; (ii) design of operation for production; (iii) securing and using the necessary materials, machines, power and labour; (iv) merchandising and marketing of the products; (v) financing the operations; and (vi) building and maintaining a large network of functional set-up. All this requires management skills with quite involved and complex procedures. If we are to be in the forefront of the industrial and commercial world, trade with other countries and keep our balance of payment position sound, we need all these skills. An institutional structure for fostering such activities and working in close integration with research institutions is the crying need of the hour.

There is also the psychological aspect of the widespread feeling prevailing in the country that anything foreign is superior to anything Indian, which pervades even our intellectual life. It is also discernible in our science and technology. In industry, nothing ensures the success of a product better than a foreign name tagged to it or its association with a foreign firm. Gone are the days of Swadeshi spirit. It may need a Gandhi to propagate a new wave of confidence in our efforts and in our achievements.

While we should develop confidence in our own efforts, we should not in the name of 'Swadeshi' re-invent what is known, unless we are denied the use of technology available abroad. When technology

can be purchased from others without compromising national interests and crippling local efforts, we need not take a doctrinaire view of things. It may be asked if technology can be purchased from others, where do Indian scientists come in? It is well known, that even where technology may be available from outside, large amount of work has to be done to adapt it to local needs and conditions. Therefore, in developing countries high priority must be given to adaptation work. Technological independence, though a desirable goal, is not easy of achievement. Not even the USA, which is perhaps the only country which has a positive balance of technological payment, is technologically independent. She pays about \$ 70 million per year to others. We should develop technological competence rather than strive after technological independence.

Science, Government and Politics

The prosperity and security of nations are determined largely by their scientific capability and industrial strength; hence, the tremendous growth of patronage of government extended to science and the spectacular outlay which governments make on scientific progress. Scientific activity is assuming an increasingly important part in the functions of our government. This is bound to grow further.

The place of the scientist in government is now taken for granted and to some extent he participates in decision-making and discharging executive functions. This situation is not without its side-effects. The possibility exists of individuals assuming roles far beyond their competence or their jurisdiction. Such instances are not wanting. I think two safeguards must be ensured. One is, the right man must be in the right place. The other is that the machinery of consultation should be such that no single individual should be privileged to give advice and take decisions of importance merely by virtue of his position. There is, therefore, a good case for making consultation by government more effective by widening its scope through scientific societies.

Science places immense power in the hands of the State. Scientists are the instruments for wielding this power. This throws scientists into the arena of politics. The example of Lord Cherwell and several others illustrates this. The scientist today finds immense scope and opportunities to assume overlordship over considerable areas of governmental activity. This is a matter which needs the attention of the scientific community, and measures should be evolved to ensure that unhealthy tendencies do not overwhelm scientists. Unless the scientific community is alert, its very integrity may be put in jeopardy.

In a parliamentary democracy where development of science is a cardinal principle of State policy, it is but natural that parliamentarians should get increasingly involved in affairs of science. It is a matter of gratification that we have an Indian Parliamentary and Scientific Committee consisting of Members of Parliament and representatives of scientific institutions. It is desirable that

parliamentarians and scientists should come in close contact so that the former may also appreciate the methods of science and their application for the welfare of the country. To enable parliamentarians to obtain authentic, objective and up-to-date information on scientific matters, it will be useful if a Science Information Unit is established in the Parliament Secretariat.

By virtue of the power and influence scientists command today, they have attained a high place in political decision-making. In certain matters they play the crucial role in the West. It will not be long before the scientists will be called upon to assume such roles in this country also. The fact that science is universal in character and does not recognize national boundaries makes it an important vehicle for fostering international understanding. In matters connected with modern defence and armament policy and in similar other issues scientists have come to occupy a special and significant position. In a world becoming increasingly dependent on science and technology, scientists must clearly understand their responsibilities. I am not stating that scientists should go into politics. The point I wish to make is that problems in the modern world cannot and should not be left to the politicians alone. Scientists and technologists have a vital and active role to play and are not merely to act as advisers.

Ladies and Gentlemen: I have covered rather a wide canvas. I have deliberately raised some questions not so much with a view to offering immediate solutions but with the intention of evoking the interest of the scientific community in these matters and provoking discussion thereon. It is desirable that members of the scientific community should interest themselves in problems around them and bring to bear upon them the scientific approach. Likewise, they should shape their own attitudes to their scientific work, society and other fields of knowledge so that they view these problems in proper perspective. Issues unrelated to science should be kept off discussion. The quality of scientific approach endows scientists with the ability to think and act objectively and we should preserve this quality at all costs. The need for creating healthy scientific public opinion in this country is greater today than ever before. Far too much of scientific matters is conditioned by officialdom. In a democracy people mould government policies; unless the scientific community in the country is able to shape and influence government policies through healthy, objective and strong public opinion, Indian science may suffer. Scientists should be aware of the snaring charms of 'organization'. 'Just as science is no magic wand, so also is organization which too cannot perform miracles. I cannot refrain myself from making an earnest appeal, particularly to young men and women that they should not fall a prey to cliches and catch phrases. There is no substitute for hard and devoted work. We should develop the will to work hard; for, nothing but diligence and dedication can bring rewards commensurate with the aspirations of the young minds.

International Symposium on Modern Optics

AN international symposium on modern optics, organized by the Polytechnic Institute of Brooklyn, in cooperation with the Institute of Electrical and Electronic Engineers and the Optical Society of America, was held in New York during 22-24 March 1967.

The purpose of the symposium was to review the recent developments in modern optics, including, among others, holography, applications of lasers, interactions of optic and acoustic waves, and various optical and photographic techniques. Authors from different countries contributed a total of 49 papers which were presented in 12 technical sessions (including 3 on holography) spread over the three days.

Opening Session

On the opening day of the symposium the guest speaker, Chalmers W. Sherwin, delivered a talk on "Synthetic aperture radar—A case history of hindsight analysis" which discussed governmental support of academic research and the significance of basic research in achieving military development goals.

Two papers, one by Glauber (European Organization for Nuclear Research) and the other by Patel (Bell Telephone Laboratories) were presented at the opening session. The first paper emphasized that much statistical information can be obtained from the multi-photon states of an electromagnetic field, generated by actual sources, by measuring photon counting correlations and statistical distributions the number of photons counted in fixed time intervals. Such a measurement would enable higher order coherence of the field to be determined and it would furnish a much more detailed characterization of the source of the field than would be possible by simple intensity measurement.

The second paper discussed the uses of CO₂ laser at 10.6 μ in investigating some nonlinear phenomena and scattering processes.

Laser Interferometry

In interferometry, coherent light obtained by isolating a single mode from a narrow wavelength spectral light source has long been used. Lasers have increased the coherence length from less than a metre to many kilometres and power in a single mode by many orders of magnitude. The scanning spherical mirror interferometer, long path multiple beam interferometer, optical delay line interferometer, etc., which utilize the new laser characteristics, were discussed by Herriott (Bell Telephone Laboratories).

Several interesting applications of a laser resonator, capable of sustaining a large number of transverse modes, were described by Pole, Myers and Wieder (IBM Thomas J. Watson Research Centre). The attainment of 350 mW. of single frequency light at 5145 Å., using a r.f. excited argon FM laser and an external FM modulator driven out of phase with respect to the laser output, was reported by Osternick

and Tary (Sylvania Electronic Systems). A detailed analysis carried out by the authors revealed the dependence of FM distortion on total laser power, mode coupling coefficient (δ), and modulation index (τ).

Holography

An investigation on the basic feasibility of making ultrasonic holograms and obtaining three-dimensional images of optically opaque objects from them was reported by Kreuzer (Perkin-Elmer Corp.). A variety of ultrasonic holograms and the images produced from them were presented, together with conventional coherent and incoherent visible light photographs of the same objects for comparison.

Uses of Fresnel zone plates in holography, coherence measurements, spectrometry, optical analogue computation and optical testing formed the subject matter for a paper by Lohmann (IBM San Jose Laboratory) and Paris (IBM Development Laboratory, Boulder). Another paper by De (Calcutta University) and Lohmann described a method of signal detection by correlation of Fresnel diffraction patterns. In this method, key words are used directly and not in the form of a matched filter. The correlation integral of the intensity distributions of the Fresnel diffraction patterns from the object and from the reference signal was computed optically.

The theory of Moiré patterns, produced by the superposition of families of curves, was discussed in two papers by Oster (Polytechnic Institute of Brooklyn) and McCurry (IBM Systems Development Division, Endicott) respectively. The first paper stressed that the phase relations in complex problems in physical optics can be solved by the Moiré technique. Concentric circles of equal spacing (the model for a cylindrical wave) when overlaid on a simple linear grating (the model for a plane wave) give the solution for the half-plane diffraction problem. The diffraction pattern for a straight edge (a primitive hologram) serves as a variable-spaced diffraction grating, which, when illuminated with parallel light, reconstructs an image of the edge. It is possible, by the Moiré technique, to produce various variable-spaced diffraction gratings including the Soret circular zone plate which is the contour map of a paraboloid of revolution.

The second paper presented a geometrical obstruction theory of multiple source Moiré patterns which result from the superposition of a grid or slit array on a similar light source array.

The problem of relating the holograms of a static field which exists over an aperture to the hologram of the field produced over planar regions which are disjointed from the aperture was discussed by Devaney and Baron (NASA). The relationship was reported to be a convolution integral which mapped the intensity pattern stored on the aperture hologram on the intensity pattern corresponding to the hologram of the field over the desired planar region.

Coherence

A re-examination of the concept of coherence by the introduction of higher than the usual second-order coherence functions was made by Picinbono (Institut d'Electronique Fondamentale, France). The statistical nature of higher order coherent field has been studied and it has been shown that they are random only by one trial which determines the value of the field at some point of origin. The study of this random variable has helped to define two kinds of coherent fields, weak and strong. For strongly coherent fields it was shown that the field was random, but the instantaneous light intensity was constant.

A method for determining photon time of arrival distributions for light from a narrow line ^{198}Hg source under various conditions of polarization and spatial coherence was described by Scarl (Polytechnic Institute of Brooklyn). The determination of this distribution is one of the methods for measuring second-order coherence in a beam of light most closely related to the photon picture of radiation.

Acoustic Interaction

An analysis of wave propagation in non-homogeneous anisotropic media was made by Auld and Wilkinson (Stanford University). Since the scale of the non-homogeneity was large compared to the relevant wavelength, geometrical optics approximations were used. Application of geometrical optics to coupled wave systems, allowing for both dispersion and dissipation, was discussed. The principles were illustrated by examples using both magnetic and piezoelectric media. The possible application of non-homogeneity effects to acoustic lenses and beam deflectors was also reported.

An interaction of light with acoustic waves in which electrostrictive coupling of two light wave of frequencies f_1 and f_2 produces an acoustic wave at the difference frequency $f_1 - f_2$ was described by Caddes (Sylvania Electronics Systems), Quate and Wilkinson (Stanford University). This effect was used by the authors to generate microwave ultrasound in crystals of strontium titanate, rutile, quartz and sapphire, with reasonable agreement between theory and experiment.

Whitman, Kropel and Lotsoff (Zenith Radio Corp.) described an optical processing technique using acoustic Bragg diffraction and optical heterodyning. The Bragg diffraction sound cell was used by them to convert the frequency spread of a r.f. signal into a spatial spread of light frequencies on the surface of an optical square law detector. Spatial filtering and local oscillator wavefront shaping could then be used to control phase and amplitude characteristics of the optical heterodyning process.

Nonlinear Optics

This session was devoted to papers dealing with interactions and scattering (including Raman scattering) of light waves in and under different media and conditions, nonlinear interference effects and frequency tunable generation of light in the visible and infrared range.

The interactions of intense light beams in fluids with anisotropic molecules were discussed by Bloem-

bergen (Harvard University). Investigations into the scattering of light waves at boundaries to parametrically modulated media were reported by Peng and Cassedy (Polytechnic Institute of Brooklyn). They presented a complete set of normal modes, for a periodically modulated medium, which is necessary for treatment of the boundary value problem. Specific results of interest in optics were also reported for cases having plane boundaries perpendicular to the axis of modulation of the medium, with various parameters of pump frequency, pump wavelength (incident), signal frequency and the basic dispersion of the (unmodified) medium.

Lasers

A description of recent experiment at Bell Telephone Laboratories on the measurement of the natural particle density and the radial density profile of electrons as well as the atomic and ionic states was presented by Gordon. The second part of his paper reviewed the technology of ion laser construction and the performance levels attained to date. The construction and performance of a singly ionized neon laser (ultraviolet range) capable of stable and long-life operation were reported by Hernquist and Fendley (Jr) [RCA Laboratories, Princeton]. An introduction and a review on the ring laser and its latest applications were presented by Macek, Meclure and Wang (Sperry Gyroscope Co., New York). In addition, the last author presented a separate paper on the behaviour of two independent oscillators such as the clockwise to anticlockwise waves in a ring laser coupled together by various mechanisms.

Electrodynamics and Diffraction

A critical review of recent researches carried out in diffraction optics with special emphasis on the generalized theory of the boundary diffraction wave was presented by Wolf (Universities of California and Rochester). It was shown that the concept of boundary diffraction wave leads to a new and mathematically consistent formulation of Kirchhoff's diffraction theory.

The reciprocity theorem of electromagnetism stems from the time reversibility of Maxwell's equation. The two proofs of this link, based on irreversible thermodynamics and pure electromagnetism respectively, require a high level of mathematics. Grivet (Institut d'Electronique Fondamentale, France), in his paper, shaped the electromagnetic proof in an elementary form.

An application of the method of scaling a laser resonator up to the microwave region to study the performance characteristics of a 90° resonator was described by Checcacci and Scheggi (Consiglio Nazionale delle Ricerche, Italy). The applicability of scalar theories in electromagnetic wave propagation was discussed in detail by Streifer and Kurtz (University of Rochester).

Information Transmission and Processing

An electro-optical signal processor capable of simultaneously recording one hundred phase-coherent channels of pulsed carrier signals on photographic

film without time dilation was described by Arm, King and Aimette (Columbia University). The technique involved is suitable for the recording and signal processing needs of radars and other multi-channel pulsed carrier signal sources characterized by high data rates.

The use of an extended version of the diagrammatic-perturbation technique to calculate the coherent field and the associated refractive index for random media was reported by Brown (Jr) [Hughes Research Laboratories, USA]. The results obtained can be applied to the propagation of optical and longer waves in media where the index fluctuations occur on a macroscopic scale.

Atmospherics and X-ray Astronomy

The design of an instrumentation system for the study of the effects of atmospheric turbulence on a collimated laser beam under near-earth conditions was described by Deitz (Army Ballistic Research Laboratories, USA). Gloge (Bell Telephone Laboratories) calculated the distortion of a coherent light beam guided by glass lenses in a gas-filled underground tube for small fluctuations of the refractive index of the gas. A simplified construction of a large-area glancing-reflection X-ray gathering system was described by Kantor, Novic and Wing (Columbia University).

Crystal Growth of Organic Solids & Mechanism of Single Crystal Growth from Melt

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IN recent years, interest in the growing of single crystals¹⁻¹³ of organic solids has been increasing rapidly. Single crystals are needed for a variety of physical studies of ever-increasing variety such as electrical and thermal conductivity¹⁴ and magnetic resonance measurements. They are also finding use as scintillators and have potential applications as ferroelectrics (guanidine aluminium sulphate hexahydrate is ferroelectric), piezoelectrics (sorbital hexaacetate is piezoelectric), semiconductors^{14,15} (large number of organic solids with π electrons are semiconductors), thermoelectrics and in several other devices. The only drawback of organic crystals is their relatively lower stability to temperature, but the limitless variety of compositions and structures possible make them suitable for many practical applications.

Organic crystals are molecular solids with molecular building blocks held together by relatively weak van der Waals' forces and hydrogen bonds. Due to this, their properties can be quite different from those of most inorganic crystals. Therefore, methods normally used for the growth of inorganic and metallic crystals have to be modified before they can be applied for growing organic crystals.

Methods for Growing Organic Single Crystals

Various methods are available for producing good quality crystals on large or small scale. These

methods can be conveniently divided into material transfer methods involving concentration gradient (growth from vapour and solution) and heat transfer methods involving temperature gradient (growth from melt). Methods belonging to both the categories have certain advantages and disadvantages (Table 1). A different classification is given by Laudise¹⁶. Though these methods are based on widely different principles, for growing a good quality crystal, the following considerations are common to all of them: (i) temperature fluctuation should be avoided, (ii) growth should proceed at a constant rate, (iii) the rate of growth should be as low as possible, (iv) large temperature gradient should be avoided, and (v) the material used should be of high purity.

Growth from Vapour

The method consists in transporting vapour from a region containing solid nutrient material at a temperature t_1 to a second region at a temperature t_2 slightly below t_1 , thus creating supersaturation which, if controlled properly, can yield good crystal nuclei and allows for their further development. This method, compared to crystal growth from melt and solution, has been rather infrequently used to grow single crystals of relatively big size. Therefore, the experimental details for growing crystals by this method are not well developed. Sears¹⁷ grew nearly perfect organic crystals by the vapour phase method. Since growth can take place in a vacuum or in an inert atmosphere, crystals free from non-volatile impurities can be grown.

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TABLE 1—ADVANTAGES AND DISADVANTAGES OF THE METHODS BELONGING TO MATERIAL TRANSFER AND HEAT TRANSFER GROUPS

Groups and methods	Advantages	Disadvantages
(A) Material transfer or concentration gradient <div style="margin-left: 20px;"> ↓ Growth from solution ↓ Growth from vapour </div>	<ol style="list-style-type: none"> 1. Almost isothermal growth environment 2. Slow growth rate; hence good quality 3. Crystals are unstrained 	<ol style="list-style-type: none"> 1. Possible contamination by container and/or transport medium 2. Growth rate slow for large-scale production
(B) Heat transfer or temperature gradient <div style="margin-left: 20px;"> ↓ Growth from melt → Moving crucible (Bridgman-Stockbarger) → Moving crystal (Czochralski) → Moving interface (Kyropoulos, Stöber) </div>	<ol style="list-style-type: none"> 1. Rapid growth rate 2. Simple apparatus 3. Large crystals obtainable 	<ol style="list-style-type: none"> 1. Quality of crystals may be poor 2. Large temperature gradient 3. Crystals require annealing 4. Constitutional supercooling may hamper good growth for heavily doped material

The mechanism of crystal growth from vapour is fairly well understood compared to the mechanism of crystal growth from melt. Growth from solution appears to proceed in the same way as from vapour. The theory of crystal growth from vapour phase can be considered under two heads: (i) the theory of growth of perfect crystals, and (ii) the theory of growth of real or imperfect crystals. The first theory, initially propounded by Gibbs¹⁸ and elaborated by others¹⁹⁻²⁴, is based on the variational principles of thermodynamics. During the first half of this century, an atomic theory of crystal growth of an ideally perfect crystal was developed²⁵⁻³¹. But there is wide discrepancy between the theoretically calculated rate of growth of a perfect crystal and that observed for a real crystal. Frank^{32,33} suggested that in crystal growth one must recognize that real crystals are not ideally perfect; they have imperfections in the form of crystal dislocations which are capable of providing the sources of steps required for the continuous growth of a crystal. This was followed by rapid advances in the understanding of the characteristics of crystal growth. Partially successful theories have been developed by Burton *et al.*³⁴. Much, however, remains to be done particularly in the understanding of the role of impurities in the growth process. The theory of dislocations has been discussed by several workers³⁵⁻³⁸.

All existing atomic theories are necessarily complicated. It would be helpful if a comparatively simple phenomenological theory could be developed. Such a theory would be the counterpart of thermodynamics and would allow the classification of numerous apparently contradictory experimental

facts. Attempts in this direction have been made by Frank³⁹ and others⁴⁰, although they have not been fully successful. Detailed treatment of various growth mechanisms is available in literature⁴¹⁻⁴³.

General Considerations

The vapour phase method can be used for growing crystals of fairly good size of all such organic solids which sublime without excessive decomposition and have vapour pressure in the range 10^{-3} to 1 atm, at some temperature up to the melting point. Below this pressure, the rate of growth becomes inconveniently slow and the chances of dendritic growth are more. Brandstätter⁴⁴ grew single crystals of 22 organic compounds by sublimation and was able to observe growth spirals on many of them. Growth spirals have also been observed in the case of *p*-toluidine^{45,46}, *n*-heptane^{47,48}, paraffin⁴⁹ ($C_{36}H_{74}$), naphthalene⁴⁶, *n*-nonatricontane⁵⁰ and other compounds^{41,51}. Weissberger⁵² has given a list of organic compounds which may be sublimed *in vacuo* without decomposing.

The best quality crystals are grown in a system near equilibrium with a relatively small temperature difference between the nutrient and crystal surfaces. The variables required to be controlled are supersaturation, the growing temperature and pressure of the system, the rate of transport of vapour which depends to some extent on the shape of the growth apparatus and whether the vapour is entrained by a foreign gas. It is more difficult to control the growth rate by entrainment of the vapour than growth in a closed system and hence this method is not used for substances having appreciable vapour pressures.

