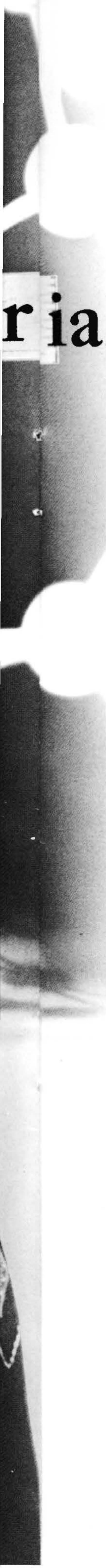
Mater



r ials Research at Bell Laboratories

An Enterprise in Versatility

An Interview with Dr. Bruce Hannay
By Mrs. Maria Hakki, Assistant Editor

"Throughout history, man's capabilities have been largely limited by the materials at his disposal," observed Sir George Thomson recently. The well-known British scientist and Nobel prize winner also pointed out that civilizations are both developed and limited by materials, as indicated by the names of various periods; to wit, the Stone Age, the Bronze Age, and the Iron Age. Perhaps we are on the brink of a new age, the New Materials Age–in the last few decades we have witnessed the industrial application of a great many materials that half a century ago existed only as chemical curiosities, or not at all.

Bell Telephone Laboratories has had quite a role in bringing about this era of New Materials. The list of new materials discovered by scientists at BTL is impressively long and constantly growing. But the question is: What is the broader role of materials research in an organization whose main concern is communication–the design and improvement of incredibly complex networks of telephone and data transmitting systems? How does materials research relate to the everyday problems of the Bell System? What is its impact on the future potentials and problems of the Bell System? With these and other questions in mind, we decided to visit the man most likely to know the answers–Dr. N. B. Hannay, Executive Director of the Materials Research Division.

With Bell Laboratories since 1944, Dr. Hannay has been active in chemical, semiconductor, and chemical physics research. He was appointed Director of the Chemical Research Laboratory in 1961, and assumed his present post in 1967.

Our first question was aimed at the heart of our visit's purpose:

Q: *Dr. Hannay, could you come up with a simple explanation of the fundamental purpose of your division in the Bell System?*

A: The Bell System has a tremendous stake in materials. Western Electric's materials purchases amount to some hundreds of millions of dollars each year, and of course the products of their manufacture are worth far more. It is vital that we base this program on designs that use the best possible materials, and in the most efficient way. The performance and life of our equipment will be determined by the materials used in the construction. It is the responsibility of the Materials Research Division to see that the Bell System has available to it all the benefits that can be gotten from modern materials research. Yesterday's answers won't do for tomorrow's problems—or even today's.

Q: *This is indeed a very serious challenge . . .*

A: Yes . . . it means that we have a responsibility for current development programs, but it also implies responsibility for the long-range technological future of the Bell System, at least for materials.

This latter is a general responsibility common to all parts of the Research Area. We know that the technology of the future depends on the new science of today. The classic example of basic research initiated long before the application became apparent is, of course, the transistor. Back in the 1930's a management decision in the Physical Research Department launched a major effort in solid-state physics, which, at that time, was considered a rather peripheral branch of physics. This decision ultimately led to the invention of the transistor, at the end of 1947. The transistor, of course, became the cornerstone of solid-state electronics, the basis for all modern communication systems. In the light of these events, it is very easy today to see that *that* decision was right—but it was far from obvious in the 1930's.

Q: *I wonder what decision today would have the same impact 20 years from now . . .*

A: We in the research area are constantly thinking about that. We want to be sure that we don't overlook the areas of research that will turn out to be critically important to us 10 or 20 years from now.

Q: *I would not want to put you on the spot and ask you to commit yourself, but could you indicate some of these areas?*

A: Two of them, I think, are materials science and the computer sciences. The significance of materials science is underlined by the realization that more and more our technology is going to need materials with properties superior to anything we now know. Computer sciences are, of course, also playing an important role in communications already—witness electronic switching—but it does not take much imagination to see a greatly expanded future role. Our BTL research ranges very widely, in laying the foundations for the long-term future of communications. It extends into such diverse fields as nuclear physics, biophysics, and the behavioral sciences; and, of course, solid-state research and other research areas will continue to be tremendously important.