Growth from vapour can be achieved in 3 ways, depending upon how the temperature gradient between the nutrient and growing crystal is produced: (i) a gradual temperature gradient is maintained over the length of the growth chamber, (ii) a constant temperature difference is maintained between the nutrient and the growth chamber, and (iii) the growth takes place on a cooled collector plate.

(i) This method is applicable to materials of low volatility. Its disadvantage is the growth of many small crystals rather than a few large ones. The type of growth obtained is very sensitive to the growing temperature, the steepness of the temperature gradient, the pressure of the system, and to the use of an entrainer gas^{53,54}. When the material transport rate is low, one-dimensional crystals (needles and rods) tend to form, whereas with higher rates two-dimensional platelets are formed.

Single crystals of anthracene^{54,55} and α,α' -diphenyl- β -picrylhydrazil⁵⁶ have been grown by this method. A somewhat modified method has been used by Mark⁵⁷ to grow thin single crystals of naphthalene, anthracene, diphenyl, *p*-terphenyl and *p*-quaterphenyl. The most promising method using this principle is by Zwerdling and Halford⁵⁸ who grew oriented disks of crystalline benzene.

(ii) In this method, which can be used for growing crystals of substances of both high and low volatility, a constant temperature difference is maintained between the nutrient and the growth regions by using two separate thermostats. Single

crystals of naphthalene⁵⁹, carbon tetrabromide⁶⁰ and ferrocene⁶¹ have been grown by this method.

(iii) In this method, a cooled collector plate is used for producing supersaturation in the growth region. Thus, the apparatus used resembles the conventional sublimation apparatus. However, provision is made here for precise control of the temperature gradient. Honigman⁶² successfully employed it for growing hexamethylenetetramine crystals. A technique in which a seed is initially present has been used to study the growth on the (110) and (111) faces of benzophenone crystals⁶³.

Growth from Solution

Of all the methods of growing organic crystals, growth from solution is the most widely employed, being applicable to both molecular and ionic compounds, organic complexes, metallorganic compounds and polymers. The advantage of the method lies in the convenience and simplicity of the apparatus.

As a rule, crystals of most covalent organic compounds grow less readily from solution than crystals of ionic salts. This is because the majority of organic crystals are formed by molecules of complex nature, which usually consist of chains or rings many atoms long. Since the growth of good crystals depends on the precise orientation of each molecule in respect of position and symmetry, the ranges of supersaturation and temperature for growing these complex compounds are rather small. Hence, the experimental conditions require precise control. The growth of perfect crystals is facilitated by high purity of the solute and the solvent, low viscosity of the solution and efficient stirring.

The solubility of almost all organic solids increases with increasing temperature. For such solids, there are three main methods of growing crystals from solutions based on (i) slow cooling of a saturated solution, (ii) evaporation of solvent, and (iii) temperature difference between regions of growth and dissolution (Fig. 1).

Point A in Fig. 1(I) represents a just saturated solution. For the crystal to grow by cooling, the temperature of the solution is lowered along line AB to point B just above the labile region. This

produces supersaturation of the solution causing a seed crystal to grow. If the cooling is very slow, the growing crystal takes up all the solute in excess of the equilibrium solubility, and though the temperature of the solution falls from t_1 at A to t_2 at B, the concentration of the solution actually proceeds from A to C. The amount of solute that can be deposited on a seed is, therefore, proportional to the distance CB, whose magnitude depends upon the temperature difference ($t_1 - t_2$).

A supersaturated solution can also be obtained by evaporating some of the solvent. In this case, since the temperature is kept constant, the concentration of the solution proceeds along the line AB' in Fig. 1(I). As long as the rate of evaporation is slow, the growth of the seed takes up the excess solid and the concentration of the solution never proceeds past point B' into the labile region.

In the third method, a temperature difference is maintained between the regions of growth and dissolution, by continuous exchange of solution between them [Fig. 1(II)]. A saturated solution in contact with the nutrient at temperature t_1 is cooled to temperature t_2 as it is transferred to the growth zone. There the solution, which is now supersaturated by an amount proportional to ($t_1 - t_2$), comes in contact with a seed, and growth proceeds. The concentration of the solution in contact with the seed is depleted along line BC. This solution is then cycled back to the nutrient zone, where it is heated and resaturated at temperature t_1 before being recirculated. In this case, the amount of solute that can be deposited on a seed is independent of the degree of cooling and the amount of solution used.

Growth by Cooling

Many types of apparatus have been employed⁶⁴⁻⁶⁷, but the most successful one is Holden's reciprocating rotary crystallizer^{10,68}. Though well suited to the growth of non-ionic organic crystals from non-aqueous solution, the Holden crystallizer has been used mainly to grow organic crystals of ionic type from aqueous solutions. Crystals of ethylenediaminetartrate⁶⁹, triglycine sulphate^{70,71}, guanidine orthophosphate⁷¹, sorbitol hexaacetate⁷², and benzophenone⁷³ have been grown using Holden crystallizer.

Growth by Evaporation

Growth by evaporation is the most common of the solution methods, because it can be used to grow substances that have positive, zero, or negative temperature coefficients of solubility. When the solid to be crystallized has a very narrow range of temperature at which it is stable, growth by evaporation may be the only suitable method, since it can be carried out isothermally. With a solvent yielding good seeds of the desired crystal available, the only other problem is to control the evaporation rate, which should be slow enough so that the metastable range is not exceeded.

Robinson⁷⁴ designed an apparatus for growing crystals of lithium sulphate monohydrate having a slightly negative temperature coefficient of solubility. Another apparatus is described by Belyaev *et al.*⁷⁵.

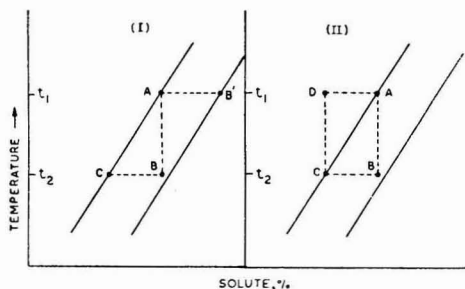


Fig. 1 — Representation of growth from solution [(I) Supersaturated solution obtained by a cooling along AB, or evaporation of solvent along AB'; (II) steps in growth by the temperature difference method: cooling of the solution along AB, crystal growth occurring along BC, heating of the solution along CD, and saturating of the solution along DA. The last two steps usually occur simultaneously]

Apparatuses have also been designed to give continuous growth by evaporation, i.e. in which the evaporated solvent is condensed, resaturated and recirculated. An early model for the commercial production of inorganic salts was the Oslo crystallizer⁷⁶.

Recently, a similar apparatus has been developed for producing crystals in the laboratory⁷⁷. Some of the compounds whose crystals have been grown by this method are malonic acid⁷⁸, *N*-acetyl glycine⁷⁹, and guanidine aluminium sulphate hexahydrate⁸⁰ from aqueous solutions; salol⁸¹ and stearic acid⁸² from benzene; succinic acid⁸² from ethyl acetate; *n*-hexatriacontane⁸³ from petroleum ether; sorbital hexaacetate⁸⁴ from 96 per cent alcohol solution; and β -methyl naphthalene⁸⁵ from ethanol.

Growth by Temperature Difference Method

It is seen from Fig. 1(II) that if some means is available to cool and transport a saturated solution to a growth region containing a seed, a continuous isothermal crystal growth may be obtained. The main requirement is that the crystal should have a fairly wide metastable range and a reasonably large positive temperature coefficient of solubility. This method is suitable for those organic compounds which have wide metastable ranges.

The experimental difficulties encountered in earlier apparatuses^{86,87} were overcome by Walker *et al.*^{88,89}. Another apparatus⁹⁰, used to date only for growing inorganic salt crystals from aqueous solutions, holds promise for the growing of organic crystals from non-aqueous solvents.

Other Solution Methods

There are several other solution methods that have rather limited use in the growth of organic crystals. One of these — growth by electro-deposition — is applicable only to those compounds that ionize in solution. The main use of this method has been in the deposition of single crystal layers, usually of metals, on various substrates serving as the appropriate electrode.

A second method, employed occasionally, involves slow dilution of a saturated solution of a substance in one liquid with another liquid that is not a solvent for the substance. By this method, small crystals of cyclonite (*sym*-trimethylenetrinitramine) were grown by slow addition of water to saturated solutions of cyclonite in conc. nitric acid⁹¹. Because of the difficulties involved in controlling diluent addition and mixing, single crystals of fairly good size are rarely obtained by dilution techniques.

A third method that may be used in special cases is growth by a chemical reaction in solution. A familiar example is of a metathetical reaction between two ionizable substances to give one soluble substance and one insoluble substance, such as the precipitation of silver salts of carboxylic acids by adding silver nitrate to aqueous solutions of the acid. Usually the precipitate is polycrystalline, but under conditions of very slow mixing, macroscopic single crystals may be formed. A variation of this method has been used to grow crystals of metal chelate salts, such as sodium-nickel triacetyl-acetate *p*-dioxane⁹².

Growth from Melt

The most successful method for the preparation of large, inorganic semiconductor crystals consists in growing the crystals from melt. Various techniques have been developed in the last fifteen years and are now being increasingly used for the growing of organic crystals also. These methods possess several advantages over the other methods. Larger growth rates are possible compared to vapour or solution methods because the solid is in constant touch with its own molecules and there is no dependence on transport of material to the growing surfaces. Since there is no solvent present, contamination is not a problem. Hence, crystals of high purity can be obtained from non-reactive systems and the pure starting material. However, the method is applicable only if the material melts congruently and without irreversible decomposition. In addition, there should be no solid state phase transformation between the melting point and the temperature to which the crystal will later be cooled. Because of these restrictions, many crystals of interest cannot be grown from liquid phase. The temperatures employed for growing crystals directly from melt are usually higher than those required in other methods and this may introduce another limitation. This, however, is not a very serious problem with organic compounds as their melting points are not very high.

Theoretically, any material that melts reversibly without chemical decomposition may be grown from melt. In practice, however, some compounds (such as SiO₂) are so prone to supercooling that it is difficult to obtain anything but a glass on cooling the molten matter. Although organic compounds do tend to supercool, specially those with complex structures, it is often possible to crystallize them from melt on cooling for a sufficient time or on inoculating the melt with a seed or pseudoseed.

All techniques of growing from melt have one common purpose: to regulate the temperature and temperature gradient within the molten material so that the area of crystallization is restricted and the rate of crystallization is controlled in such a way as to yield a single crystal. Other factors which require consideration are the shape of the crystal container, rate of motion of either the container in relation to the furnace or the furnace in relation to the container and the use of a seed crystal, if any.

The physical properties of organic solids differ markedly from those of inorganics and metals, and hence it is often essential to modify the techniques for growth from melt which have been designed primarily for the growth of inorganic and metallic crystals.

Nacken-Kyropoulos Technique

In this technique, which is originally due to Nacken⁹³, crystallization from melt is achieved by dipping a small single crystal seed attached to the hemispheric end of a cooled copper rod into the surface of the molten material and then the seed is slowly withdrawn. By arranging in such a way that the seed is slightly cooler than the melt, material solidifies on the seed as it is withdrawn.

With suitable precautions, the material withdrawn from the melt solidifies as a large single crystal. Nacken, in this way, was able to grow large single crystals of salol and benzophenone.

If a single crystal seed is not available, a polycrystalline seed is used. The seed is dipped into the melt and then withdrawn in the usual manner. While it is being withdrawn, the temperature of the melt is increased slightly, causing the seed to taper to a narrow neck. When the neck is not wider than that required to support the final crystal, the temperature of the melt is restored to its original value and the seed starts increasing in diameter. This process, first employed by Kyropoulos⁹⁴, is usually effective in selecting a single crystal from the original polycrystalline seed (Fig. 2). A modern version of the Nacken-Kyropoulos crystal growing apparatus⁹⁵ is shown in Fig. 3.

The advantages of the Nacken-Kyropoulos technique are that the selection of a single crystal seed can be made more easily, impurities are rejected downward rather than upward against gravity and the growing crystal is unstrained, as it does not come in contact with the container walls. The main disadvantage is that, because crystal growth depends both on the degree of cooling of the melt and on the constantly varying rate of heat removal through the seed and the cooling rod (as the seed grows outward from the rod), it is very difficult to control the growth rate. Single crystals of naphthalene^{11,96,97} have been grown by this method.

Crystal Pulling

Crystal pulling, due originally to Czochralski⁹⁸, is very similar to the Kyropoulos technique, but with one essential difference that the crystallization here is entirely due to cooling of the solid substrate (the temperature of the melt is kept constant).

A simple crystal pulling apparatus is shown in Fig. 4. The melt is introduced into a capillary tube, where it usually solidifies as a single crystal which acts as a seed crystal for pulling. After the seed has been wetted and lifted again so as to be correctly spliced, the temperature of the molten material is lowered to just above the melting point and held there. Crystallization takes place as the crystal is steadily pulled from the melt.

The technique requires very fine control, and often elaborate equipment, if a vacuum or an inert atmosphere is required. In certain cases, where the melt has particularly high vapour pressure, a pressure of inert gas greater than that of the atmosphere is used. The stability of the melt is, however, the biggest limitation of this method.

In general, organic materials, with their low thermal conductivity and low surface tension, would seem to present difficulties in growth by pulling. Mention has been made in literature of the growth of a few organic compounds by this method¹¹.

Bridgman-Stockbarger Technique

This technique is based on the very early studies by Gemez⁹⁹ and Tamman¹⁰⁰ and later ones by Obreimov and Shubnikov¹⁰¹. It was observed^{99,100} that when melts were supercooled into their metastable region and crystallization was initiated at one end of

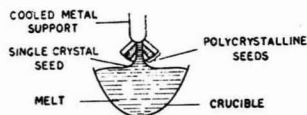


Fig. 2 — Representation of single crystal seed selection

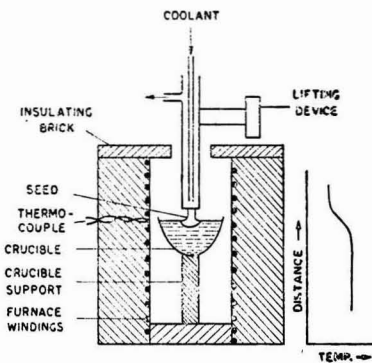


Fig. 3 — Nacken-Kyropoulos crystal growing apparatus

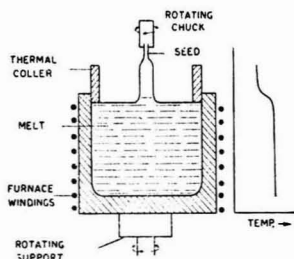


Fig. 4 — Apparatus for crystal growth by pulling

narrow tubes, although many crystals would commence to grow, but only one crystal by its orientation and speed of growth would win out, giving rise to single crystal growth along the remainder of the tube. Therefore, for growing large single crystals, the problem is to find a reliable method of initiating a single crystal nucleus and of propagating it through a large volume of the material. The initiation of growth was achieved by touching the metastable melt with a piece of its own solid⁹⁹, the process now known as seeding, or by further localized cooling at the tip of the capillary¹⁰⁰. Although these methods of nucleation of the melt are still in use, various methods of controlling the propagation of growth have been devised to yield good single crystals.

The above method was used in an improved form by Bridgman¹⁰² to grow metal single crystals (Fig. 5). A single insulated furnace was employed, through which the crystal container was lowered by a clock motor. The constricted tip gave the highest probability of initiating single crystal growth. The containers were provided with an upper chamber

having another constriction where the metal was first melted before being introduced in the lower region, the constriction acting as a filter to remove impurity metal oxide particles. Crystallization took place as the container tip emerged from the furnace, which was held at temperatures of 50-100°C. above the melting point, the exact amount being not critical¹⁰².

Stockbarger¹⁰³⁻¹⁰⁵ achieved better control over the solid-melt interface in an improved form of Bridgman apparatus (Fig. 6) used to grow large single crystals of inorganic fluorides. Both the insulated furnaces were controlled separately. The upper furnace was maintained at a temperature 50-80°C. above, and the lower one 50-80°C. below, the melting point of the material to be crystallized. Since it is desirable that the temperature gradient between the two furnaces should be as steep as possible, a baffle, designed to pass snugly over the descending container, separates the two furnaces. Smooth, polished platinum baffles, which were efficient heat reflectors, were used, thus cutting down the radiation along the tube and increasing the temperature gradient. For organic crystals, asbestos baffles¹⁰⁶ are suitable. Good results have also been obtained by using a hollow cooling coil as a baffle through which the coolant is circulated¹⁰⁷.

Stockbarger employed conical tip crystal containers. The sharp temperature gradient imposed on the tip, as the container is lowered through the baffle, plus the heat loss at the tip to the metal support rod provides conditions suitable for the attainment of a single crystal nucleus. Nucleation at the tip can also be accomplished by cooling the point of the tip with a jet of cold air¹⁰¹. The use of single crystal seeds^{55,108} for initiating single crystal growth is now common.

Crystal containers of various materials have been used. Silica is the most suitable material, as the crystal can be completely enclosed and sealed off, preventing contamination and loss of vapour. Silica can also be covered with a graphite layer thereby reducing the sticking of materials to the silica surface. Glass is used in the case of low melting point materials and organic solids. Graphite or carbon, platinum and several other refractory oxides have also been used. For organic compounds, glass tubes may be treated with chlorosilane for avoiding the adherence of crystals to the container walls¹⁰⁹.

The Bridgman-Stockbarger method, with various modifications, has proved useful for preparing single crystals of many semiconductors and alkali halides. But it cannot be used for materials which expand on solidification, e.g. germanium, indium antimonide, and gallium antimonide. However, crystals of these materials can be grown by this method if horizontal furnaces are used. Although not designed originally for the growth of organic materials, the Bridgman-Stockbarger technique is applicable to a wide variety of organic solids that melt without decomposition. Even high volatility is not a deterrent if the growth is carried out in a sealed tube. Among the organic solids whose single crystals have been prepared by the Bridgman-Stockbarger technique are anthracene^{55,106,108,110,111},

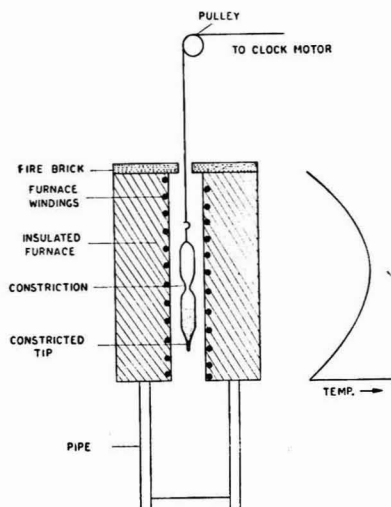


Fig. 5 — Bridgman's apparatus for crystal growth from melt

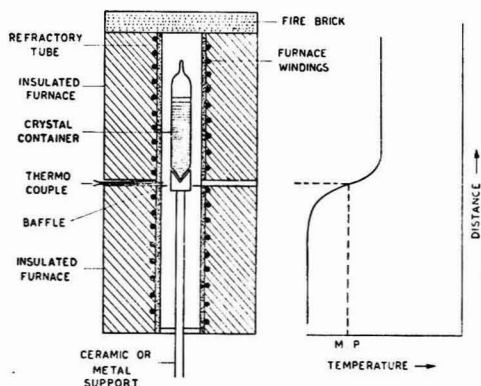


Fig. 6 — Stockbarger's double furnace apparatus

cyanuric chloride¹¹², stilbene^{112,113}, naphthalene^{55,96,110,114} [Datt, S. C. & Verma, J. K. D., *Indian J. pure appl. Phys.*, **6** (1968), in press], acenaphthene¹¹⁵, etc.

Organic crystals are more difficult to grow than inorganic crystals, mainly due to their supercooling tendencies and their low thermal conductivity. Since almost the entire heat of fusion of the growing crystal must be removed through the solid, a solid with poor thermal conductivity will take longer to solidify per unit volume than a good thermal conductor. For this reason, organic crystals are usually lowered through the furnace at slow rates (1 mm./hr or less). When the rate of passage exceeds the rate at which the heat of fusion can be removed from the solid-liquid interface, the quality of crystal will suffer due to formation of misoriented molecules, impurity inclusions, and extraneous

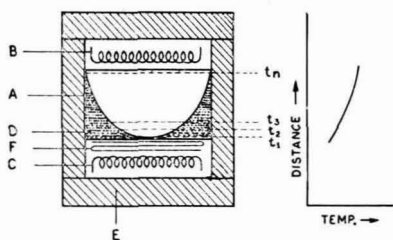


Fig. 7 — Stöber's apparatus for growing crystals from melt [A, crucible; B and C, heaters; D, material having as nearly as possible the same thermal conductivity close to that of the crystal; E, insulation; and F, coils for circulating coolant]

nucleations. The great supercooling tendencies of organic materials require care in the construction of the crystal container tip, as well as a steep temperature gradient at the diaphragm, to initiate single crystal growth in the tip.

Stöber Technique

The solid-liquid interface can be made to move simply by moving the crystal container, as in Bridgman-Stockbarger technique, or by controlling the temperature gradient across the container. The latter method was adopted by Stöber¹¹⁶ (Fig. 7) who obtained large, clear single crystals of sodium nitrate and other inorganic salts.