Q: *What about the needs of the Bell System today, in materials?*

A: Coupled with long-range responsibilities the Materials Research Division also deals with more immediate problems. We serve as consultants to the development areas, we are concerned with the materials and processing problems of the Western Electric Company, and we even get involved in maintenance problems of the Operating Companies. A considerable part of our effort is devoted to short-range problems.

The Materials Research Division is rather unique among the divisions of Bell Laboratories. It represents a kind of microcosm of all activities at BTL. Basic long-range research, applied research, development, engineering—we run the gamut of activities.

Q: *Then, this implies competence in many levels. Can an individual fill all of these roles?*

A: Not usually. We rely on the interaction between research people and applied people in our organization, although some individuals can play both roles. Also, materials research is really an interdisciplinary science. It is a joint effort of chemists, metallurgists, physicists, mechanical engineers, ceramists, and others. And this is a very healthy and beneficial combination. The interaction of these different disciplines stimulates new thinking and helps create new materials and applications.

Q: *You mentioned a few minutes ago the importance of discovering new materials. For the uninitiated, this responsibility would seem difficult to handle. After all, how can you decide: 'today we're going to find a new material'?*

A: Obviously this is one of our major functions. People not in the business think that the discovery of new materials is a very mysterious process, and sometimes it is. It takes a lot of insight into the fundamental bases for materials properties.

Ideally, synthesis would start out with a list of all the desirable or needed macroscopic properties—properties like electrical conductivity, light absorption, modulus, and so forth—and then use fundamental principles to put together the right atoms in the right structure to achieve these properties. Usually we don't know enough to do it quite this neatly, and we have to add in some intuition. The difference between success and failure lies in being clever enough and experienced enough to decide which relationships are important and which are not, and on this basis to narrow the search to the most promising materials. After all, there may be 10 million or so chemical compounds, and it would obviously be impossible to try them all. So perhaps it's an alchemy of science, intuition, luck, and hard work.

Q: *I imagine the ability to do this plays a critical part in establishing the future technological position of the Bell System.*

A: Yes. Consider, for example, the field of optical communications, which is of intense interest to the whole research area because of the enormous bandwidths that are possible, in principle. We might be able to build such a system right now, but it would be much too expensive—it would not be economically competitive with existing alternatives.

The achievement of an economically attractive and technically practical optical communication system clearly requires better materials—for tunable laser sources, beam modulation, transmission paths, detectors, and so on. We may then have to solve some other problems, such as switching, before we have a system, but right now the problems are materials limitations.

Q: *How far are we along this road?*

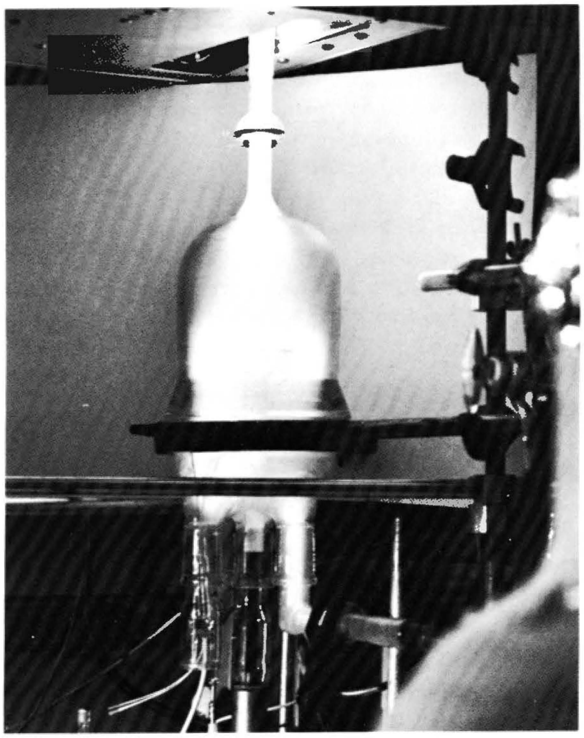
A: We have discovered some important new optical materials in the Materials Research Department in the last two or three years.* We hope to continue to lead the way with still better ones. Among our new laser materials were calcium tungstate doped with neodymium ($CaWO_4$:Nd), which gave the first continuous solid-state laser operating at room temperature, and yttrium aluminum garnet doped with neodymium (YAG:Nd), the material with the lowest threshold for continuous room-temperature operation. We have the most promising nonlinear optical materials, such as lithium tantalate and barium strontium niobate for modulation of the light beam, and lithium niobate and barium sodium niobate for harmonic generation and tunable parametric oscillators. There are other interesting new materials coming along also, such as the iodates and tellurium.