Better control over the initial nucleation may be obtained by replacing the smooth bottom of the Stöber crucible with a conical tip¹¹⁷. Nucleation can be achieved either by preferential cooling of the tip or by employing a suitable seed crystal. Both oriented substrates of higher melting crystals¹¹⁸ and crystal seeds of the same material¹¹⁹ have been used.

Crystals of toluene¹¹⁹, naphthalene^{119,120}, *p*-dichlorobenzene¹¹⁶, and *p*-dibromobenzene¹¹⁶ have been grown by this technique.

Compared to Bridgman-Stockbarger method, the Stöber method has been very rarely used; the reason being that, although both methods have the same wide applicability and inherent advantages, critical control of the solid-liquid interface is probably more difficult to attain by varying the temperature gradient than by changing the position of the crucible in relation to the heat source.

Zone Melting Techniques

Zone melting, originally due to Pfann¹²¹, has been discussed elsewhere by Datt *et al.*¹⁰⁹. Although there are some references in the literature^{55,122-127} to the formation of single crystals in the last step of the zone refining process, the application of zone refining appears more pertinent in the preparation of ultra-pure materials for use in growing crystals.

Another related technique is the temperature gradient zone melting^{121,128,129} or the travelling solvent method^{130,131}. It consists in placing a very thin zone of a suitable solvent between a seed and a rod-shaped charge. A high temperature gradient is maintained across the solvent zone, causing the

material to dissolve on the hotter side and crystallize on the cooler side. The zone moves thereby and in the process produces a single crystal. So far the technique has been applied only to inorganic semiconductors^{130,131}. Because of the usual absence of solid solubility of solvents in organic systems, however, the technique shows great promise for growing single crystals of organic compounds. But a number of difficulties have to be overcome before the method can be practically applied¹⁰⁹.

Special Methods

Crystals of some substances cannot be grown by any of the methods discussed above. Special methods like growth under high pressure and temperature conditions have to be used in these cases.

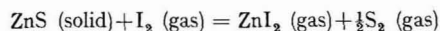
Growth in the Solid State

A typical example of growth in the solid state is grain growth in metals during annealing. A polycrystalline ingot, originally composed of many grains, often undergoes gradual transition on heating at a temperature below the melting point; the more stable grains grow outwards by consuming neighbouring grains. Under suitable conditions, one or two grains may extend the entire length of the charge, resulting in a specimen that consists of one or two large crystals. However, a large increase in grain size is generally not observed in commercial materials when annealed in the 'as-cast' condition. In materials of very high purity, it is possible to obtain large crystals from a polycrystalline casting by grain growth.

Some organic solids can grow in the solid state by migration of grain boundaries on annealing. The solids studied are camphor¹³², pinene hydrochloride¹³³, TNT¹³³, DDT¹³⁴, and octachloropropane¹³⁴. While with some solids such as DDT and TNT grain growth depends on the crystallographic orientation, in others like octachloropropane grain growth depends on the shapes of the grains and is practically independent of their crystallographic orientation¹³⁴. In both cases, the driving force for the movement of grain boundaries is apparently lattice strain arising either from cold working or from temperature changes.

Growth through Chemical Change

The first application of this method was for growing tungsten single crystals^{135,136}. Recently, Nitsche *et al.*^{137,138} grew crystals of binary and ternary chalcogenides by a chemical transport reaction. In this process, the solid to be crystallized (e.g. ZnS) is placed at one end of a sealed tube along with a substance forming a volatile compound with the solid. When the tube is heated, an equilibrium is established:



Thus, if a suitable temperature gradient is produced along the length of the tube, solid ZnS can be made to form volatile gases in one part of the tube and deposits out as crystals in another part,

due to the shift in equilibrium of this reaction with temperature.

Very little work has been done on growing organic crystals through a chemical change. According to Buckley¹³, crystals of phthalic anhydride may be obtained by heating solid phthalic acid, the heat dispelling water and yielding the volatile phthalic anhydride, which collects as long needles in the cooler parts of the container.

Growth through Application of High Pressure and Temperature

The growth of crystals of difficultly soluble substances, which are not amenable to melt or vapour techniques, may require the use of special growth methods involving the employment of high pressure and temperature. A typical example is the production of diamond in the laboratory under pressures of the order of 100,000 atm. and temperatures around 2000°K.¹³⁹

Due to low solubility, quartz crystals cannot be grown from solution under ordinary conditions; however, at pressures near 15,000 lb./in.² and temperatures around 400°C., quartz crystals may be grown from alkaline solutions at rates of approximately 0.1 in./day¹⁴⁰. High pressure increases the solubility to a point at which growth from solution is possible. In the same way, organic solids whose physical properties make it difficult for the crystals to grow by ordinary means may be grown from organic solvents through the use of high pressure and temperature.

Mechanism of Single Crystal Growth from Melt

The production of single crystals from melt involves the provision of conditions under which atoms or molecules of the melt 'freeze out' on to a nucleus, which is itself a single crystal, in such a manner as to perpetuate the lattice array of that nucleus. Such a nucleus may be a 'seed' crystal, or the nucleation may occur spontaneously in a supercooled melt at the end of the container. In the latter case it is probable that a large number of nuclei will be formed initially. However, because of competitive growth, only one of these nuclei will extend for any distance into the crystal.

At the freezing interface, latent heat is evolved continuously and if the crystal is to grow at the expense of the melt, the latent heat must be removed continuously. If the melt is, at all points, at a temperature equal to or greater than the melting temperature, T_m , the latent heat can be removed (when the material is *in vacuo*) only by conduction down and radiation from the portion of the charge which has already crystallized. Thus, a temperature gradient must be maintained along the length of the crystallized solid. However, if some portion of the melt is supercooled, a part of the latent heat will be dissipated by conduction into the melt, but a supercooled melt is deleterious to the growth of good quality crystals and should be avoided. Generally, there exists a temperature gradient in the melt with temperature increasing away from the interface. In such cases there is a net flow of heat from the melt through the interface which also must

be conducted down the solid. The heat transfer equation is:

$$K_s A_s \frac{dT}{dx_s} - K_l A_l \frac{dT}{dx_l} = AL\rho \frac{dx}{dt} \quad \dots(1)$$

where K is the thermal conductivity of the material; A , cross-sectional area of the charge; T , temperature; x , coordinate of the interface, measured along the charge; ρ , density of the material; and L , latent heat of the material. The subscripts s and l relate to the solid and liquid phases respectively.

Since the cross-sectional areas A_s , A_l and the area of the interface A are equal, Eq. (1) becomes

$$K_s G_s - K_l G_l = RL\rho \quad \dots(2)$$

where G is the temperature gradient and R the growth rate, i.e. rate of movement of the interface.

The maximum rate of growth of a crystal is governed by the rate at which the latent heat is removed from the solid-liquid interface, in the absence of supercooling, and when the temperature gradient in the melt is zero ($G_l = 0$), it is given by

$$R_{max.} = K_s G_s / L\rho \quad \dots(3)$$

But, very often, the material contains a finite amount of soluble impurity. Hence, to avoid inhomogeneities in the crystal, there must exist a temperature gradient in the melt, the magnitude of which must increase with increasing amounts of solute and which will vary according to the nature of the solute. Thus, in any real crystal growth experiment the growth rate must be less than $R_{max.}$

Eq. (1) involves the values of the temperature gradients and thermal conductivities close to the interface. The value of G_s for a crystal grown *in vacuo* will depend on the emissivity of the solid and the temperature of the surroundings to which it radiates, as well as on the thermal conductivity of the solid which is itself temperature dependent. The rigorous expressions for G_s and $R_{max.}$ applicable to all melting temperatures, are^{141,142}:

$$G_s = \left(\frac{dT}{dx}\right)_{x=0} = \left[\frac{2e\sigma}{3rK_m T_m} \{ (T_m^6 - T_0^6) - 3T_0^4 (T_m^2 - T_0^2) \} \right]^{1/2} \quad \dots(4)$$

and

$$R_{max.} = \left(\frac{dx}{dt}\right)_{max.} = -\frac{K_m}{\rho L} \left(\frac{dT}{dx}\right)_{x=0} \quad \dots(5)$$

$$= \left[\frac{2e\sigma K_m}{3rT_m \rho^2 L^2} \{ (T_m^6 - T_0^6) - 3T_0^4 (T_m^2 - T_0^2) \} \right]^{1/2} \quad \dots(6)$$

where r is the radius of the vertical cylindrical ingot in thermal contact with its melt at $x = 0$; T_0 , temperature of the surroundings to which it radiates; K_m , thermal conductivity at the melting temperature; σ , Stefan's constant; and e , emissivity of the surface.

If $T_m \gg T_0$, T_0 may be neglected and Eq. (6) then reduces to

$$R_{max.} = \left(\frac{dx}{dt}\right)_{max.} = \left[\frac{2e\sigma K_m T_m^5}{3r\rho^2 L^2} \right]^{1/2} \quad \dots(7)$$

For low melting point materials, such as naphthalene, T_m is not $\gg T_0$ and the terms in Eq. (6) cannot be neglected, in fact they contribute 20-30 per cent for such materials.

Eq. (7) shows that R_{\max} is proportional to r^{-1} and is greater, the thinner the crystal, a fact borne out by experience. The actual maximum growth rate obtainable will be less than the value given by Eq. (7), since the crystallized solid near the end of the furnace is radiating to surroundings which are at a temperature greater than T_0 and also heat radiation from the solid ingot is considerably reduced by shielding of the crystal container. The maximum growth rate may be further increased by the use⁵⁵ of a 'heat sink'.

The growth process can be pictured as a molecule by molecule addition to an already existing crystal lattice. This can readily occur on all but a few close-packed, low index faces. The rate of growth on these close-packed faces is so much slower than on other faces that it determines the maximum rate of growth of the crystal. A new layer of molecules can be started on a perfect low index surface only by the formation of a disc of molecules which must have a radius, r , greater than r_c , the critical radius, if it is to be stable. The critical radius can be obtained as follows⁴¹.

The free energy, F , of such an island monolayer is given by

$$F = -\pi r^2 \omega + 2\pi r \Upsilon \quad \dots(8)$$

where ω is the free energy per unit area gained when a molecule becomes attached to the nucleus and Υ is the free energy per unit length of the step at the boundary of the nucleus. At the point of maximum free energy, F_0 , where

$$dF/dr = 0 = -2\pi r \omega + 2\pi \Upsilon$$

we have $r = r_c$, the critical radius. Thus

$$r_c = \Upsilon/\omega \quad \dots(9)$$

and

$$F_0 = \pi \Upsilon^2/\omega \quad \dots(10)$$

The number of molecules required for a stable nucleus of some organic compounds has been calculated (Table 2) from the velocity of ultrasonic waves in the liquid^{143,144}. Calculation of the frequency of formulation of such a nucleus has also shown that finite growth rates are possible only when the extent of supercooling is greater than the critical value, usually of the order of several degrees Centigrade.

TABLE 2 — NUMBER OF MOLECULES IN A STABLE NUCLEUS

Substance	Number of molecules
Naphthalene	808
Phenol	750
Azobenzene	960
Paraffin	610
Sn, Pb, Bi alloy	735

The maximum growth rates from the above mechanism have been found to be of orders of magnitude smaller than the observed rates. One explanation for this anomaly is that certain dislocations, such as screw dislocation, provide a mechanism of growth that does not require secondary nucleation to propagate a growing crystal face^{32,33}. Hillig and Turnbull¹⁴⁵ calculated the growth rates on a screw dislocation for a crystal grown from melt and the results agree with the experimental values for two organic liquids, glycerine and salol.

An explanation for the different modes of solidification observed in different crystals is that some crystal surfaces tend to be smooth, whereas others do not³⁴. The conditions, which govern the smoothness or roughness of the interface for a given material, have been deduced by evaluating the relative surface free energy (i.e. the free energy of the surface relative to that of an atomically smooth plane) as a function of the fraction of the surface atomic sites which are occupied¹⁴⁶. It was found that the growth surface will be rough or smooth according as $\alpha \gtrless 2$, where

$$\alpha = \left(\frac{L_0}{kT_E} \right) \left(\frac{\eta_1}{v} \right) \quad \dots(11)$$

where L_0 is the change in internal energy between the two phases; k , Boltzmann's constant; T_E , equilibrium temperature of the two phases; η_1 , total number of nearest neighbours out of a possible total of v , of a molecule in a monomolecular layer parallel to the plane face; and (η_1/v) , the fraction of the total number of nearest neighbours in a plane parallel to the face under consideration. All crystals have some surfaces which are rough, and which, therefore, do not require surface nucleation, but some crystals do not have any smooth surface. Faces which are smooth at the equilibrium temperature (α slightly greater than 2) become rough when supercooling takes place. A smooth surface is distinguished by large well-developed facets. This is characteristic of growth from vapour or from dilute solution (where $\alpha \sim 20$) but can also occur in a few cases of growth from melt. A rough surface has no facets and growth can proceed on such a surface with only a nominal extent of supercooling.

Most organic compounds have a value of L_0/kT_E for fusion which is greater than 4. All these compounds should grow with large flat faces exposed to the liquid. Salal and thymol, for example, do grow this way. A few organic compounds have L_0/kT_E between 2.5 and 4. They may or may not grow with one or more smooth faces, depending on their crystal structures. These materials have not been investigated experimentally.

Morphology of the Solid-Liquid Interface

Two conditions of heat flow are recognized at the interface. In the first case, 'normal' growth, the direction of heat flow is through the solid [Fig. 8(I)]. There is a slight supercooling of the melt at the interface, but only sufficient for growth to take place, the temperature in the melt being everywhere higher than in the solid. In the second

case, the liquid is supercooled and the temperature may be lower than that in the solid [Fig. 8(II)]. Heat flow may now be either through the solid or through the liquid. Under these conditions very high growth rates are possible. However, this leads to dendritic growth.

The structure of the solid-liquid interface in a growing crystal can assume any of the following forms: (i) step-like, (ii) cellular, (iii) dendritic, or (iv) facets, depending on the growth conditions and material. The particular form depends on the parameters G , R , C_0 (the average concentration of any solute material), K (its segregation coefficient), and D (its diffusivity in the solvent liquid material). The prediction of the steady state interface has been discussed by Bolling and Tiller¹⁴⁷⁻¹⁵⁰.

Step-like interface — When the plane of the solid-liquid interface corresponds fairly closely to a principal crystallographic axis, the surface consists of a series of steps, each step being approximately parallel to the main surface¹⁵¹. A possible mechanism for this has been proposed by Chalmers¹⁵². If the interface is tilted slightly away from the close-packed plane, it will acquire steps of mono-atomic height which will be the closer together the greater the angle of tilt (Fig. 9). Further, if the growth is to proceed by the 'freezing out' of atoms (or molecules) at the re-entry corners which the edges of the step provide, then the steps will move across the interface from right to left. The rate of movement of these steps depends on the rate of conduction of heat from the interface through the solid, on the rate of transfer of heat from the liquid to the solid, and on the liberation of latent heat. This liberation will cause steps which are close together to grow more slowly than those which are widely separated. In Fig. 10(I), therefore, steps B and C will move slowly and A and D more rapidly. This leads to the production of multiple steps [B, C and D in Fig. 10(II)] which will move even more slowly. An initial irregularity in step distribution would, therefore, lead to the production of large multiple steps across the crystal surface.

The same results could be obtained if it is assumed that new layers¹⁵³ are formed on each of the steps¹⁵². The probability of a new layer forming is greater in the region remote from the growing step, i.e. between C and D [Fig. 10(I)]. The formation of a new layer causes the distance from C to D to become very small, while the distance D to E increases correspondingly. D-E becomes the most probable site for a new layer, with the result that E may approach C and D. Thus, several large steps would develop from a series of smaller ones.

Unless there is a permanent growth step at E, some nucleation must occur to maintain growth. Each new layer may be formed by two-dimensional nucleation on the surface of the 'cells' which occurs across the surface. For instance, the site A in Fig. 11 is very suitable, as this point is most remote from the site B where latent heat is being liberated. Growth from the melt can, therefore, be explained without recourse to dislocations, although presumably growth will be facilitated by their presence. There is, however, no doubt that dislocations do exist in crystals grown from the melt^{145,154}. The

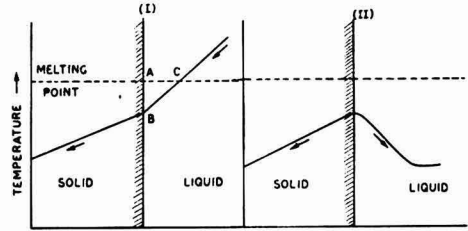


Fig. 8 — Temperature conditions and direction of heat flow shown by arrows for (I) normal growth and (II) rapid growth

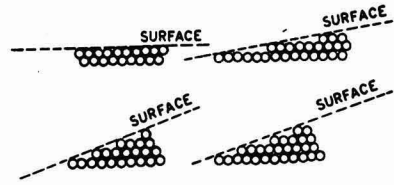


Fig. 9 — Steps on different crystallographic faces

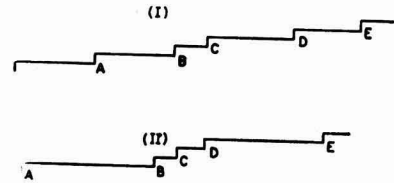


Fig. 10 — Representation of the process of formation of large steps

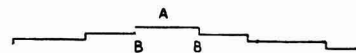


Fig. 11 — Representation of the process of formation of steps for two-dimensional growth

observed density of dislocations varies from 10^3 to $10^8/\text{cm}^2$, depending on the material and the conditions during growth. Metal crystals grown from melt appear to have, on the average, higher dislocation density than ionic crystals, such as the alkali halides and organic crystals grown in the same way.

Cellular interface — The substructures known as 'fine lines' (ref. 155) or 'corrugations' (ref. 156) have been investigated. While trying to establish whether this was a surface or body phenomenon, it was found that the solid at the interface consisted of an array of hexagonal cells whose centres projected into the melt slightly ahead of their boundaries. The same structure was revealed throughout the crystal. Hence, the crystal consists of a number of parallel elements of prismatic form, and the observed corrugations are the lines of intersection of pairs of these elements with the free surface.

At medium rates the hexagonal cells were very regular. At higher rates, a small percentage of the cells had enlarged considerably and projected into the melt. At low growth rates, the cellular structure was suppressed, although the striations remained. The cellular structure could also be suppressed by a steep temperature gradient (75°C./cm.) at the solid-liquid interface. An investigation¹⁵⁷ of the cell size as a function of G and R for a given concentration has shown that the cell width increases linearly with $1/RG$. The shape of the cells also varies with the orientation of the interface.

The cellular structure has been shown to be largely due to the presence of impurities¹⁵⁶. Goss¹⁵⁸ has shown that the impurities not only have a profound effect on the appearance of the substructure, but may even make the growth of single crystals at high rates difficult if present at about 0.1 per cent of their solubility limit. It is not clear, however, at present, to what extent the substructure can be reduced by completely removing of impurities.

The transition from a 'smooth' (or step-like) to a cellular interface has been investigated by a number of workers^{157, 159-162}. The breakdown begins with the appearance of pox on the interface. Initially the pox marks are widely scattered, but their size and density increase as the transition approaches. Pox marks appear only on interfaces which do not exhibit a platelet structure. Just within the cellular region the interface consists of a mixture of pox and irregular cells, and the cells subdivide into elongated cells. Still farther away from the transition, the elongated cells subdivide into an array of nearly regular cells. In Fig. 12 (ref. 150) the various transition morphologies are shown as a function of constitutional supercooling¹⁰⁹ produced by redistribution of the solute at the interface, due to changes in composition of the melt. The subject of constitutional supercooling and the conditions for no supercooling have been reviewed by Hurle¹⁴² and Brice¹⁴³.

Dendritic interface—When the extent of supercooling, whether constitutional or thermal, becomes large, the growth becomes dendritic. Dendrites are projections or tree-like skeletons formed ahead of the coherent solid-liquid interface and consist of primary dendrite arms often parallel to the direction of growth and secondary dendrite arms growing out at right angles from the primary arms (Fig. 13).

The exact mechanism of growth is not fully understood, but several significant observations^{147, 150, 153, 163-172} have been made. The temperature distribution near the interface must be similar to that shown in Fig. 14, as the dendrite pushes into the melt it encounters regions of increasing supercooling which results in an increasing rate of growth. The tip of the primary arm of the dendrite appears to be rounded and there appears to be a preferred orientation for growth. In various metallic systems, the dendrite always forms along the cube axis^{148, 149, 163, 164, 166}. It is suggested that, in general, the axis of the dendrite could be interpreted as the axis of a pyramid formed by the closest packed planes of the lattice. According to

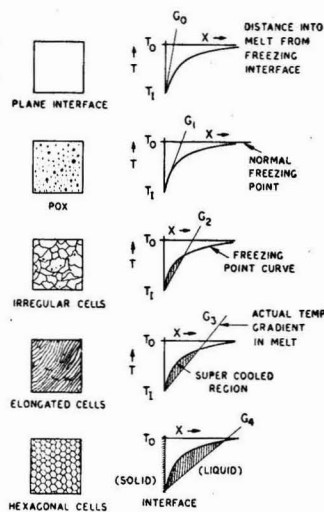


Fig. 12 — Morphologies on decanted interfaces of tin and lead as a function of the degree of constitutional supercooling existing ahead of a planar interface



Fig. 13 — Primary and secondary dendrite arms

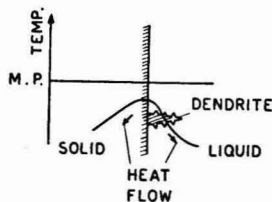


Fig. 14 — Temperature profiles depicting growth of dendrites

this view, the dendrite advances by two-dimensional nucleation of each of the four walls of the pyramid, two-dimensional nucleation being relatively easy in the supercooled melt.