Q: *The process of "studying the fundamental properties of materials" is another one of those research activities that are sometimes difficult to relate to some practical situation, or to see the practical benefits . . .*

A: It may be difficult—at least for the uninitiated—to appreciate the potential practical benefits of a research project at the start but of course we're really looking for the longer term benefits. Perhaps we can make this clearer with an example—let's take fundamental studies of crystallization behavior. A material we have been using in large quantities for many years is polyethylene, even though we haven't known until recently much about its solidification pattern, or "morphology." Several years ago we began to study this

*The Search For Nonlinear Optical Materials For Laser Communications, RECORD, January 1968.

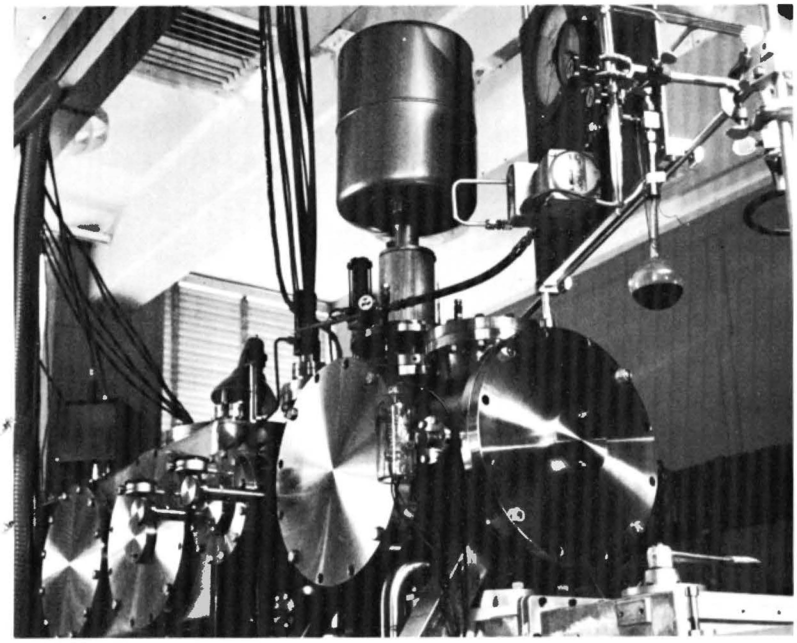
Injected into a mixture of water and glycerine, the swirling pattern of colored ink simulates the way most liquids would behave during a widely used crystallization process (called the Czochralski method). The copper rod barely touching the liquid surface simulates the already solidified crystal portion. Both the crucible and the cylinder can be rotated independently in either direction and at different speeds, and the ink pattern depends on the combination of rotations. By observing the flow pattern, scientists can predict, for example, the distribution of impurities in the solid, and thus find ways to control it.