Studies on cellular structure^{156, 173} have suggested that dendritic growth may be a different form of normal growth rather than a completely different process. A possible picture may be as follows. Normal growth occurs by the edgewise expansion of steps (Fig. 15). Any impurities in the melt will be rejected by the edgewise growth and will accumulate in the troughs (C) to which the steps advance. Dislocations and substructure must be generated at C to accommodate the impurities.

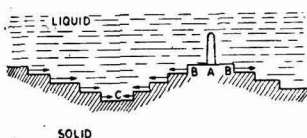


Fig. 15 — Dendritic growth

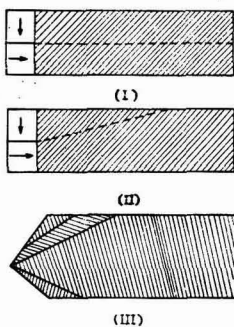


Fig. 16 — 'Crowding out' of the seed with less favourable orientation

At slow growth rates the impurities have more time to escape from the advancing step and may homogenize in the melt. The reduced concentration of the trapped impurities is reflected in the reduced substructure, i.e. increasing cell size. New layers may be created by two-dimensional nucleation, specially at points such as A (Fig. 15). The rate of nucleation will depend on the conditions at the interface, but nucleation will be a relatively slow process. Consequently, under conditions of supercooling, the few nuclei formed will tend to develop before others can form. This is so because the nucleus, now an embryo dendrite, encounters increasing supercooling as it grows into the melt, and, therefore, grows increasingly rapidly.

As a possible defect in crystals, dendrites are easily avoided; they can form only when the extent of supercooling in the melt is considerable and can be avoided if supercooling is guarded against.

Faceted growth — Crystals of some semi-metals, many semiconductors (gallium, germanium^{141,165,167}, bismuth¹⁷³, silicon¹⁷⁴, indium antimonide¹⁷⁵, etc.) and organic compounds have an external form bounded by large facets. All these materials have $\alpha > 2$ (refs. 146, 176) (Eq. 11) and the faceted structure is taken to be characteristic of a smooth interface where surface nucleation is required to start new layers. A mechanism for the appearance of facets on the crystals has been proposed by Petrov¹⁷⁷.

Nucleation and Growth of Stray Crystals

There is always a preferred orientation for growth, so that, if more than one nucleus forms, those with the preferred orientation may 'crowd out' others with less favourable orientations¹⁷⁸. If two crystal

seeds with different orientations are placed side by side and grown together, for slow growth rates the boundary between the crystals runs parallel to the direction of growth [Fig. 16(I)], but for faster growth rates, the seed with the preferred orientation diverges and tends to 'crowd out' the less favoured seed [Fig. 16(II)]. This process seems to be important in the growth of crystals by the Bridgman-Stockbarger method. During the period of rapid growth following nucleation, i.e. when the melt is supercooled, nuclei with preferred orientation will grow more rapidly, and 'crowd out' the less favoured nuclei [Fig. 16(III)]. Bridgman-Stockbarger method sometimes gives a single crystal and sometimes a polycrystalline specimen, although the growth conditions appear to have been identical. This may be not due to the formation of different numbers of nuclei, but to their different orientation. Thus, an attempt to grow a crystal of controlled orientation will be futile if a new crystal is formed whose orientation is unrelated to that of the seed crystal. For such a crystal to be formed it must first be nucleated and then grown. It is referred to as a stray crystal.

A stray nucleus may exist on the surface of the crystal container, on the free surface of the molten material, or within the melt itself. If it exists in the melt, then, for growing, it must exist in a supercooled region of the melt so that the latent heat which it evolves is taken up by the melt, thus reducing the extent of supercooling. Supercooling may be either thermal, due to the finite rate of freezing, or to radiation of heat from the melt, or constitutional. The effect of the latter is greater, the greater the solute content, the greater the growth rate, and the lower the temperature gradient in the melt. Thermal supercooling may occur at fast rates of growth by radiation from the melt. To prevent stray nucleation at a free surface, the growth should be either in inert atmosphere or vacuum.

If the growth conditions are such as to lead to the subsequent occurrence of constitutional or thermal supercooling, the probability of stray nucleation taking place will depend on the amount and extent of supercooling. The solutes with large values of $|1-K|$ are most effective in producing constitutional supercooling.

The probability of stray nucleation resulting from supercooling has been examined by Chalmers¹⁷⁸. If the extent of supercooling at the interface is represented by AB [Fig. 8(I)], under the existing temperature gradient in the melt, supercooling will occur over the distance AC into the melt ahead of the interface. Increase in the temperature gradient in the melt will reduce AC. The probability (P) of stray nucleation depends on the extent of supercooling and the time for which it is operative, and thus the relation

$$P = \int_0^S s dt \quad \dots(12)$$

where s is the amount of supercooling operative for a time dt . If S , the maximum extent of supercooling, is proportional to the speed of freezing,

AR , then for a temperature gradient G ,

$$P = \frac{A^2 R}{2G} \quad \dots(13)$$

Thus the probability of stray nucleation increases with increasing growth rate and with decreasing temperature gradient in the melt, G .

Spontaneous formation of a nucleus in the melt is unlikely as it requires a large extent of supercooling, any stray nucleus which is formed within the melt is probably produced from an already existing nucleus. According to Holloman and Turnbull¹⁷⁹, the initial growth in a melt takes place frequently from such existing stray nuclei consisting of impurities. For this, the crystal structure of the impurity particle should be similar to that of the solid material for it to behave as a successful nucleating agent. In material with unique crystal structure, e.g. gallium, initial nucleation can be expected to occur only by the production of a gallium nucleus, and that is why the extent of supercooling in gallium is frequently pronounced.

Regarding the circumstances in which a stray nucleus can grow, if the stray nucleus is nucleated at the surface of the crystal, the shape of the solid-liquid interface will determine whether or not it will grow into the crystal. If it is assumed that the growth of both the crystals, the main and the stray one, proceeds at right angles to the interface, then the stray nucleus will grow into the crystal for an interface concave to the melt (Fig. 17); for a planar interface the stray nucleus will grow only on the surface and for a convex interface the stray nucleus will grow out immediately. Thus, by having the interface shape sufficiently convex to the melt, all stray nuclei, even those more favourably oriented than the main crystal, can be suppressed.

If the solid at the interface is convex, the net flow of heat radially in the melt, adjacent to the interface, is inwards and if it is concave, the heat flow is outwards to the surface of the melt. The amount of heat lost from a unit length of a cylindrical crystal of radius r by conduction parallel to the axis is proportional to r^2 . The amount of heat lost by radiation from the surface is proportional to r . Thus, the ratio of heat removed from the interface by conduction to that lost by radiation is proportional to r . Therefore, the concavity of the interface increases with decreasing r . This is consistent with the observation that it is easier to grow thick crystals than thin ones.

Sometimes, during the growth of a single crystal the orientation of the crystal alters in such a way

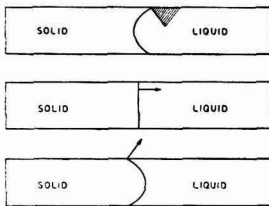


Fig. 17 — Effect of interface shape on the growth of stray crystals

that the new crystal cannot be considered to be stray in the sense that its orientation is unrelated to that of the main crystal. The orientation bears a twin relationship to the main crystal, i.e. the new crystal is the image of the main crystal in a plane called the twinning plane. Twinning can also occur about a single line — the twinning axis — and the difference between the components may be a simple rotation or a combination of rotation and reflection. Several possible reasons for the formation of twins in crystals have been advanced¹⁸⁰⁻¹⁸⁴. To avoid twinning, slow regular growth and high purity of the material are necessary and thermal stresses, in particular, should be avoided.

Origin of Imperfections

The imperfections that may occur as a result of solidification may be classified as point, line, surface and volume defects. No single crystal has yet been produced with a perfectly periodic lattice array free from all imperfections.

Point Defects

The only point defects likely to be found in crystals which have not been subjected to bombardment by energetic particles or to very high local stresses are vacancies. Vacancies in excess of the concentration corresponding to thermal equilibrium are considered as defects. Fall in temperature, after the completion of solidification, produces an excess concentration; a more relevant point, however, is whether an excess concentration is produced by the process of solidification itself. If growth takes place by the addition of single atoms or molecules, it is possible that a site could be filled by an atom or molecule from the crystal rather than by an atom or molecule from the melt. The relative probability of these two events is governed largely by the appropriate activation energies and is of the order of 10^{-3} to 10^{-4} . Hence, one atom or molecule in 10^3 or 10^4 that fills a site is expected to come from the crystal and to leave a vacancy. These vacancies migrate rapidly and many reach the interface, but it may be expected that a substantial fraction, which increases with increasing speed of motion of the interface, will not reach the interface.

Dislocations

Three possible mechanisms have been proposed for the origin of dislocations during solidification: (i) stresses due to non-planar isothermal surfaces, (ii) stresses due to variation of lattice parameter caused by non-uniformity of solute content, and (iii) condensation of vacancies to form discs which collapse to dislocation rings.

There is strong evidence for the occurrence of the first two causes, but the third one, which is inherent in the process of solidification, is relatively unimportant; Dash^{185,186} grew silicon crystals in which very large volumes were free from dislocations. The requisite conditions are very high purity and a planar crystal-melt interface, which would be expected to decrease the importance of the first two causes. It may, however, be argued that the condensed vacancy mechanism is still valid and

the dislocations so formed are able to move out of the crystal as it grows.

Surface Imperfections

The surface imperfections to be considered are grain boundaries and lineage boundaries. The former occur when two independently nucleated crystals grow adjacently; the origin of such boundaries is, therefore, associated with the nucleation of new crystals in a melt in which a crystal is already growing. Lineage (or macromosaic) boundaries are those between different parts of a crystal originating from a single nucleus. Many, if not all, boundaries of this type are formed by the aggregation of dislocations into boundary arrays. The difference in the orientation increases progressively with increasing distance from the point of origin¹⁸⁷. The directions of the lineage boundaries are controlled by the direction of cellular growth when present; in other cases the lineage boundaries are apparently random in direction.

Volume Imperfections

Any heterogeneity of composition can be regarded as a volume imperfection; heterogeneity arises from the rejection of solute by the solid (or the preferential solution of solute in the solid). This causes the melt near the growing interface to differ in composition from the melt that is more remote. Any movement of solute, whether caused by diffusion or by mass movement of the liquid containing it, causes the final distribution of solute to be heterogeneous. Diffusion must always occur and its extent is controlled by the concentration gradient and by the time available; mass movement can occur as a result of convection caused by differences in temperature or by the difference in density resulting from the changed concentration of the solute, or as a result of the change in volume on freezing.

Requirements for Successful Crystal Growth from Melt

The growth of good quality single crystals from melt is an art as well as a science and it is difficult to generalize the exact conditions required for successful crystal growth, since these tend to differ from one crystal to another.

The primary consideration is that the material should be of high purity. Mechanical and thermal stability of a high order is essential for crystal perfection. A good crystal has both a high macro- and a high micro-perfection. Macro-perfection can be considered as freedom from stray crystals, twin boundaries and generally any large angle boundaries, such as lineage or striations. Micro-perfection represents freedom from dislocations and point defects such as vacancies, interstitials and impurities.

Macro-perfection

Formation of stray nuclei can be prevented by avoiding supercooling of the melt, stress at or near the solid-liquid interface and by having a controlled solid-liquid interface shape. These preconditions can be achieved by taking a pure material, maintaining a fairly steep temperature gradient in the

melt, having a slow growth rate and providing a vacuum or inert atmosphere. Stresses due to thermal expansion and contraction should be reduced by ensuring that the material does not wet or adhere to the containers. A planar or slightly convex interface helps in reducing the stresses as well as prevents the growth of stray crystals at the surface of a growing crystal. It may be advantageous to make the ingot almost square in cross-section. The cross-section should also be large enough to minimize edge effects, but not sufficiently large to make temperature across the surface difficult to stabilize.

Micro-perfection

High purity of the material is essential for attaining micro-perfection. It is not possible to grow single crystals from the melt entirely free from dislocations. However, the dislocation density is probably lower when growth takes place from a high quality seed crystal than when no seed is used. In the latter case growth will commence by the formation of dendrites in a supercooled melt and the complex thermal pattern and the inter-dendritic segregation which result probably give rise initially to large numbers of dislocations some of which will be perpetuated throughout the crystal. Thermal stress and mechanical vibration are other possible causes of production of dislocation.

Vacancies will always be present, since there is an equilibrium concentration of vacancies in the crystal which increases with temperature. It is probable that the absence of thermal stress, achieved by having planar or slightly convex isothermals, and a small temperature gradient in the solid reduces the extent of multiplication. If possible the solid should be maintained at a temperature low enough for the equilibrium concentration of defects to be negligible, but high enough for any defects to be sufficiently mobile to diffuse either back to the interface or to the free surfaces. The temperature gradient at the interface should be as steep as is consistent with this and with the fact that the temperature of the melt should be as uniform as possible and (in general) low enough for the vapour pressure to be low; under these conditions growth rate should be as low as possible.

To sum up, the crystal growth apparatus should have the following features: (i) be free from vibration; (ii) permit uniform growth (i.e. constant rate of movement either by the furnace or the crystal container as well as constant power to the furnace); (iii) provide a wide range of growth rates; (iv) keep the crystal in vacuum or inert atmosphere; (v) permit control of the shape of the solid-liquid interface; (vi) provide fairly steep temperature gradients in the solid and the melt; (vii) the crystal container should be of fairly low thermal conductivity and preferably not wetted by the material; and (viii) the material should be of high purity.

Summary

The methods of growing single crystals of organic solids, including special methods applicable to those compounds whose single crystals cannot be grown by the conventional methods are discussed. The advantages and disadvantages of the various

methods are outlined. The mechanism of formation of single crystals, the morphology of the solid-liquid interface and the types of imperfections and causes of their origin are dealt with in detail. The requisite conditions for growing good single crystals are listed.

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Course on the Genetics & Physiology of Bacterial Viruses

In the series of ICRO/UNESCO training courses on recent techniques in cell research, a South-East Asian regional course on the genetics and physiology of bacterial viruses will be held from 24 June to 27 July 1968, at the Pharmacology Laboratory, Indian Institute of Science, Bangalore 12, under the auspices of the Indian Institute of Science, Bangalore, Tata Institute of Fundamental Research, Bombay, and Bhabha Atomic Research Centre, Bombay. Opportunity will be given to the participants of carrying out by themselves a number of fundamental experiments designed as an intro-

duction into the modern quantitative experimental methods used in the field. Demonstrations, seminars and group discussions will help to complete the theoretical background. A number of leading specialists will deliver lectures on special topics.

The number of participants is limited to sixteen. Only post-graduate students in the fields of physics, chemistry and biology (including biochemistry and microbiology) will be accepted.

Applications for joining the course should be sent to the Pharmacology Laboratory, Indian Institute of Science, Bangalore 12.

The Enigma of the Mechanism of Action of Hormones

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AT the outset the terms of reference require precision. In recent years a number of symposia and conferences have been held on this intriguing, highly complex and elusive subject. The available data and the views of principal workers in the field have been adequately stated in the proceedings of these symposia¹⁻³. This article would not, therefore, attempt a repetition or restatement of the same. As the main purpose of reviews in this series is to stimulate research in the field, we have chosen to seek instead a reappraisal of some of the known, but perhaps not equally well-recognized, facts which according to the authors may have pertinent relevance to the understanding of this poorly understood problem. The approach is essentially that of a worker in the field attempting to assess the available data in the context of experimental conditions under which it may have been obtained and trying to evolve a working model which may fit with some of the known facts, and which may also serve as a basis for experimentation to define the many blank areas. This reinterpretation may have justification on the grounds that the exact and detailed mechanism of action of hardly any hormone is known so far, even though substantial progress has been registered in this area in the last few years. The origin of endocrinology dates back to 1849. This branch of science has thus had over a century and quarter of investigators' effort. There is, therefore, room for fresh speculation. At best, such an exploratory exercise may provide new avenues for experimental approach. At worst it would point to the need for rethinking and seeking alternate perspectives.

It is apparent that this review would have a number of inherent limitations. For one, it would not lay claim to be comprehensive and all-embracing. It is well-nigh impossible to discuss all hormones in the limited space of one review article. A limited number of hormones will, therefore, be inevitably selected as the main focus of attention. It is possible that the models evoked for these hormones may be applicable to other hormones, but it is equally likely that they may not have any relevance to the hormones omitted from discussion.

General Properties and Characteristics

Some of the features common to most hormones are:

(1) They are active in minute concentrations, often of the order of a few picograms (10^{-12} g.) or microgram (10^{-6} g.). On rough calculations, it may be surmised that the number of hormone molecules per unit target tissue cells is finite.

(2) They affect some tissues, but not all. The spectrum of action varies with the hormone. Some are highly selective, others more generalized.

(3) It seems that a hormone in its *primary* action affects one or a limited number of reactions in a

tissue and does not influence *directly* all other metabolic activities of the cell. This is in fact expected from a regulatory agent. Its secretion is provoked in response to a given situation and its action is, therefore, tuned to fulfil a given task. For many hormones it is now possible to discern an initial reaction whose product in a second stage leads to diverse metabolic effects (see, for example, Sutherland⁴). It is necessary, though often difficult, to distinguish between a primary event and its secondary consequences.

(4) It has been possible in a relatively few cases up to now to evolve systems where the effect of a hormone can be manifest *in vitro*. Others show their effect only on administration to the animal *in vivo*. This may be due to several reasons, among which may be the following:

(a) The sensitivity of the methods of detection available may limit the ability to assess the action of a hormone *in vitro*.

(b) The rate of reactions in animal cells is reported to be slower than the reaction rates in unicellular organisms. The *in vitro* studies usually restricted to a limited time period may not provide adequate scope for development of the effects.

(c) The 'active' form of the hormone may not be the chemical form in which it is secreted by the endocrine gland. It may require partial breakdown or alterations before it attains the effective molecular status. Circulation through other organs may be necessary for this purpose. The zymogen form of secretory enzymes is a familiar example in biology, where partial proteolysis is necessary to obtain the molecule with catalytic properties. Similarly, angiotensin, the biologically active octapeptide, is formed from the parent protein by a two-stage proteolytic splitting off reaction.

(d) Another reason for the inability to produce *in vitro* the action of all hormones may be that the hormone may require some elements involved in the structure and organization of the tissue at the organ level, which are lost or disarranged in the preparation of the *in vitro* system. There is at the moment very little concrete information on the factors implicit in the intercellular linkage and in tissue organization.

Latent Period of Action — Primary and Secondary Events

Many hormones have a latent or lag phase, during which the habitual effects of their action are not discernible. Some examples are summarized in Table 1.

Why is the action delayed? Is it due to the relative slowness of metabolic reactions in the animal tissues? Is it because of the necessity of the conversion of the hormone to an active derivative, which is a time-consuming process? Is it that the habitual criteria employed to assess the

TABLE 1 — LATENT PERIODS AND DIVERSITY OF METABOLIC EFFECTS INDUCED BY HORMONES

No.	Action observed	Time after the hormone treatment at which the effect is observed	References
GROWTH HORMONE			
1.	Increased removal of alpha amino isobutyric acid from blood	15 min.	5
2.	Hypoglycemia	30 min.	6, 7
3.	Fall in the level of non-esterified fatty acids (NEFA) in plasma	30 min.	8, 9
4.	Increased uptake of glucose by tissues (muscle, adipose tissue) <i>in vitro</i>	30-60 min.	10, 11, 12
5.	Increased oxidation of glucose to CO ₂ and increased lipogenesis in adipose tissue <i>in vitro</i>	30-60 min.	12, 13
6.	Stimulation of RNA polymerase activity		
	(a) in liver	1 hr	14
	(b) in muscle	3 hr	15
7.	Increase in non-esterified fatty acids (NEFA) in plasma	2 hr	8
8.	Decreased lipogenesis in adipose tissue	3½ hr	12
9.	Increased synthesis of RNA (messenger and ribosomal) in liver	5 hr	16, 17
10.	Stimulation of protein synthesis	12-24 hr	18
11.	Hyperglycemia and glycosuria	2-4 days	19, 20
12.	Gain in body weight	4 days	20, 21
EPINEPHRINE AND NOREPINEPHRINE			
1.	(In perfused heart)		
	(a) Increase in systolic pressure	} A few sec.	} 22
	(b) Increase in heart rate and coronary flow		
	(c) Increase in active phosphorylase		
2.	Increase in active phosphorylase:		
	(a) In muscle <i>in vivo</i>	60 sec.	23, 24
	(b) In heart <i>in vitro</i>	2-5 min.	25
	(c) In liver <i>in vitro</i>	2-10 min.	26
3.	Increased release of non-esterified fatty acids (NEFA) in adipose tissue <i>in vivo</i>	5 min.	27
4.	Increased oxygen consumption <i>in vivo</i>	5-15 min.	28
5.	Increased concentration of (U- ¹⁴ C)-valine in brain cortex slices	30 min.	(Sharma, Shail K. & Talwar, G. P., unpublished data)
6.	Decreased incorporation of amino acid in liver slices	45 min	29
7.	Increase in the efflux of sodium and potassium in intestinal smooth muscle	45 min.	30
8.	Increase in phosphofructokinase in skeletal muscle <i>in vitro</i>	60 min.	31
9.	Increased release of amylase from parotid gland slices	60 min.	32
10.	Diminished glucose uptake by diaphragm <i>in vitro</i>	90 min.	33
11.	(In fasting animals)		
	(a) Increase in urinary creatinine	1 day	} 34
	(b) Increase in urinary phosphorus	2 days	
	(c) Low blood glucose	5 days	
	(d) Loss in body weight	5 days	
	(e) Low glycogen in liver and diaphragm	5 days	

TABLE 1 — LATENT PERIODS AND DIVERSITY OF METABOLIC EFFECTS INDUCED BY HORMONES — *Contd*

No.	Action observed	Time after the hormone treatment at which the effect is observed	References		
ESTRADIOL					
1.	Increase of nuclear RNA synthesis	2-5 min.	35		
2.	Increased phospholipid synthesis	1-4 hr	36		
3.	Increased activity of some amino acid activating enzymes in uterus	3 hr	37		
4.	Water imbibition	4 hr	38		
5.	Increased vaginal metabolic activity	6 hr	39		
6.	Increased mitotic activity of vaginal epithelium and increase in the epithelial thickness	16 hr	40		
7.	Increase in dry and wet uterine weight	24-48 hr	36		
CORTISONE					
1.	Inhibition of respiration and (2- ¹⁴ C)-glycine incorporation into proteins and nucleic acids of lymphocytes	30 min.	41		
2.	Increased incorporation of (³² P)-orthophosphate in liver RNA	2 hr	42		
3.	Stimulation of RNA and protein turnover in regenerating and resting liver	3-4 hr	43		
4.	(a) Increased concentration of isotonic saline soluble ground substance (b) Decrease in the dermal concentration of glucosamine (c) Decrease in the dermal concentration of insoluble collagen (d) Increase in the dermal concentration of scleroprotein	} 24 hr	44		
5.	Increase in urinary nitrogen			48 hr	45
6.	Anti-inflammatory action			4 days	46
7.	Decrease in body weight			5 days	45
HYDROCORTISONE					
1.	Decrease in alpha amino isobutyric acid uptake in isolated diaphragm	10-30 min.	47		
2.	(In perfused liver) (a) Increased tyrosine transaminase (b) Increased tryptophan pyrrolase	A few min. } 2 hr	48		
3.	Glycogen deposition in liver	8 hr		46, 49, 50	
TRIIODOTHYRONINE					
1.	Increased synthesis of rapidly labelled nuclear RNA	3 hr	} 51		
2.	Stimulation of DNA dependent RNA polymerase	8 hr			
3.	Increase in the mitochondrial and microsomal incorporation of amino acids into protein	27 hr			
4.	Increase in the mitochondrial cytochrome oxidase	28 hr			
5.	Stimulation of microsomal glucose-6-phosphatase and NADPH-cytochrome-C reductase	30 hr			
6.	Increased basal metabolic rate	35 hr			
7.	Increase in liver weight	54 hr			

action of a hormone are in fact secondary or tertiary events? More work would be necessary to answer these questions. All the same it would be logical to postulate that the primary action of a hormone should be an immediate consequence of its first interaction and that this interaction should occur as soon as the hormone in its active form reaches the site of action. The techniques of labelling almost any chemical compound with tritium have opened a new approach for following the fate of a hormone after administration. (^3H)-Estradiol is observed to reach its target tissues within 5 min. after injection^{52,53}. It is retained by these tissues against a concentration gradient. It is further observed that the uptake of estradiol is a selective process and is predominant in those organs which respond biologically to its action⁵²⁻⁵⁵ (also Sachar, R. C., Sen, K. K. & Talwar, G. P., unpublished data). Apparently, these observations have important indications. In the first place they would suggest that the initial action of the hormone on its target tissues is a rapid and instantaneous process provided it can be identified. It follows that the effects observed several hours after the hormone administration may only be the secondary consequences of the initial reaction. If this proposition is accepted, it will be necessary to re-examine the validity of the conventionally listed metabolic effects of the hormones. It will also be necessary to explore afresh the hitherto undetected interactions occurring in the initial phases of the hormone action.

Mechanisms Involved in the Selective Action of Hormones on Tissues

It has been stated above that some hormones act on specific tissues and not on all tissues of the body. As examples, one may cite the tropic hormones secreted by the anterior pituitary. TSH acts on the thyroid, ACTH on the adrenals and the gonadotropins on the gonad endocrine glands. There are no detectable effects of these hormones on other endocrine glands, nor directly on other tissues except perhaps the pituitary and some selected areas of the brain. 17β -Estradiol is also fairly selective in its action influencing primarily a few organs and not all organs of the body. What could be the reason for this phenomenon? The easiest hypothesis would postulate the existence of specific markers in the target tissue which are recognizable by the hormone. We have investigated the case of 17β -estradiol. When radioactive estradiol is injected into ovariectomized rats, it is observed that in the uterus this hormone is associated with a heavy particulate fraction and with a macromolecular fraction present in the cytoplasm⁵⁴. Macromolecules having these properties are not present in tissues like lung, diaphragm, etc., which do not respond biologically to this hormone. Moreover, the uterine fractions exhibit a high degree of stereo-specificity for binding to a steroid hormone. For example, it would not bind cortisone. There will be even a discrimination for binding stereoisomers: 17β -estradiol is readily bound, while no binding is shown for 17α -estradiol under identical conditions. Inciden-

tally 17α -estradiol in equivalent doses is also not estrogenic in terms of its biological effects on the animals.

Recently we have assessed *in vivo* and *in vitro* the estradiol binding capacities of nuclear and cytoplasmic G100-P-1 fractions from several tissues of the rat and calf. Even though more work would be necessary to make definite conclusions, the present data suggest a correlation between the specific binding capacity of a tissue for estradiol and its biological responsiveness to the action of this hormone. A 'target' tissue may, therefore, differ from a 'non-target' tissue in that the former in its differentiated state has the capacity to synthesize macromolecules which act as receptors for the hormone. Through their agency, the tissue is able to recognize and pick up the hormone from circulation and in some cases to retain it. The repression of the 'receptor' synthesizing capacity would eliminate the tissue from the orbit of the action of a given hormone. This viewpoint prompted by the observations on estradiol raises fruitful avenues of investigation for other hormone systems.

Finite Binding Sites

Fig. 1 shows a typical dose response curve for two hormones. The curve is linear in low range of the hormone concentration only and attains a plateau at a value which varies from hormone to hormone. The effective doses for some hormones are listed in Table 2. These observations can be interpreted in terms of the existence of finite receptor sites in the cells for these hormones. Once these sites are saturated, no further increase is

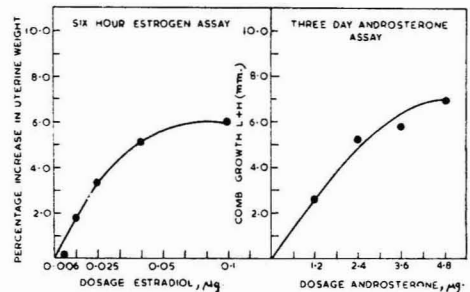


Fig. 1 — Dose-response curves of estradiol (data from ref. 55) and androsterone (data from ref. 56)

TABLE 2 — ORDER OF EFFECTIVE DOSES OF SOME HORMONES

Hormone	Dose	Increase observed	References
Testosterone	1-2 µg.	Comb growth	57
Estradiol	0-025 µg.	Uterine weight	58
ACTH	5 mU./100 mg. tissue	Corticosteroid production	59
Cortisone	0-5 µg.	Glycogen deposition	60
Epinephrine	0-03 µg.	Phosphorylase activation	22

observed in the quantitative effects provoked by the hormones.

Hormones and Morphogenesis

The emergence of a number of secondary sex characteristics on the onset of puberty is a familiar example. If the secretion of gonadal steroid hormones is deficient either because of hypopituitary function or because of ovarian or testicular malfunction, the development of secondary sex characteristics is also delayed or suppressed. Administration of the androgens to a child or even to a female induces the growth of beard, hoarseness of voice, a change in the pattern and distribution of hair and fat on the body, etc. On the other hand, the female gonad hormones induce the development of the breast tissue and other features characteristic of the female. These observations suggest clearly the morphogenetic role of steroid sex hormones on the differentiation and development of some tissues at appropriate stages of growth. Another interesting example supporting this conclusion is the reported induction of a new protein with high serine content in the liver of a rooster or immature hen by injection of estradiol⁶¹.

A direct proof of the action of a hormone at genetic level is furnished by the observations on the insect *Chironomus tentans*. Ecdysone, a steroid hormone produced in the prothoracic gland of the insect, produces 'puffing' of some chromosomal segments in the giant salivary gland chromosomes^{62,63}. During larval development, ecdysone and the juvenile hormone of the corpora allata are secreted together to initiate larval molting. The transformation to the pupa occurs when the juvenile hormone is lacking and ecdysone is secreted alone. Ecdysone injection leads to 'puffing' in the region I-18-C of the first chromosome of *Chironomus tentans* larvae. The same locus undergoes 'puffing' during formation of the prepupa. Puffing implies here the thickening of the chromosomal segment as detected visually under the microscope. With the use of appropriate radioactive precursors, it has been shown that the 'puff' is an active region of RNA synthesis. In other words, the hormone action results in the activation of a genetic segment, the chromatin at this locus is changed from a dense to a loose type and the transcription of the genetic information in this part of the genome starts occurring.

Several other hormones have a key role in the development and growth of the individual. Thyroid deficiency at an early stage of life leads to stunted growth and mental deficiencies typical of 'cretinism'. Growth hormone deprivation leads to 'dwarfism'. These well-established observations define clearly the role of these hormones in the growth and development of tissues in multi-cellular organisms. The role of thyroid hormones in anuran differentiation, i.e. transformation of tadpoles into frogs, is also well defined⁶⁴.

General Postulates on Mechanisms

In the above sections some of the characteristic properties and features common to several hormones have been discussed. Before proceeding to

the description of the current status of our knowledge on the mechanism of action of a few hormones, it may be appropriate to project, for the sake of discussion, the various possibilities by which hormones can influence cellular metabolism.

Influence on the permeability and cyto-skeleton of cells—In the first instance it may be logical to postulate that the hormones may influence the permeability of the cells to defined metabolites. Cells are organized structures. There are barriers between the intracellular and extracellular environment. The non-availability of a metabolite (which is not synthesized by the cells or a metabolite whose supply is primarily from exogenous sources) can be a limiting factor for the occurrence of a whole chain of reactions. It is well known that the uptake of most of the metabolites and mineral ions by the cells is an active process dependent not only on the expenditure of energy, but also there is the involvement of stereo-specific receptor molecules in the uptake process. In bacterial systems permease type of proteins have been described which permit the uptake of sugars and glycosides⁶⁵. One of the seasoned hypotheses for the mode of action of insulin envisages the effect of the hormone on the permeability of the peripheral tissues to sugars⁶⁶⁻⁶⁹. Insulin promotes the transfer of extracellular glucose to intracellular compartment which is probably the basis of the hypoglycemic action of this hormone. Some of the features of this action have been summarized by Levine⁶⁹ as follows:

(a) The hormone sensitive system is receptive to sugars like galactose, D-xylose and L-arabinose but not to D-arabinose, rhamnose, gluconate and glucuronate, etc., i.e. there is a degree of stereo-specificity for the uptake of sugars.

(b) It shows saturation kinetics, suggesting the limited availability of a specific carrier.

(c) Distribution of the sugars in the extracellular fluid is quite rapid in comparison with the rate of entry into the cell interior.

(d) The responsive sugars compete with each other for the transport system.

(e) The insulin effect as tested on the rat diaphragm *in vitro* shows a low Q_{10} (1.2 between 10° and 37°C.).

(f) The responsive sugars are not phosphorylated during entry into cells.

The effect of some other hormones on the uptake of metabolites other than sugars has also been reported. Growth hormone, for example, promotes the uptake of several amino acids *in vitro* in rat diaphragm preparations⁷⁰.

In view of the fact that there exist also intricate structural relationships within the cell, the concept exposed in the foregoing paragraphs can be generalized to include a possible effect of the hormones on the internal cyto-skeleton of the cell. The enzymatic components of the particulate fractions of the cells can have an action only when they have access to the substrates and cofactors. A building block can thus be a limiting factor in a biosynthetic reaction so long as it is not made available at the enzymatic sites of synthesis. The converse may be equally true. The catabolic enzymes present in the lysosomes become effective

only when the lysosomes are disintegrated. Some workers have postulated hormonal role in the stabilization of lysosomes⁷¹.

Activation or repression of a biologically active molecule—A second possibility of the action of a hormone is the situation where the interaction of the hormone with a tissue component results in the activation or repression of a biologically active molecule. This is a fairly composite statement and would probably be true for most cases. One of the better worked and illustrative examples is the activation of a structural enzyme adenylyl cyclase by epinephrine which acts on ATP to form 3',5'-cyclic AMP. The cyclic AMP in turn activates a number of other reactions, such as the conversion of phosphorylase *b* to the enzymatically active form phosphorylase *a*⁷². Phosphorylase *a* causes glycogenolysis and hyperglycemia. The case of epinephrine points to another interesting feature of hormone action, namely that the action of a hormone is like a cascade phenomenon. An initial event leads to another through a product of the reaction. This may explain to some extent the observed time lag between the different effects of a hormone (Table 1).

Hormonal influences on de novo synthesis of enzymes and biologically active molecules—Hormones may activate a pre-existing protein to make it biologically active. They may also induce the synthesis of one or more proteins as part of their primary action, which would in turn usher in various types of metabolic activities. The growth promoting action of several hormones is well established. Growth hormone and thyroid hormones (in physiological concentrations) influence the growth of the bones and other tissues markedly. Estradiol has a dramatic action on the growth of uterine tissue. The role of androgens as anabolic steroids is well known. Even steroids like cortisone, whose overall effect is a negative nitrogen balance, induce nevertheless the synthesis of transaminases and other amino acid oxidizing enzymes in the liver. There is thus a definite action of many hormones on processes leading to the synthesis of proteins.

Hormones may affect the transcription (synthesis of RNA) or translation (synthesis of polypeptides on pre-existing messenger and ribosomal RNA) processes or both. In fact the two are closely synchronized operations and each would affect the other in course of time. Opinions are still divergent as to whether the hormones act in the first instance at the translation step or at the transcription step. The available data do not permit a conclusion on this point. The clearest evidence in favour of an action at the level of translation process is the work of Sokoloff and colleagues on the action of thyroid hormones *in vivo* and *in vitro* on the incorporation of labelled amino acids into microsomal proteins⁷³. In chronic thyroid deficiency, the inherent protein biosynthetic activity of microsomes is depressed and can be restored towards normal by thyroid hormones. It has been seen that if thyroxine is preincubated *in vitro* with mitochondria and an oxidizable substrate, a factor is produced which is effective in stimulating the amino acid incorporating capacity of microsomal fractions *in vitro*. There

are also numerous observations favouring a primary action of hormones on the transcription step. The case of ecdysone has been cited above, where it is possible to visually detect the activation of cistrons in terms of loosening of the chromatin and an active RNA synthesis in these loci. The template activity of the chromatin is found increased in target tissues after administration of androgens⁷⁴. It is also observed that estradiol gets bound to an appreciable extent in the nuclear fraction of the uterus^{74a}. There are also reports of an increase of RNA synthesis in the uterus 2 or 5 min. after injection of estradiol⁷⁵. No effect on the synthesis of proteins is detectable at this time period. The experimental evidence is, therefore, in favour of a primary action on RNA synthesis for some hormones and on processes leading to the synthesis of proteins for other hormones. The issue remains open and requires further investigation.

Current Knowledge on the Mode of Action of a Few Hormones

After having discussed several features of the action of hormones in general terms, a couple of concrete cases are now discussed. The choice of these hormones has been primarily dictated by our research interest in these hormones. They evoke nevertheless issues which are common to many other hormones.

Mode of action of pituitary somatotropin or growth hormone—Growth hormone is a polypeptide having a molecular weight of 45,000 in bovine species and 25,000 and 21,500 in monkey and man respectively. The amino acid sequence of human growth hormone has recently been worked out by Li *et al.*⁷⁶. There is a degree of species-specificity for the biological action of this hormone. Rat responds to the hormone from practically all species, excepting fish, but in humans and monkeys the growth hormone from primate species only is effective. The guinea-pig responds only to its own growth hormone.

The removal of pituitary in animals leads to a marked diminution of the growth of animals. Administration of pituitary extracts or purified growth hormone alleviates this condition and restores growth. In man, hypopituitary function is associated with 'dwarfism' and hyperpituitary activity results in acromegaly and gigantism. In its biological effects the hormone is thus associated with growth processes.

It has also a number of other metabolic effects. On the carbohydrate metabolism, it has both an 'insulin-like' and 'insulin antagonistic' action. The former is believed to be due to the formation of a polypeptide breakdown product of the growth hormone which has biologically insulin-like properties. It has also been reported that growth hormone stimulates the secretion of insulin from the pancreas [reference may be made to the work of Young and collaborators^{76,77}], which may be indirectly responsible for the insulin-like action of growth hormone on some metabolic processes. It is further believed that growth hormone has a hyperglycemic action, presumably by the inhibition of hexokinase reaction. Two phases are discernible in the action

of growth hormone on carbohydrate and fat metabolism. In the first phase, the action of growth hormone is similar to that of insulin. It favours the transfer of glucose from extracellular to intracellular compartments, a property which is also reported to be expressed *in vitro* in rat diaphragm preparations¹⁰. In this phase the action of growth hormone on lipid metabolism consists of a stimulation of lipogenesis in adipose tissues¹². This action is in contrast to the effect of growth hormone on lipid metabolism in the second phase, where the action is primarily lipolytic. The lipids are mobilized from the adipose tissue. The blood level of non-esterified fatty acids (NEFA) is raised^{78,79}. The exact mechanisms implicit in these effects are poorly understood.

The inherent relationship of this hormone with the general growth of the body points to the importance of this hormone in protein synthesis. The administration of this hormone causes a positive nitrogen balance⁸⁰. It is further seen that this effect is due to an amelioration of the synthesis of proteins rather than a decrease in the breakdown of proteins^{81,82}. In hypophysectomized animals, the incorporation of radioactive amino acids into proteins *in vivo* and *in vitro* is lower than in the control animals. The injection of growth hormone to the animals restores the deficiency^{83,84}. A systematic examination of the protein synthesizing components in cell-free system shows that there is no change in the amino acid activating enzyme activities in the two cases; the major difference is in processes taking place at the ribosomes. The capacity of ribosomes to incorporate activated amino acids into polypeptides is impaired⁸⁵. These observations lead to the enquiry whether the growth hormone has any effect on the ribosomal (and messenger) type of RNA. Several years back we reported the stimulation of the incorporation of radioactive orthophosphate into RNA fractions of the liver after injection of growth hormone to animals^{16,17}. The increase was primarily in the nucleolar fractions of RNA. With the prolongation of the time of incorporation of radioactive precursors, the microsomal fractions of RNA were also highly labelled. The nuclear fractions of RNA were subfractionated and analysed on sucrose density gradients. Their molar base ratios were also determined. These investigations showed that the growth hormone administration to female plateaued rats stimulated the synthesis of both ribosomal and messenger RNA in the liver¹⁷. Similar conclusions have been made by other workers⁸⁶ and by us employing alternate experimental approaches in hypophysectomized animals⁸⁷. The increase of both the ribosomal and messenger RNA synthesis would logically offer the basis for increased protein synthesis observed in the cells and tissues. This does represent one of the vital metabolic activities stimulated by the growth hormone. The question, however, remains open as to whether it is a primary event of the action of this hormone. There is a lag period of about 3 hr before the action on RNA synthesis is demonstrable. From the foregoing discussions it would be necessary to investigate the events taking place

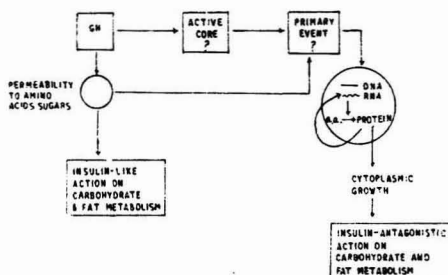


Fig. 2 — Schematic representation of the current views on the mode of action of growth hormone

in this early period. In another series of experiments, Gupta and Talwar⁸⁷ obtained a highly suggestive evidence pointing to the action of the growth hormone on the rate of RNA synthesis primarily. In adult animals, the hormone does not seem to activate repressed cistrons. The molecular species of RNA synthesized in the hormone deprived and hormone administered animals is essentially identical as seen by hybridization experiments⁸⁷.