The technologies needed for the creation of thin-film circuitry include the means for producing insulating films. One of the novel ways of doing it is shown above. When an organic vapor in its basic monomer form flows into the glass jar containing gas plasma, their interaction causes the monomers to polymerize, and the organic material deposits as a thin insulating film. The process is simple—most any gas will do for the plasma, including nitrogen, oxygen, and argon (shown here)—and it is potentially useful for encapsulation or insulation in thin-film circuits. In this experiment a thin polymer film was deposited on a ceramic surface having beam leads.

intensively, and we now know a great deal about the extremely complicated way the molecules are organized in the solid. But the real point is that we now see a number of ways in which the important mechanical, electrical, and chemical properties depend on this morphology, and we also know ways to affect the morphology, so we're in a position to begin to "tailor-make" properties.

Similarly, basic studies of crystallization in inorganic materials will have long-range consequences of practical importance. Most of us are already fully aware of the fact that new and interesting electronic devices often depend upon crystals of new materials, but such things as metal texture also depend upon crystallization. Now, the performance of most of our electronic devices—transistors, integrated circuits, silicon camera tubes, solid-state lasers, optical modulators, etc.—depends on the quality of the crystal, i.e., the silicon or barium sodium niobate or whatever else is used. And the properties of metals depend upon their texture. Our fundamental studies are telling us why crystals grow



"Materials" not only includes solids but liquids and gases, as well. Responding to communication needs of the Bell System, materials people are also exploring the earth's atmosphere. The ability to bounce radio waves off the ionosphere and hence establish contact with points out of sight and over the horizon has long played an important part in long-distance communications. This molecular beam apparatus is vital in studies of the electrical behavior of simple molecules, including those populating the ionosphere and having significant effects on communications. It creates and characterizes excited energy states, called metastable states, of molecules, which occur frequently and may disrupt communications, but which are very difficult to study in the atmosphere because of generally short lifetimes.

the way they do, and something about the origin of a number of things we are going to have to control—not only the ways impurities are distributed through the solid, but also the stresses that reside in the crystal, optical inhomogeneities, dislocations of atoms within the crystal structure, and so on.

Now, why do materials crystallize in so many different forms? Let me tell you about some recent work that is really very important, as it has finally given us the key to why crystals grow the way they do, with facets, in flat plates, in dendrites, or in spherulites. One of our researchers found the answer by discovering that there is a certain thermodynamic property of each material that determines the way it crystallizes. He can reproduce all kinds of crystallization phenomena by taking transparent organic materials with different values of this thermodynamic property and crystallizing them—the transparency of the organic material lets him watch the whole process. On this same basis he can explain why crystallization of ordinary materials happens the way it does, and can predict the crystallization behavior of any material.

Still another recent discovery is a new crystal growth process—the VLS, or vapor-liquid-solid method. This has explained for us many of the mysteries of "whisker" growth.*

Q: *Does this mean that we have solved the problems of whisker growth on metals like tin and zinc that can be so troublesome in switching systems?*

A: For the most part, we understand the origins of whiskers. However, the VLS mechanism only applies to vapor-transport whisker growth. In other cases, we have identified very different mechanisms.

Q: *You pointed out that a considerable fraction of your division's time is spent on development and engineering-oriented activities. How do these fit into the concept of materials research?*

A: I might illustrate this point with an area that has long been of interest to us both scientifically and technologically. This is the degradation and stabilization of plastics.

We are using tremendous quantities of plastics, more than 200 million pounds each year, and it is essential that they have the life expected of Bell System equipment—typically 20 to 40 years.

Polyethylene is by far the biggest single material—by volume—the Bell System uses, and the major fraction of this goes into cable sheath and wire insulation. Without protective additives ordinary polyethylene would not last more than a few weeks when exposed to normal atmospheric conditions. Light and heat would break down its molecules, and the material would rapidly lose its essential properties.

We have studied the basic chemistry of the

*Mechanism of Crystal Growth Discovered, RECORD, April, 1964.

reaction of organic molecules with oxygen and have a good understanding of much of the degradation process. We have also been able to develop antioxidants and stabilizers, often in combination, that have enormously lengthened the usable lifetime of the plastics we use—for example, polyethylene in cable sheath will last for many decades.*

Closely related is the attack of ozone on rubber. Everyone has seen the telltale sign—a cracking of the surface. It is particularly bad where the ozone concentration is high, as it is in areas with heavy smog. We have recently begun for the first time to unravel the fundamental chemical reactions occurring between ozone and rubber, and this immediately led us to the development of new antiozonants.