The current status of the mode of action of this hormone is shown in Fig. 2 in a schematic manner. A detailed review on this hormone appears elsewhere⁸⁸.

Mode of action of epinephrine and norepinephrine

— The manner in which epinephrine and glucagon cause hyperglycemia is one of the few hormone actions understood in precise terms. The pioneer work of Sutherland and Rall⁸⁹ has shown that these hormones activate an enzyme adenyl cyclase in target tissues (such as liver), which gives rise to the formation of a cyclic nucleotide 3',5'-AMP from ATP. 3',5'-AMP acts as a cofactor for the enzyme which phosphorylates dephosphophosphorylase into phosphophosphorylase in the liver. Phosphorylase a being the catalytically active form of the enzyme, the stored glycogen in the tissue is broken down. There is good experimental evidence for all steps proposed in the scheme. 3',5'-AMP mediates several of the reactions induced by catecholamines. About a dozen systems in which 3',5'-AMP is involved have been reported (Table 3). The catecholamines declenche a cascade type of reactions, the product of one reaction triggering the next. Fig. 3 presents in a schematic form the manner in which epinephrine is believed to affect the metabolic activities of the tissues (in particular glycogenolysis). It is possible to put in evidence the initial interaction of the catecholamines with the tissue receptors (Sharma, Shail K. & Talwar, G. P., unpublished data). Sharma and Talwar have observed a change in available thiol groups of the hypothalamus and cerebral cortex slices on the addition of catecholamines in concentrations of 10^{-4} to $10^{-6}M$ *in vitro*.

Mode of action of 17 β -estradiol — This 18-carbon steroid is produced by the ovaries. The 17 β -stereoisomer is the natural estrogen in mammals and causes among others a marked proliferation of the uterine tissue. The 17- α isomer is biologically not

potent in equivalent doses. On ovariectomy, the uterus atrophies and is reduced to a basal state of existence. With the administration of a tenth of a microgram of estradiol to the ovariectomized rats, dramatic proliferative changes occur in the uterus, vagina and other target tissues of this hormone.

Various hypotheses have been advanced to explain the mode of action of this hormone. It may, however, be stated that the mechanism of action of this hormone is not yet known precisely.

(1) One of the first hypotheses was put forward by Szego *et al.*^{107,108}. Estradiol was believed to release histamine in the target tissues, which in turn caused changes in the permeability of the tissue to water and other metabolites. Tissue proliferation was considered to be a consequence of these initial changes. This hypothesis has the merit of implicating an amine mediator, a situation which is analogous to the believed implication of tyramine in the action of vasopressin on toad bladder¹⁰⁹. It would also explain the hyperemia and increased imbibition of water by the uterine tissue which takes place within an hour of the injection of estradiol. This hypothesis has, however, failed to gain active support, even though there is no strong reason to shelve it. The water imbibition is prevented by puromycin and appears to be dependent on the synthesis of proteins¹¹⁰.

(2) Another hypothesis was advanced by Villet *et al.*¹¹¹, which postulated the role of estradiol as a cofactor in a transdehydrogenase. The transdehydrogenase would make available one more ATP during the oxidation process and would support the anabolic processes. This hypothesis has more or less been abandoned, as this enzyme is extremely low or absent in rat uteri. The enzyme was purified from the placenta. This hypothesis is, however, illustrative of the general possibility that estradiol might activate a biologically active molecule.

(3) Hechter *et al.*¹¹² have recently claimed that 3',5'-AMP and several other nucleotides can induce the uterotrophic changes characteristic of the estradiol action. This is an interesting avenue for further research.

(4) Notides and Gorski¹¹³ and Mueller¹¹⁴ believe that the early estrogen action comprises the synthesis of a vital protein, which then sustains the RNA.

Enzyme or process affected	Tissue	Change in activity or rate	References
Phosphorylase	Heart, muscle and liver	Increased	23, 24, 26, 90
UDPG- α -glucan transglucosylase	Diaphragm	Decreased	91
Phosphofructokinase	Heart, liver fluke (<i>Fasciola hepatica</i>)	Increased	92, 93
Lipase	Adipose tissue	do	94, 95
Tryptophan pyrrolase	Liver	do	96
Steroidogenesis	Corpora lutea, adrenal cortex	do	97, 98, 99
Ketogenesis	Liver	do	100
Incorporation of L-leucine into protein	do	Decreased	101
Conversion of acetate to fatty acids and cholesterol	do	do	100
Lactate \rightarrow glucose	do	Increased	102
Release of amylase	Rat parotid	do	32
Permeability to water and sodium	Toad bladder	do	103, 104
Sugar transport	Thyroid	do	105
HCl secretion	Gastric mucosa	do	106

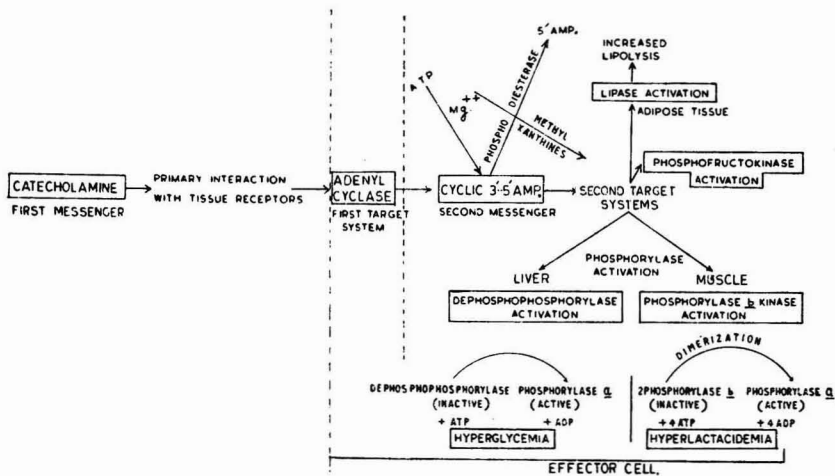


Fig. 3 — Schematic representation of the mode of action of catecholamines

synthesis. This conclusion is derived from two types of experiments. In the first instance these workers observed that puromycin inhibits the increase in RNA synthesizing capacity of the uterine nuclei which is induced by estradiol treatment *in vivo*¹¹⁶. In a subsequent series of experiments¹¹³, uteri from the rats were taken out at various time intervals (30 min., 60 min., etc.), after a massive dose of estradiol *in vivo*. The uteri were incubated *in vitro* in a medium containing radioactive amino acids for prolonged periods (90 min. and beyond). The soluble proteins were fractionated by starch gel electrophoresis and their radioactivity determined. A fast moving peak was discernible which was more radioactive in uteri pretreated with estradiol. This is an attractive experiment, but it is putting in evidence a phenomenon which occurs between 30 and 120 min. after estradiol treatment. It remains to be verified whether the synthesis of this protein occurs in the earlier stages. The crucial period for putting in evidence the primary event is the first 5 or 10 min. From the work of Jensen and Jacobson⁵² it is known that estradiol is picked up by the uterus very rapidly from circulation and that a substantial amount of the steroid is present in the uterus after 5 min. Hamilton *et al.*¹¹⁶ observed a 500 per cent increase in RNA synthesizing capacity of the uterine nuclei, 20 min. after estradiol administration. More recently Means and Hamilton⁸⁵ have shown that an increase in the incorporation of radioactive uridine into RNA of the uterus is observed even at 2 or 5 min. after estradiol administration *in vivo*. No parallel effect on the synthesis of proteins was detected at this early time period¹¹⁷. If these observations are valid, they would negate the hypothesis of Gorski and Mueller and would indicate that the primary effect of estradiol would be on RNA synthesis and not on the protein synthesis. In course of time, of course, the two processes would be synchronized and would influence each other. Several other workers have reported recently results of their experiments which were designed to seek a clarification whether the steroid hormones affected the RNA or the protein synthesis in the first instance. Clever and Romball¹¹⁸ working on the ecdysone induction of puffs in *Chironomus tentans* have come to the conclusion that the first puff induced by ecdysone is dependent on RNA synthesis and is prevented by actinomycin-D. Kidson¹¹⁹ working on the action of cortisone on lymphocytes in cell culture has observed the effect of the steroid on RNA synthesis in 2 and 5 min., while no effect on protein synthesis is observed in the early stages of the action of this steroid. A direct evidence for the involvement of RNA in the uterine proliferation (under hormonal influence) is furnished by the experiments of Segal *et al.*¹²⁰, where the RNA extracted from the uteri of rats pretreated with estradiol induced an increase in the height of epithelial cells of the endometrium in a manner similar to the action of estradiol.

(5) Talwar *et al.*^{54,121} put forward the viewpoint that the combination of estradiol with the uterine macromolecular receptors results in a process leading to the derepression of the synthesis of RNA,

which then becomes the basis of a generalized increase in protein synthesis and tissue proliferation. This view evolved from the following observations:

(a) Administration of estradiol to ovariectomized rats induced an early increase in the rate of RNA synthesis³⁶. The rise in RNA synthesis preceded in time sequence the phase of the generalized increase of protein synthesis and increase in wet and dry weight of the uterus.

(b) Inhibition of DNA dependent RNA synthesis prevented the expected biological response of the target tissue to estradiol^{122,123}.

(c) In analogy with the observations on growth hormone, the hormone treatment resulted in an increase of both the ribosomal and messenger type of RNA, i.e. there was a generalized stimulation of all types of RNA and not just of a single or limited number of messenger RNA molecules.

(d) The RNA polymerase activity as assayed in nuclear aggregate preparations showed an increase at an early stage of hormone action when no new synthesis of protein was evident. This would suggest an activation of the pre-existing enzyme system.

(e) When (6,7,8H)-17 β -estradiol was injected into ovariectomized rats, the estradiol was found in the uterus mainly bound to a heavy particulate fraction and to a macromolecular component of the high speed supernatant fraction⁵⁴. The heavy particulate fraction has since been purified by differential centrifugation in sucrose gradients and 80 per cent of estradiol radioactivity of the heavy particulate fraction is accountable in the nuclei^{174a}. Current biological knowledge shows that almost all RNA in animal tissues is synthesized in the nuclei.

(f) G100-P-1 fraction from ovariectomized rat uteri inhibits *in vitro* the activity of purified *Esch. coli* RNA polymerase. The same fraction from animals pretreated with estradiol is much less inhibitory. Preincubation of the G100-P-1 fraction with estradiol *in vitro* leads to a reduction of its inhibiting influence on the purified bacterial RNA polymerase system^{54,121}. Sopori *et al.*¹²⁴ have further examined this system. The inhibition is not due to the presence of catabolic enzymes, such as protease, ribonuclease, deoxyribonuclease, adenosine triphosphatase and guanosine, cytidine or uridine triphosphatase. The inhibiting factors and the sensitivity to estradiol are labile entities and can be lost or denatured on standing or by treatment with various agents. The order of addition of the reactants is an important consideration for obtaining reversion of inhibition. It has also been observed by these workers that the estradiol binding capacity and the property of inhibiting the RNA polymerase migrate in the same fraction during partial purification of the G100-P-1 fraction on DEAE-cellulose.

Wacker *et al.*^{125,126} have made identical observations on a steroid-induced bacterial system. Testosterone induces a number of enzymes in *Pseudomonas testosteroni*. The kinetics of induction are similar to the hormone effects in mammalian organs. They observed that radioactive testosterone was bound to a proteinic macromolecular component present in the high speed supernatant fraction,

which is not retained on Sephadex G100. It was further observed that the macromolecular fraction from the non-induced bacteria (NIMF) inhibits *in vitro* the activity of purified *Esch. coli* RNA polymerase. Preincubation of the NIMF fraction with testosterone *in vitro* markedly reduced the inhibition. Preincubation with dienediol [$\Delta^4,17(20)$ -pregnadiene-11,21,diol-3-one], on the other hand, has no effect on the inhibition. These results independently obtained on another steroid-induced system are very much similar to our observations on the estradiol-uterus system. The phenomenon may have a general validity. There has also been one report of the failure on the part of investigators to obtain reversion of the inhibition by estradiol *in vitro*¹²⁷. The reasons for this apparent discrepancy are not clear for the time being. They used a different enzyme, i.e. from *Micrococcus lysodeikticus*, which was also not as highly purified as the *Esch. coli* RNA polymerase obtained by us from Dr Maitra and Dr Hurwitz. Various other operational factors, namely the order of addition of reactants, the stage at which purine nucleoside triphosphates are added, the relative concentration of the reactants, etc., may also influence the interaction of the inhibitor with components of the reaction mixture, as is clear from other studies¹²⁴.

In the event that these observations on the effect of a uterine factor on purified bacterial enzyme find their validity and counterpart on the uterine RNA polymerase, it would mean that the RNA synthesizing system is repressed in ovariectomized (or hormone deprived) rat uterus and that the uptake of estradiol by the tissue results in the derepression of this system. This conclusion has, however, to await the purification of the RNA polymerase from the uterus and several other controls.

An important lacuna in this field so far has been the lack of an appropriate system for obtaining the response of the uterus to estradiol *in vitro*. It is known that estradiol is picked up by the uterus both *in vivo* and *in vitro* and that the hormone remains predominantly unaltered chemically in the target organs. Furthermore, some of the responses of the uterus to systemically given estradiol are fairly rapid. The inability to stimulate in clear terms *in vitro*, the expected metabolic reactions of the uterus to estradiol, points to the need for further search of the missing links. A sound model for the mechanism of action of this (and other hormones) can emerge only when all components of the system are identified and a basis set for their integration to produce *in vitro* by rational design, at least some of the characteristic features of their action *in vivo*.

Concluding Remarks

Hormones are defined chemical entities and are products of special cells. Their synthesis has evolved as a characteristic feature of the multicellular organisms, in which they serve as agents for the vital functions of regulation. Some hormones have also an important role in morphogenesis and maintenance of specific tissues. During the last five decades, most of the hormones have been purified

and crystallized. The chemical structure of many hormones has been determined. A number of them have also been synthesized.

Hormones are active in minute concentrations. A large body of literature exists listing the metabolic activities of the tissues affected by the administration of the hormones. It is not unusual to come across conflicting reports on the action of a hormone, which has given rise to some confusion and ambiguity on the action of the hormones. In most cases such contradictions have resulted from either the use of high pharmacological doses of the hormone or because of the prolonged periods after the hormone administration at which the observations are made. The latter point is an important consideration. The initial effect of a hormone should be an early reaction, which in turn becomes the basis of secondary and tertiary events. The type and range of effects would, therefore, vary, depending on the time period at which observations are made. This review has discussed this and other issues pertinent to an evaluation of the mode of action of hormones. The necessity for a reappraisal of the early interactions of the hormones with components of the target tissues has been stressed.

The review has evoked and discussed some characteristic features of the action of hormones which have general implications, but has concentrated on an evaluation of the current status of our knowledge on three hormones, namely pituitary growth hormone, epinephrine and 17β -estradiol.

Acknowledgement

This article is dedicated to an esteemed friend and collaborator, Dr Sheldon J. Segal, whose constant encouragement and sustained help enabled us to have a glimpse in this exciting and complex problem. This work was supported by research grants of the Department of Atomic Energy, Ford Foundation, Council of Scientific & Industrial Research, and the Population Council.

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Atmospheric Sciences & Scientific Hydrology Research Committee

The Governing Body of the Council of Scientific & Industrial Research has constituted a new Research Committee on 'Atmospheric Sciences and Scientific Hydrology' in place of the Advisory Committee for Rain and Cloud Physics. Researches on the

monsoon, rain making and atmospheric chemistry will come under the purview of the new Committee. The schemes on the subject, at present being looked after by the Physical Research Committee, will also be transferred to the new Committee.

REVIEWS

INTRODUCTION TO THE THEORY OF PARTIAL DIFFERENTIAL EQUATIONS by M. G. Smith (D. Van Nostrand Co. Ltd, London), 1967. Pp. x+214. Price 25s.

This book is suitable for the final year of an honours course in mathematics or for M.Sc. by examination of the British universities. The presentation and treatment of the subject are systematic and will be useful for postgraduates and research scholars. One should have a sound knowledge of the theory of ordinary differential equations and complex analysis to understand the text. The author has solved many problems and examples with answers have been given.

Chapter 1 deals with the partial differential equations of mathematical physics. The equations of analytical dynamics have been presented.

Chapter 2 deals with the fundamental existence and uniqueness theorems. The Cauchy-Kowalewski method has been explained.

Chapter 3 introduces first-order equations (linear, semi-linear and quasi-linear) with two independent variables. The linear equations with n independent variables, determination of complete integrals, solutions of Cauchy problem and the one-dimensional Hamilton-Jacobi equation, and first-order equations with n independent variables have been discussed.

Chapter 4 considers second-order linear equations. Simultaneous first-order equations, linear equations of the second order with two independent variables, the hyperbolic equation and the reduction of a linear equation to a canonical form have been discussed.

Chapter 5 treats the linear partial differential equations of the second order in more than two variables. The Cauchy problem and its solution, the characteristic surfaces, bicharacteristics, the adjoint equation and the conformal have been explained.

Chapter 6 is devoted to the study of the Laplace equation in two, three and n dimensional space.

Chapter 7 deals with the wave equation in one, two and three dimensions.

Chapter 8 deals with the diffusion or heat conduction equation. The physical significance, finite bar, semi-infinite bar solutions, and similarity solutions have been discussed.

Chapter 9 is devoted to the study of Green's functions. The Dirichlet and Neumann problems for the Laplace equation have been explained clearly.

Chapter 10 discusses the Riemann theory of hyperbolic equations. The equations of waves, Volterra's solution of the wave equation in three variables and Hadamard finite values of infinite integrals have been discussed.

Chapter 11 considers simple properties of generalized functions.

Chapter 12 is devoted to the study of the system of equations of order greater than two.

Chapter 13 contains the equations of fluid dynamics, the linear cone field, inviscid compressible steady flow in two dimensions and also for an electrically conducting fluid.

In the appendix, the Gauss theorem in n dimensions, the volume and surface area of the n dimensional unit sphere, expansion theorems of Fourier, singularities of Legendre functions and identity involving derivatives have been added for reference.

U. A. SASTRY

TEXT BOOK OF FLUID DYNAMICS by F. Chorlton (D. Van Nostrand Co. Inc., Princeton, New Jersey), 1967. Pp. xiv+399. Price 35s.

This book differs essentially from the usual text-books on fluid dynamics in that it combines in one volume perfect, compressible and viscous flows plus mathematical treatments of thermodynamics and magnetohydrodynamics.

Throughout, the subject is based on vectorial methods. An introduction to these methods is given in the first chapter. The next four chapters deal with kinematics of ideal fluids in motion, equations of motion and two- and three-dimensional flows. The coverage includes method of images, potential flows, the circle theorem, use of conformal representation and vortex theory. Chapter 6 deals with the basic laws of thermodynamics as a preparation for the study of gas dynamics in Chapter 7. This chapter discusses wave motion, isentropic gas flows, shock waves and the method of characteristics. Chapter 8 deals with viscous flows and discusses some solutions of Navier-Stokes equations and gives an introduction to Prandtl's boundary layer theory. The last chapter deals with magnetohydrostatics and magnetohydrodynamics and includes a treatment of magnetohydrodynamic waves and shocks.

The reviewer had proposed in a symposium held under the auspices of the Calcutta Mathematical Society in 1960 that the present hydrodynamics course in Indian universities should be replaced by a more broad-based course including a treatment of viscous, compressible and hydromagnetic flows. The reviewer had also suggested the introduction of stability, turbulence and non-Newtonian fluid flows in the course. The present book is the first text-book which meets these requirements partially and thus deserves to be adopted in the M.Sc. mathematics courses of Indian universities. The text-book can be covered in a one-year course without any difficulty.

The treatment of all the topics is, however, on classical lines and is not as exciting as one would wish it to be. However, the treatment is careful and correct throughout. The adoption of this book, it is hoped, will pave the way for better books and will break the monotony of the courses based on books by Lamb, Ramsey and Milne-Thomson which have held the field for too long a period.

J. N. KAPUR

VECTOR ANALYSIS AND CARTESIAN TENSORS WITH SELECTED APPLICATIONS by Krishnamurthy Karamcheti (Holden-Day Inc., San Francisco), 1967. Pp. xiii+225. Price \$ 10.50

The aim of this book is twofold, viz. (i) to clearly and systematically explain the basic concepts of vector analysis, Cartesian index notation, and Cartesian tensor analysis; and (ii) to illustrate, by selected applications in different fields of engineering and mathematical physics, their use in the formulation of physical problems and in the derivation of some general results relating to these fields.