Another very broad area that illustrates our applications-oriented work is ceramics. A nice way to think about our involvement in it is in terms of the control and the understanding of ceramic microstructure. Ceramics are used in the Bell System in many different ways—ferrite cores for twistor memories, substrates for integrated circuits, transducers for ultrasonic delay lines, etc. In most applications the properties depend critically upon the microstructure.** Only by controlling this microstructure can we optimize the material. This has led us to study the chemical preparation of the starting materials, as well as a variety of fabrication methods. Our recently developed "freeze-dry" process,*** for example, insures an unprecedented degree of uniformity in chemical composition and in particle size, and this leads in turn to greatly improved ceramic bodies. We expect this freeze-drying method to become very important for preparation of ceramics with maximum performance requirements. Western Electric people are already looking into it.

Q: *Is the Materials Research Division really involved in processing problems, or was the discovery of the freeze-dry method a lucky accident?*

A: By "materials" we really mean "materials and processes," and we are often deeply involved in the basic aspects of bulk processing. This is what led us some years ago into the discovery of such things as zone melting and epitaxial methods for semiconductors. We have many current examples of research on bulk processes, including such diverse areas as polymer extrusion, the sources of texture in magnetic alloys as they are processed, diffusion in thin films, and many others. This work complements that at the Western Electric Engineering Research Center, in Princeton, N. J., which has the responsibility for specific processes that relate directly to their manufacturing needs.

Q: *How do you relate to development areas in activities that are clearly of interest to them?*

A: We cooperate very closely with our development areas, and with Western Electric also—it is essential that we do so. Our responsibilities often include the specification of the materials the development organizations use in their designs. Thus we have generated the technical requirements in the specifications for the plastics purchased by Western Electric for telephone handsets and wire insulation, for adhesives, for aluminum in aluminum conductor cable, and for thousands of other materials.

Q: *How does this cooperation work out in practice? Are there any difficulties in dealing with groups scattered all over the map of the United States?*

A: Often the first step is taken by the development areas. They come to us and tell us their needs and requirements, and we work with them to develop the materials to satisfy these needs. We consult with the people in Indianapolis on materials for station apparatus, with Baltimore on wire and cable, Columbus and Hawthorne on switching equipment, and so forth. In other cases, the first step is taken by us, when our research results suggest possible applications.

As far as the geographical separation goes, we use the telephone and airlines to solve that problem. Some of our development friends are, of course, near at hand, in New Jersey locations. In one instance, Switching Development has a small group located here, with a major purpose of maintaining close working relations between us. Here we are concerned with electrical contact performance, including films on contact surfaces, as well as arcing and erosion phenomena.

Q: *Does your involvement with development people end when the materials are specified?*

A: It would be nice if we could say that everything always works out the way it was planned.

*Aging Problems of Plastics, RECORD, May 1968.
**Controlling Ceramic Microstructures, RECORD, May 1965.
***Very Pure Ceramics Prepared by "Quick Freezing," RECORD, May 1967.

But problems do develop, in manufacture and in the field. It is part of our job to help solve these problems.

Q: *Assuming these do not arise, do the responsibilities of the Materials Division end as soon as the product is in manufacture?*

A: No, because we are continually looking for ways to help Western Electric make things more efficiently and less expensively. Let's take drop wire as an example. It is used to connect telephone cables to homes and other individual locations. It is made with a double extrusion. The first puts a rubber coating on the wires, and provides the necessary electrical insulation. The second extrusion puts a neoprene jacket on top of the rubber to add other required properties —abrasion resistance, weather tolerance, etc. This drop wire is perfectly satisfactory—it gives quality performance and is quite trouble-free. Drop wire could be regarded as a solved development problem. But as far as Western Electric is concerned, the book isn't really closed on any job if there is a possibility that it can be done more cheaply. For this reason we've been developing a new version, which will use a neoprene that allows a greater use of fillers such as oils and other low-cost materials, and thereby reduces the cost. This could lead to an estimated half-a-million dollars saving a year for Western, without changing the basic wire design or its performance.