The book is a self-contained text for those students of engineering and physical sciences who have only a knowledge of elementary calculus. The first chapter carries a discussion of vector algebra and includes an introduction to orthogonal curvilinear coordinates. In the second chapter, the concepts of gradient, divergence and curl are introduced. The third chapter introduces line, volume and surface integrals while the theorems of Gauss, Green and Stokes are introduced in the fourth chapter.

The fifth chapter discusses the concepts of irrotational and solenoidal vector fields and leads to the decomposition theorem according to which, under certain general conditions, a vector field can be represented as the sum of an irrotational field and a solenoidal field. The solution of the Laplace equation by Green's function method is also discussed. An appendix of this chapter gives a clear account of the topological notions of connectivity, reconcilable paths, etc. The sixth chapter derives expressions for gradient, divergence, curl and the Laplacian in orthogonal curvilinear coordinates.

The seventh chapter discusses applications of vector analysis to mechanics and motion of an ideal fluid. In the mechanics section, central forces, rigid body motion, rotating frames and Euler's equations are obtained, while in the fluid flow section, both kinematics and kinetics are discussed and Euler's equations are derived.

The last three chapters deal with Cartesian tensors and their applications to fluid mechanics and elasticity. At the end of the book more than one hundred selected problems are given on the first seven chapters. It is, however, surprising to find that no problems are given on the last three chapters.

The treatment throughout is lucid, clear, precise and highly motivated. The get-up and production of the book are excellent. A cheaper edition of this book is highly desirable for students. For libraries, the book can be recommended as it is.

J. N. KAPUR

ELECTROCHEMISTRY OF MOLTEN AND SOLID ELECTROLYTES: Vol. 4 — THERMODYNAMICS AND KINETICS OF ELECTRODE PROCESSES edited by A. N. Baraboshkin & S. F. Pal'guev; translated from the Russian by Halina Wroblowa [Transactions (Trudy) No. 7 of the Institute of Electrochemistry, Ural Academy of Sciences] (Consultants Bureau Enterprises Inc., New York), 1967. Pp. viii+165

This booklet is the fourth of a series of collections devoted to high temperature physical chemistry and electrochemistry of molten and solid electrolytes.

It comprises the results of 22 original investigations concerning thermodynamics of molten salt mixtures, electrode processes during deposition and anodic dissolution, physical properties of carbonate melts and theoretical and experimental studies of electroconductivity and the kinetics of electrode processes with solid electrolytes carried out at the Institute of Electrochemistry of the Ural Branch of the USSR Academy of Sciences.

Molten salt galvanic cells were employed to calculate the enthalpy of dissolution of BeCl_2 and BeCl in molten alkali halides; the results agreed within 20 per cent of those estimated from a quasi-lattice model. The e.m.f. method has also been used to study the equilibria between metallic titanium and molybdenum with their respective ions in molten alkali chlorides and the determination of redox potentials. Another group of papers are concerned with electrolysis of molten salt solutions. Electrolysis of pure AgNO_3 , for example, has been carried out to study the formation of crystal nuclei. Conditions for obtaining compact cathodic deposits of Nb from chloride baths and the effect of valence state of Zr on the structure of the deposit have been worked out. Corrosion of Zr metal in molten KCl-NaCl in dry air and in dry chlorine has been studied.

Molten carbonates are known to interact with many compounds. Effect of addition of small amounts of oxides, salts and bases in changing the surface tension (maximum bubble pressure method) of alkali metal carbonates and their binary and ternary mixtures has been reported. Another study concerns the use of platinum-oxygen electrode as a reference system in molten carbonates as solvent.

Among the problems concerning solid electrolytes are the dependence of electroconductivity of oxides on partial pressure of oxygen, characteristics of galvanic cells with a partially electrochemically solid electrolyte and electropolarization and kinetics of electrode processes occurring in such cells.

The availability of the English translation of this collection of papers would be greatly welcomed by electrochemists interested in molten and solid electrolytes.

H. C. GAUR

EXPERIMENTAL TECHNIQUES IN PHYSICAL METALLURGY by V. T. Cherepin & A. K. Mallik (Asia Publishing House, Bombay), 1967. Pp. xi+428. Price Rs 30.00

Although man's association with metals dates back to prehistoric times, his engineering performance in this field began to improve only since World War I, because improvements in existing materials could then be effected or new alloys developed with scientific appreciation of the principles of physical metallurgy. Physical metallurgy is indeed the language with which metals speak of their potentialities and limitations which can be deciphered only with extensive and intensive experimentation. So perfect has been the resulting understanding that commercial engineering applications can now be reliably designed on the basis of predicted properties and performances.

As the authors themselves state in their preface, the variety of experimental techniques in physical metallurgy have grown phenomenally in recent years. In many instances, routine applications of the principles of physical metallurgy have permitted control over the quality of production and have led to methods of industrial quality control. The rigorous, intensive testing of the electrical, magnetic and mechanical properties of metals and a study of their phase transformations with the help of dilatation, thermal analysis, magnetic permeability determination, etc., necessarily introduced a great deal of sophistication in the experimental techniques. However, in order that provocative experimentation is self-generating, the investigators must have an understanding of the related sciences and technologies such as optics and electron optics, electronics, and vacuum systems and vacuum measuring gauges, besides temperature measurement. The lucid presentation of most of this in the book has been possible as both the authors have had considerable experience in the field of metallurgy.

The book is divided into ten chapters. The first chapter deals with methods of obtaining high temperatures in laboratory, temperature measurement and control. The second introduces the reader to vacuum techniques including design of pumps, vacuum systems and measuring gauges; the vacuum systems of the usual equipment such as electron microscope and evaporation unit are also briefly discussed. The third and fourth chapters deal with the metallographic examination with optical and electron microscopes. These chapters also make the reader familiar with experimental innovations such as phase contrast microscopy, interference microscopy, high temperature vacuum microscopy, etc. Much of these two chapters is written for the undergraduate student in metallurgy. This is followed by a small chapter on thermal methods, but the discussion of calorimetric techniques is relatively brief. The sixth and seventh chapters cover electrical and dilatometric magnetic methods. In the eighth chapter, the authors discuss experimental techniques based on measurements of elastic and inelastic properties of metals and alloys and cover a wide range from introductory treatment to the nature of experimental problems which can be investigated with their help. Similarly, the ninth chapter on magnetic methods, after an elementary discussion of properties, generation and measurement of magnetic field, passes on to their measurement and applications in the study of phase transformation. A useful feature of the book is in its tenth chapter which draws attention to the statistical nature of experimental observations.

The scope of experimental techniques is vast and the authors have widely used their discretion in the selection of techniques in their book. Thus, important techniques such as electron and X-ray diffraction have not been discussed along with the techniques of growing single crystals, mechanical testing and applications of radioactive isotopes in physical metallurgy.

The book is primarily intended for students of physical metallurgy and is strongly recommended.

RAJENDRA KUMAR

LIQUID-PHASE OXIDATION OF HYDROCARBONS by N. M. Emanuel, E. T. Denisov & Z. K. Maizus; translated from the Russian by B. Z. Hazzard (Plenum Press Inc., New York), 1967. Pp. 350. Price \$ 22.50

During the last few years, liquid-phase oxidation reactions of hydrocarbons have become very important inasmuch as several new and highly successful industrial processes have been developed for obtaining important chemical products like phenol, adipic acid, benzoic acid, terephthalic acid, etc. Russian workers have been very active in the field of kinetics and mechanism of liquid-phase oxidation reactions of hydrocarbons. These liquid-phase oxidation processes are chain reactions and, because of the presence of free radicals in such processes, they are of great significance in the development of the chain theory of the slow branched chain reactions proposed by N. N. Semenov. Hence, a book based on the work done in Russia on this subject is particularly welcome because the authors are eminent and active workers in this field.

The book is divided into the following nine chapters: (i) The chain mechanism of oxidation reactions, (ii) Experimental methods for studying the kinetics and mechanism of liquid-phase oxidation reactions, (iii) Elementary reactions of liquid-phase oxidation, (iv) Kinetic laws of the degenerately branched chain reaction, (v) Sequence of the formation of oxidation products, (vi) Initiation and catalysis of liquid-phase oxidation, (vii) Inhibitors in oxidation processes, (viii) The kinetic laws of induced and coupled oxidation, and (ix) The oxidation of individual hydrocarbons.

The book is written in a thorough, systematic, clear style with a strong emphasis on the theory of chain reactions and mathematical analysis of kinetics. Experimental methods have been given in sufficient detail to enable research workers to follow the techniques in an unambiguous manner. The book is a valuable contribution to the field of liquid-phase oxidation of hydrocarbons and research workers in the field will find it invaluable in their work. Because of the high price its acquisition would have to be limited to the libraries though individuals would also benefit by having a personal copy.

N. R. KULOOR

MODERN ORGANIC CHEMISTRY by John D. Roberts & Marjorie C. Caserio (W.A. Benjamin Inc., New York), 1967. Pp. xxi+844. Price \$ 10.75

Of late, there has been a spate of books covering the broad field of organic chemistry. These are generally entitled *Principles of organic chemistry*, *Modern organic chemistry* or simply *Organic chemistry*. The authors of each individual volume have claimed a certain novelty of approach and a departure from the old beaten track of classical organic chemistry, in keeping with the fast developing modern concepts in this branch of science. Even though this is to be expected in view of the tremendous progress this field has witnessed during the last decade or so, very often the instructor as well as the student is left bewildered and faced with the difficult problem of a proper choice of a suitable text-book in the subject.

The present book by Roberts and Caserio comes as a further addition to this already imposing array of text-books on organic chemistry. A perusal of this volume, however, leaves one with no choice but to recommend it as an excellent text-book for both undergraduate as well as graduate students.

The text of the book is a compressed version of the larger treatise *Basic principles of organic chemistry* published by the same authors three years ago. In the process of compressing, the total number of chapters (thirty-one) have been left intact and only certain details and tables, etc., not essential to the presentation of the basic concepts, have been omitted. The philosophy and the fundamental approach to the subject have thus been well maintained in this book as in the larger volume. One direct result of the shortening process is reflected in the reduction in price. At \$ 10.75 for a cloth-bound volume of 844 pages of art paper, the publishers deserve to be congratulated, especially in these days of ever rising costs.

The order of presentation of topics in this book is indeed novel, as claimed by the authors. Most authors of text-books of organic chemistry follow an order of presentation which is a matter of personal choice and opinion. It does not really matter very much for the present-day training of the organic chemist whether the chemistry of alkane and cycloalkanes should definitely precede that of the aromatic compounds or whether they should be intermingled and so on. What is indeed new in this book, as in the older and larger volume, is that a fairly heavy dose of physical and chemical principles and application of spectroscopic methods to structural analysis is delivered quite early in the initial chapters, followed by a repetitive elaboration in subsequent ones. Although the authors feel, as indicated in their preface, that such a treatment of the subject could be at least partially controversial, in the reviewer's opinion it is essential for the training of the modern organic chemist, who has to span the borderline subjects of physical, inorganic and biochemistry as well as a part of the biological sciences. The emphasis on thermochemistry and its application is also a novel feature of this book.

The only criticism one might offer for this book is that in the process of shortening the earlier larger volume and yet trying to maintain its breadth of coverage, substantial details have been left out on several topics so that the reader finds his appetite only partially whetted and has to turn quickly to either the larger book or elsewhere for a more sumptuous meal. However, this, in a way, has been the authors' objective which the present book satisfies admirably.

B. D. TILAK

INTRODUCTION TO EXPERIMENTAL ECOLOGY by T. Lewis & L. R. Taylor (Academic Press Inc., London), 1967. Pp. xi+402. Price 37s. 6d.

In recent years, a considerable number of publications on the subject of ecology have appeared, but the majority of these do not deal with the experimental aspect. There was, therefore, need for a practical guide-book to help beginners to plan out field experiments. The book under review is a

most welcome volume, which will meet the present-day requirements in a large measure.

The book contains six chapters and 14 appendices. The first two chapters are meant to introduce a student to the science of ecology. Chapter 3 deals with 'analysis in ecology', admirably explaining certain useful statistical methods. Chapter 4, the longest and the most useful one, gives exercises in ecology. A number of experimental techniques and equipment generally used in ecological research are explained in the fifth chapter, and the sixth one deals with the keys to common land invertebrates.

It is, however, felt that the first two chapters meant to introduce the subject are rather too brief and it might have been worth while to elucidate the subject. In particular, the organization of a community could have been discussed in detail, although a few penultimate exercises deal with the composition of community, community structure and community diversity.

The statistical methods explained in the third chapter will be of great advantage to zoologists who are sometimes not trained in statistics. The science of ecology is fast becoming a quantitative subject and, therefore, application of statistics is necessary. The statistical methods are explained in a simple manner and, as the authors claim, this section is restricted to the requirements of the exercises.

The fourth chapter forms the most useful part of the publication and contains 45 exercises relating to the following aspects: Variability of living things; Development of animals; Responses and adaptations of animals to the physical environment; Animal behaviour; Habitats; Interdependence of plants and animals in habitats; Animal abundance and distribution; Distribution maps and gradients; Daily and seasonal cycles of activity and abundance; Fluctuations in population density; Biological equilibrium; Dispersal; Interspecific competition; Food relationships, predation and parasitism; Community structure and diversity; and Evolution. Every exercise is explained under Introduction, Hypothesis, Apparatus, site and time of year, Procedure, Results, and Conclusions. Most of the exercises are designed for the study of invertebrates, especially insects, but this fact does not necessarily limit the scope of the exercises and many of these could be models for work on other animals also.

The keys to land invertebrates are illustrated with diagnostic features and they add to their usefulness for ecologists who may not be systematists. The arrangement of keys is a very commendable effort of the authors.

Techniques and apparatus used in ecological work are well explained. It would, however, have been desirable to add a few paragraphs in the fourth chapter about record keeping, field notes, photographic and laboratory records.

The book is an important contribution providing valuable information on the planning of simple experiments on ecological aspects and analysis of data for the student of ecology.

The printers are also to be congratulated, along with the authors, for an excellent job done and for keeping the price line to 37s. 6d.

G. C. TANEJA

BOOK NOTES

THE INDIAN EPHEMERIS AND NAUTICAL ALMANAC FOR THE YEAR 1968 (Manager of Publications, Delhi), 1967. Pp. xxii+468. Price Rs 14.00 (32s. 8d. or \$ 5.04)

The *Indian ephemeris and nautical almanac* is being issued annually since 1957 by the India Meteorological Department. The present volume, the eleventh in the series, covers the period up to 22 March 1969. The data are presented in 5 parts. The first 3 parts present data on (1) sun, moon and planets; (2) stars; and (3) eclipses and occultations. Part 4 contains data tables giving miscellaneous information. Part 5, entitled 'Indian calendar', makes available, to the *Panchang* makers in India, the astronomical data suited to their requirements. The significance of the items included in the publication, the methods for making various calculations and explanatory notes on the terms used in the body of the text are explained in the last 25 pages.

PROBLEMS IN GEOPHYSICS RELATING TO THE CRUST OF THE EARTH (National Geophysical Research Institute, Hyderabad), 1966. Pp. 223. Price Rs. 2.00. This publication contains the texts of 16 papers presented at a symposium held at the Department of Geology, Osmania University, Hyderabad, on 30 and 31 January 1964 under the auspices of the Geophysics Research Board and the National Geophysical Research Institute, Hyderabad. For 9 papers only the abstracts are given. The papers included fall under the following broad categories: Geophysical exploration, Seismology, and Physical properties of rocks. The papers pertaining to oceanography have been excluded. Inclusion of brief notes on discussions following the presentation of papers would have enhanced the value of the publication.

PUBLICATIONS RECEIVED

OPTICAL ROTATORY DISPERSION AND CIRCULAR DICHROISM IN ORGANIC CHEMISTRY, INCLUDING APPLICATIONS FROM INORGANIC CHEMISTRY AND BIOCHEMISTRY edited by G. Snatzke (Heyden

& Sons Ltd, London), 1967. Pp. xvi+416. Price \$ 13.50

MANY-BODY PROBLEMS AND OTHER SELECTED TOPICS IN THEORETICAL PHYSICS edited by M. Moshinsky, T. A. Brody & G. Jacole (Gordon & Breach Science Publishers, New York), 1967. Pp. xii+955. Price: cloth \$ 49.00, paper \$ 15.75

PREDICTION ANALYSIS by John R. Wolberg (D. Van Nostrand Co. Inc., Princeton, New Jersey), 1967. Pp. xi+291. Price \$ 10.75

THE BIOCHEMISTRY AND PHYSIOLOGY OF INFECTIOUS PLANT DISEASES by Robert N. Goodman, Zoltán Kiraly & Milton Zaitlin (D. Van Nostrand Co. Inc., Princeton, New Jersey), 1967. Pp. x+354. Price \$ 12.50

GRUNDLAGEN DER SYNTHESE VON ZWISCHENPRODUKTEN UND FARBSTOFFEN (Akademie-Verlag, Berlin), 1966. Pp. xvi+1059

TRIPLE STATE (The Cambridge University Press, London), 1967. Pp. xv+544. Price 90s.

MAGNETISM AND MAGNETIC MATERIAL 1967 DIGEST edited by W. D. Doyle & A. B. Harris (Academic Press Inc., New York), 1967. Pp. xiii+280. Price \$ 11.00

THE PRINCIPLES OF HETEROCYCLIC CHEMISTRY by Alan R. Katritzky & J. M. Lagowski (Methuen & Co. Ltd, London), 1967. Pp. xvi+183. Price 45s.

WORK DONE IN INDIA ON VIRAL AND RICKETTSIAL INFECTIONS OF VERTEBRATES — A BIBLIOGRAPHY compiled by Surendra Mohan & T. R. Srinivasan (Indian National Scientific Documentation Centre, New Delhi), 1967. Pp. xii+339. Price Rs 50.00

SELECTED PAPERS OF GEORGE HEVESY (Pergamon Press Ltd, London), 1967. Pp. ix+447. Price 90s.

POLYMERS-MACROMOLECULES VISCOSITY-MOLECULAR WEIGHT STUDIES by A. R. Kemp (A. R. Kemp, Consulting Chemist, 231 Prospect Avenue, Long Beach, California), 1967. Pp. ix+168

NEWER METHODS OF NUTRITIONAL BIOCHEMISTRY: Vol. 3, edited by Anthony A. Albemese (Academic Press Inc., New York), 1967. Pp. xv+527. Price \$ 18.50

Process for the disposal of radioactive wastes

A continuous process for the disposal of highly radioactive wastes, from nuclear reactors, by converting them into phosphate glasses has been developed at the Brookhaven National Laboratory, USA [I & EC, *Proc. Des. Develop.*, 6 (1967), 314]. Glasses have been considered as a suitable medium for the long-term storage because of their resistance to environmental degradation and capacity for holding the fission products. The phosphate system, instead of the silicate system, has been favoured because of the simplicity associated in processing the waste as a liquid and the highly unbreakable character of the glass product.

The phosphate glass is produced in three steps. In the first step, orthophosphoric acid is added to the raw waste and in the second, the volume is reduced by the low temperature evaporation (130-160°C.) of water and other volatiles. The final step consists of removing the other volatiles by heating the solution to 1200°C. in a platinum crucible and converting the concentrate to molten glass. The phosphate anion complexes the bulk cations, so that appreciable concentration of the mixture is possible without precipitation of an excessive amount of solids.

A pilot plant with a capacity of 1.5 cu. ft of glass per day has been operating in the laboratory for the last two years using several types of simulated purex waste. Based on the process information obtained, a full-scale demonstration prototype plant is being constructed at Battelle North-west Laboratory, USA.

A new apparatus for making air-vapour mixtures

A method has been worked out for preparing mixtures of organic vapours and air of known composition for use in physiological experiments and in the calibration of a gas chromatograph using the unusual property of silicone rubber as a diffusing membrane. Organic liquids such as diethyl ether diffuse through silicone rubbers at a constant rate proportional to the surface area of the membrane and

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inversely proportional to its thickness.

Silicone rubber tubing of the appropriate diameter was made into a container for the liquid by closing one end with silicone rubber moulding paste, and it was mounted on a glass tube through the other end. The container was inserted in an outer tube through which air was allowed to flow at a constant velocity. The container was weighed periodically to determine the loss of liquid; the length of the silicone rubber tube was adjusted to get the derived composition of the outflowing mixture, issuing out of a side tube.

Compounds like carboxylic acids, thiols and ketones caused the rubber to swell thereby altering the rate of diffusion; but once this dimensional change reached its completion, the membrane worked satisfactorily. This method cannot be used for compounds which polymerize in air and block the pores [*Chem Ind.*, (1967), 1487].