We also have other studies in the mill that could eliminate one of the two extrusion steps, and this might lead to even larger savings. Two approaches look promising. One involves the use of a rubber compound (ethylene-propylene diene monomer, or EPDM), the other is based on a plastic (polyvinyl chloride, or PVC).

Q: *Your people really seem like jacks-of-all-trades—research, development, and engineering. I presume that in many instances they also have to design their own test instruments . . .*

A: Yes, our research people often devise test equipment. And sometimes these items find their way to Western Electric. One of our people built a device that uses fluorescent X-rays to measure metal film thickness, because we needed an analytical facility of this kind. However, Western Electric also is very interested in the measurment of film thicknesses, to control such operations as electroplating. We therefore adapted the instrument to make it suitable for

"The Materials Research Division is rather unique among the divisions of the Bell Telephone Laboratories. It represents a kind of microcosm of all activities at BTL. Basic long-range research, applied research, development, engineering—we run the gamut of activities."

factory use, and it has gone to Western Electric. Eventually we even hope to make it a part of the production line, to provide an automatic check on electroplated parts. This could mean a lot to Western Electric, as it has always been a problem to monitor the thickness of electroplated layers rapidly enough to provide effective control over the process—and this is one area where it is particularly true that better controls are needed to improve the quality of the product and reduce reject rates. This is the kind of cooperation that helps reduce the gap between laboratory and manufacturing processes.

Q: *There has been a lot of talk recently about materials shortages . . . would you like to comment on the expected impact of these on the Bell System?*

A: Except in a few isolated instances, I think that they are not likely to be serious. The most conspicuous example is copper, and there could conceivably be others, special materials such as palladium, which is used for electrical contacts. The supply for most of our large volume bulk materials is really not threatened, and by and large the materials used in electronic devices are used in relatively small quantities.

We are, however, concerned about the copper situation, and there has been a substantial effort in the development area to meet this problem. The approach has been to develop an aluminum conductor cable, and it has now reached the field-trial stage. Our metallurgists have been heavily involved, with the responsibility for finding a suitable aluminum alloy and processing cycle to achieve the needed combination of mechanical and electrical properties. This has been accomplished in cooperation with the aluminum industry. This illustrates another point about our applications work—we provide a link to the materials-producing industries, and often work closely with them in the development of products we need.

Q: *The scientific community has often been accused of giving a cold shoulder to problems facing our whole society, including such much-publicized ones as air and water pollution, and urban problems. Is there any work in this division that could help in these areas?*

A: We are involved in these areas indirectly, but the impact of our work could be large. For example, consider air pollution. Ozone reactions are very much part of the smog problem, and I mentioned earlier that we are doing some pioneering work on these reactions. Even more broadly, we are concerned with understanding and controlling photochemical reactions of air and hydrocarbons—and, basically, smog originates in reactions of this kind. Or take housing. Our work in the stabilization of plastics has led the field, and this could eventually have broad implications for low-cost housing materials and urban development. And, of course, there are many other similar situations.

Q: *Is all the materials work of Bell Laboratories in your division?*

A: By no means. In the components area a very substantial number of people are concerned with the development of materials and processes for electronic devices. Their work and ours are complementary, and we cooperate closely in many ways. Materials and processes are really quite inseparable from the component development for which they are responsible, and this is clearly shown by the fact that one of the three divisions in the Electronic Components Area has as its responsibility materials and processes related to electronic components. Other development areas sometimes have small internal materials groups and they look to us for continued strong support in materials.

Whatever the application, materials research is basic—after all, everything we make is made of something, and we are always going to be concerned with that something—making it better, or cheaper, or so unique that it allows us to do completely new things.