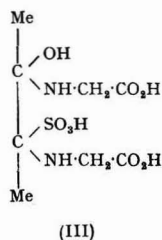
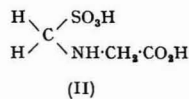
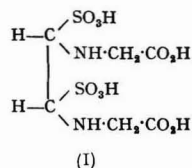
Novel synthesis of *cis*- and *trans*-vinyl bromides

Addition of bromine to *trans*-1-hexenyl disiamylborane obtained from the reaction of 1-hexyne with bis(3-methyl-2-butyl) borane gives either *cis*- or *trans*-1-bromo-1-hexene, depending upon the procedure used to eliminate the elements of disiamylboron bromide from the dibromide intermediate. Hydrolysis yields the *cis* derivative and thermal decomposition in refluxing carbon tetrachloride the *trans*-isomer. This procedure is applicable to a number of 1-alkynes. But in the case of phenylacetylene, solvolysis of the intermediate gives the *trans*-bromostyrene and pyrolysis gives the *cis*-isomer. In the case of the alkynes the addition of bromine proceeds through the usual bromonium ion mechanism resulting in *trans* addition, and the solvolysis involves a *trans* elimination and the thermal decomposition a *cis*. It is suggested that in the case of phenyl-substituted vinylborane the addition of bromine

may be *cis* [*J. Am. chem. Soc.*, 89 (1967), 4531].

Novel adducts of sulphur dioxide with carbonyls and amino acids

A new form of bound sulphur dioxide is shown to be a bisulphite adduct of Schiff's bases resulting from the interaction of carbonyls and amino acids. When sulphur dioxide is bubbled through a suspension of glycine (0.1 mole) and glyoxal (0.05 mole) in water (15 ml.) an exothermic reaction set in and the colour of the suspension slowly changed from green to brown. The reaction was complete in about 2 hr when a crystalline product (I) formed in 50-70 per cent yield. Glycine and formaldehyde under similar conditions gave (II) and glycine and diacetyl (III).



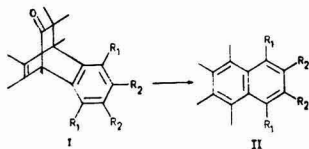
These adducts are all strong acids. They do not give barium sulphate on treatment with barium chloride nor do they react with iodine, indicating that sulphur is present as sulphite group. The IR spectra of these compounds showed the following characteristic bands: $\lambda_{\text{max}}^{\text{KBr}}$ 1750 cm^{-1} (unionized

COOH), 1600 (NH_2^+), 1240 and 1040 (SO_3H) [*Chem. Ind.*, (1967), 1492].

Synthesis of octamethyl-naphthalene

A simple, high yield synthesis of octamethylnaphthalene which also has the virtue of generality for the synthesis of substituted naphthalenes and other ring structures has been reported [*J. Am. Chem. Soc.*, **89** (1967), 4554].

Addition of benzyne to hexamethyl-2,4-cyclohexadienone gives (I, $\text{R}_1 = \text{R}_2 = \text{H}$), which can be converted to (II) by one of several routes. For example, 1,2,3,4,5,8-hexamethylnaphthalene could be obtained in 87 per cent yield from (I, $\text{R}_1 = \text{CH}_3$, $\text{R}_2 = \text{H}$) by reaction with dimethylsodium in dimethylsulphoxide at 70°C. for 4.5 hr.



Adduct (I) may be quantitatively reduced by lithium aluminium hydride to a mixture of epimeric alcohols, which with sodium hydride in dimethylsulphoxide gives the corresponding naphthalene. Pyrolysis at 400°C. is another method for the conversion of (I) to (II). Octamethylnaphthalene is best prepared from 1,2,3,4,5,8-hexamethylnaphthalene (II, $\text{R}_1 = \text{CH}_3$, $\text{R}_2 = \text{H}$) by bischloromethylation and LiAlH_4 reduction.

Stabilization of enzyme activity by organic solvents

The finding that certain otherwise unstable enzymes such as benzylalcohol dehydrogenase from *Pseudomonas* sp., homogentisicase from bovine liver, and alcohol dehydrogenase from yeast can be stabilized by the presence of acetone or ethanol [*Nature, Lond.*, **215** (1967), 417] is of considerable significance for biochemical work which is often handicapped by loss of activity of the unstable enzymes during preparation and storage.

Benzylalcohol dehydrogenase has a half-life of less than 3 hr in

0.05M phosphate buffer, pH 7.5 at 5°C., and reducing and chelating agents have no significant retarding effect on the loss of activity. In the presence of 10 per cent acetone or ethanol, the enzyme is completely stabilized for well over 25 hr. Yeast alcohol dehydrogenase is completely stabilized for more than 20 hr by 1 M molar glutathione. Bovine liver homogentisicase is highly unstable in the presence of air; 10 per cent acetone renders the apoenzyme completely stable even after 24 hr storage, but the holoenzyme continues to lose activity even in the presence of acetone though more slowly than in the absence of acetone. The holoenzyme of homogentisicase retains its activity if preserved under anaerobic conditions, whereas the apoenzyme as well as benzylalcohol dehydrogenase do not retain their activity under anaerobic conditions in the absence of organic solvents. It is tentatively suggested that the stabilization of the enzyme activity by organic solvents is caused by the retention of the 'native state' of the protein conformation.

Food Preservation Research in Australia

The annual report of the Division of Food Preservation, Commonwealth Scientific & Industrial Research Organization (CSIRO), Australia, for the period 1965-66 gives an account of the research activities of the Division in the fields of physics, food chemistry, plant cell physiology, microbiology, meat research, fish, and packaging and preservation of foods.

Theoretical equations have been developed representing low velocity aeration of granular beds and enabling the production of the relative humidity and temperature of the air as well as the moisture contents of the grain anywhere in the bed. These equations are being applied to the determination of conditions for the drying of bulk bins of rice. A new form of differential gauge has been constructed which permits measurement of small differences in pressure at a total pressure of less than 0.1 Torr. A hydrocooler designed prevents dehydration of oranges during cooling. Modifica-

tions in the existing mechanical rice throwers have been made improving the mixing of the rice as it is placed in the bin; an instrument has been designed which cuts off aeration of rice when the ambient relative humidity is higher than 5 per cent. Using these devices, successful drying of mixtures of rice of high and low moisture contents is now possible. Rigorimeters have been designed to record changes in muscle length and extensibility of wheat over the pre-rigor and immediate post-rigor periods.

The spheres of interest of the Division of Food Chemistry are the volatile constituents of foods, lipids and phospholipids, cyclopropanoid compounds, proteins and carbohydrates and their reactions with nitrogen and sulphur compounds. A simple technique developed for resolving complex mixtures of volatiles from frozen peas into simpler mixtures involves chromatography on silica gel in Teflon tubing using low boiling solvent (monofluorotrichloromethane, b.p. 25°C.) for development. Study of the chemistry of intermediates involved in non-enzymic browning reactions is being continued. An unsaturated ketose, 3,4-dideoxy-D-glycero-hexosulos-trans-3-ene has been synthesized for the first time. It has been found that sulphur dioxide inhibits the browning of amino sugar derivatives present in food by forming both acyclic and cyclic bisulphite addition compounds.

During study of physiology of growth and the ageing process in plants, the relative roles of nuclear and extranuclear DNA in chloroplast development, the nucleic acid and protein synthesizing systems present in chloroplast and the extent of participation of cytoplasmic enzymic system in the synthesis of chloroplast have been studied. Protein and amino acid metabolism of leaves undergoing accelerated senescence following detachment from the plant has also been studied. A net loss of protein has been observed in the wheat leaves in the first 24 hr following detachment; this loss is associated with a very rapid catabolism of some of the related amino acid residues. Proline accumulation has been shown in both

attached and detached leaves of wheat.

A culture apparatus for the autotrophic growth of the unicellular alga, *Chlorella pyrenoidosa*, has been developed and growth curves under a variety of conditions have been obtained. An oxygen electrode method has been devised for the measurement of photosynthetic and respiratory oxygen exchange in the liquid phase. An absolute requirement for cytochrome *f* in the photoreduction of nicotinamide adenine dinucleotide phosphate has been shown for the first time by the addition of purified cytochrome *f* to the lamellae from *Euglena*. The addition of cytochrome *f* restores cytochrome photo-oxidation and the kinetics are similar to those observed in whole cells.

Investigations into the effect of physiological stress, method of stunning and slaughter on the meat quality are being continued. The effect of water and feed deprivation and transport on the glycogen concentration of muscles has been studied. A simple method for determining density of meat samples has been developed. The method permits the estimation of fat content with an accuracy of 1-2 per cent in the low fat range.

Investigations on fishes have been concerned with the practical aspect of preservation by freezing and also with the general biochemical and physiological changes in the muscle post-mortem in order to ascertain possible effects on the ultimate eating quality.

Laboratory and field trials on packaging of fresh fruits and vegetables are in progress. Packing bananas in sealed polyethylene film cartons has been observed to delay the commencement of ripening for period up to 10 days even at -80°F . Thiabendazole [2-(4'-thiazolyl)-benzimidazole] has been found to be an effective fungicide to control mould infection of *Gloeosporium musarum*. The use of layer pads impregnated with a mixture of sodium-O-phenyl phenate and metabisulphite has been found promising for packing grapes for export. A technique for culturing and ripening banana slices has been developed.

The work in the Division of Processed Fruits and Vegetables is

concerned with various aspects of production of food crops, such as selection of varieties, horticultural practices and harvesting procedures. A pilot scale equipment devised for puncturing peas before freezing prevents wrinkling of the skin of frozen peas when cooked. A simple water injection method enabling the assessment of the volume of intercellular space in different varieties of apples has been developed. A chemical method for the quantitative assay of limonin, bitter principle of oranges, based on thin layer chromatography using 2,4-dinitrophenylhydrazine has been developed. An apparatus, making use of phosphorus pentoxide electrolytic hygrometers, has been constructed for studying the mechanism of water vapour diffusion in flexible packaging films. The results obtained with this apparatus are in excellent agreement with those obtained by the gravimetric method. The water vapour transmission rate of 0.0025 in. polyethylene at 20°C . can be determined in 2 hr. The new apparatus provides information on transient behaviour as well as on steady state diffusion. Two procedures for estimating the oxygen permeability of packages made up from flexible films have been developed.

Bulletin of the All India Institute of Medical Sciences

This bulletin is the latest addition to the existing family of medical journals in India. The bulletin is being published quarterly from July 1967 by All India Institute of Medical Sciences, New Delhi. The bulletin will publish critical reviews on various topics in contemporary medicine and related biology. It will carry advance communications from the faculty of the Institute on the results of their latest researches and a verbatim record of the clinico-pathological conferences held at the Institute. Results of researches into indigenous diseases with the use of modern methods will also figure in the bulletin. Further information regarding subscription, etc., may be obtained from the Editor, *Bulletin of the All India Institute of Medical Sciences*, New Delhi 16.

Announcements

■ *Advanced School on Theory and Technology of Semiconductors* — An international advanced school on theory and technology of semiconductors is to be held at the Indian Institute of Technology, Delhi, from 8 April to 5 May 1968. Lectures at the school will cover the following subjects: Band theory of semiconductors, Transport phenomena in semiconductors, Semiconductor materials (including thermoelectric materials), Organic semiconductors, Thermal conductivity, Infrared absorption, and Semiconductor devices. Practical training will be conducted on the following topics: Raman scattering of normal modes of silicon and germanium by reflection technique, Transmission measurements on the absorption edge and on impurities doped silicon and germanium, Crystal growth from vapour phase, Preparation of thin film MDM structures and determination of their characteristics, Diode and other P-N junctions and their characteristics, and Impurity diffusion in semiconductors.

Further details regarding the school can be had from its Director, Dr S. C. Jain, Department of Physics, Indian Institute of Technology, New Delhi 29.

■ *A Seminar on Gas Chromatography* will be held at the Indian Institute of Petroleum, Dehra Dun, on 20 and 21 May 1968. The main subjects of discussion will be: (i) Development of gas chromatography; (ii) Instrumentation; and (iii) Applications. The last date for the submission of papers is 31 March 1968. Further details regarding the seminar can be had from Dr R. K. Srivastava, Indian Institute of Petroleum, P.O. IIP, Dehra Dun.

■ *An International Symposium on Turbulence of Fluids and Plasmas* will be held in New York during 16-18 April 1968 under the auspices of the Microwave Research Institute of the Polytechnic Institute of Brooklyn, with the cosponsorship of the Air Force Office of Scientific Research, the Office of Naval Research and the Army Research Office and with the cooperation of the Institute of Electrical and

Electronics Engineers, Microwave Theory and Techniques Group and the Optical Society of America. The main topics of discussion will be: Identification of the basic turbulence phenomena in uncharged fluids; Introduction to basic phenomena of turbulence in uncharged fluids and plasmas; Significance of fluid and plasma turbulence in science and technology; Theoretical and experimental descriptions of turbulent media — fluids (uncharged gases and liquids) and plasmas (including interactions with electromagnetic fields); and Experimental diagnostic techniques and related interactions with turbulent media. The last date for submission of contributed papers is 15 January 1968. For consideration, a 500-word abstract should be submitted. Correspondence should be addressed to: PIB Symposium Committee (Attn: Jerome Fox, Executive Secretary), 333 Jay Street, Brooklyn, New York 11201.

■ *A Symposium on the Scanning Electron Microscope: The Instrument and Its Applications* will be held on 30 April and 1 May 1968 at IIT Research Institute, Chicago, Illinois, USA. Papers will be presented on various aspects of this instrument and its applications in metallurgy, material science, chemistry, biology, electrical engineering and electronics. Additional information about the symposium can be had from Dr Om Johari, IIT Research Institute, 10 West 35th Street, Chicago, Illinois 60616, USA.

■ *Textile Association Silver Jubilee Conference* — The Textile Association (India) will hold its Silver Jubilee Conference in New Delhi on 13 and 14 April 1968. A commemoration volume bringing out the current status of the textile industry will be published. Attempts are also being made to organize a workshop, in which leading professional experts in the country would be invited for an intensive 3-day discussion. The workshop will review both the economic and technological aspects

FORTHCOMING INTERNATIONAL SCIENTIFIC CONFERENCES, 1968

<i>Date</i>	<i>Conference</i>	<i>Place</i>
14-15 Feb.	International Solid State Circuits Conference	Philadelphia
2-16 March	Thirteenth Congress of the International Society of Sugar Cane Technologists	Taipei
7-8 March	Thirty-first International Congress, Institute of Sugar Beet Research	Brussels
March	International Symposium on the Preservation of Cultures and Sera	Bern
March	International Conference on the Universal Aspects of Atmospheric Electricity	Tokyo
March	International Symposium on Radiosensitizers and Radioprotective Drugs	Milan
25-28 March	Fifth International Aerospace Instrumentation Symposium	England
9-11 April	International Symposium on Pulse-rate and Pulse-number Signals in Automatic Control	Budapest
16-19 April	Fourth International Vacuum Congress	Manchester
23-26 April	International Conference on Magnetics	Washington
April	International Colloquium on the Synthesis of Peptides	Orsey
April-May	Fifth International Congress for Noise Abatement	London
1-15 May	International Congress on Lightweight Concrete	London
6-10 May	Seventh International Metal Finishing Conference	Berlin
6-11 May	Eighth International Congress on Combustion Engines	Brussels
13-17 May	Sixth International Mechanical Pulping Conference	Atlanta
13-18 May	Sixth International Congress on Electro-heat	England
15-17 May	International Rubber Conference	Berlin
19-22 May	International Congress of Cytology	Rio de Janeiro
19-25 May	International Symposium on Protein and Polypeptide Hormones	Liège
20-22 May	International Symposium on Microwave Theory and Techniques	Detroit
27-31 May	International Symposium on Recovery of Pulping Chemicals	Helsinki
May	International Conference on Thermionic Electrical Power Generation	Stresa
May	International Colloquium on Natural Interstices and Flaws in Metals	Grenoble
May	International Colloquium on Structure and Properties of Solid Surface	Paris
May or June	Sixth International Congress, Association for Cereal Chemistry	Vienna

of the textile industry and make suitable recommendations which would be presented to the main conference.

The technical sessions will include discussions on spinning, weaving and chemical processing. In addition, there will be two general sessions on modernization, marketing and export promotion and on education and training in textile industry.

■ *Award for Research in Ceramics* — Nominations have been invited

by the Indian Ceramic Society for an award of Rs 5000 for the best research work carried out by an Indian national in the country in the field of ceramics including glass, enamels, pottery, refractories, ceramic raw materials, processes and products, etc.

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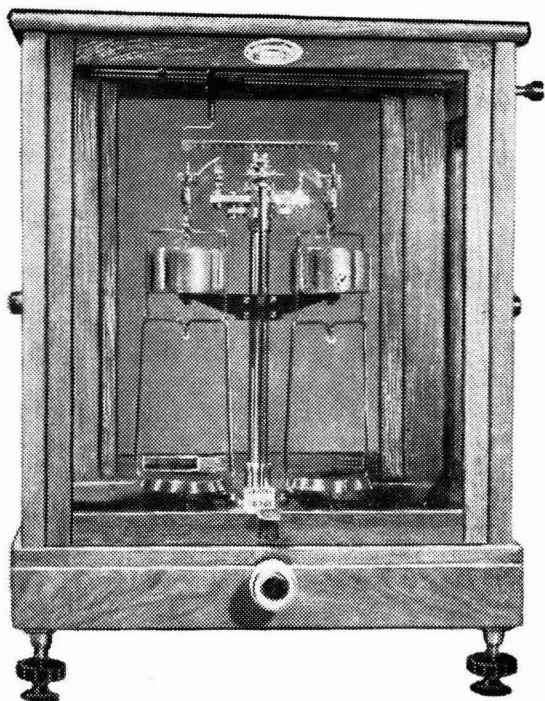
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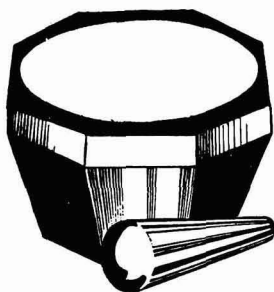
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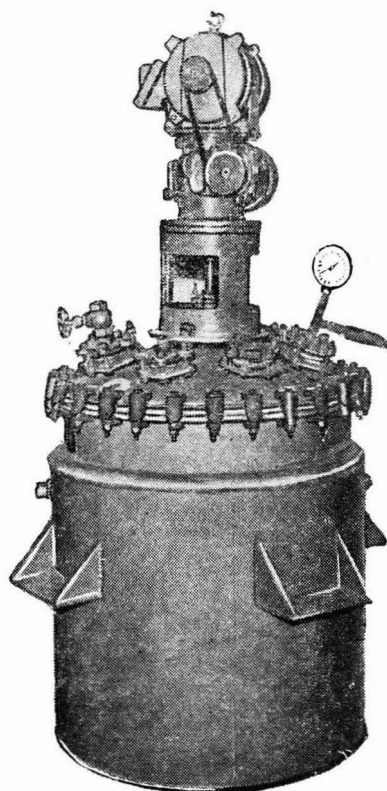
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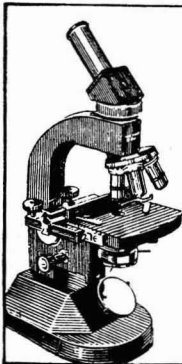
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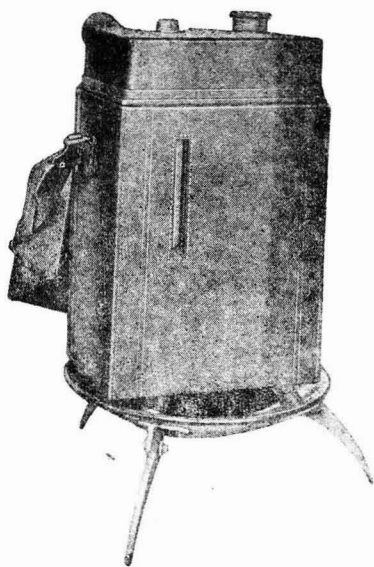
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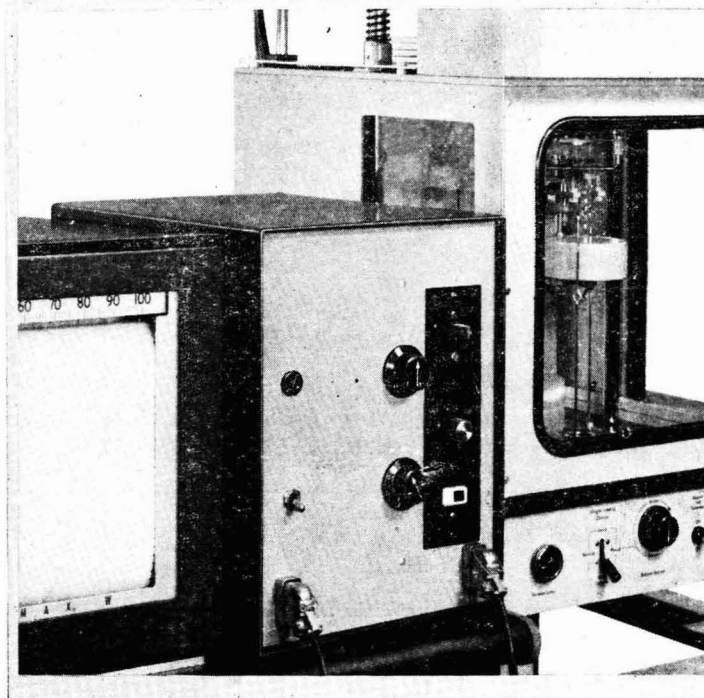
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