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BY GEORG VON BÉKÉSY

FEEDBACK PHENOMENA BETWEEN THE STRINGED INSTRUMENT AND THE MUSICIAN

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STRINGED INSTRUMENTS are probably the most sophisticated music-producers ever developed. Their correct handling demands a tremendous knowledge and a memory of many different factors. But before I talk about stringed instruments and the musician, I would like to introduce myself.

I am a biophysicist. I do not play any stringed instrument; I am not a hi-fi fiend; I seldom watch television; I go to concerts only a few times a year. I am definitely a laboratory man. Being mainly interested in the physiology and psychology of the ear, I have had difficulty understanding why some violins can be bought for $25 and, on the other hand, why some have been sold at auctions in London for $25,000. An art collector will pay for the name of the artist when he buys a painting. But a musician may be willing to pay only 30 per cent of the price for the name of the artisan who made his instrument and the remaining 70 per cent for its musical qualities. It is, therefore, quite natural for a physicist to want to investigate the physical differences between two violins that vary widely in price. Can these differences be put down in numbers? To what degree are they consequences of psychological and physiological phenomena?

Today, if we want to solve a problem, we usually start by forming a team complete with an office, an administrator, and a secretary. But the sophisticated violin was developed about two hundred years ago by a few individuals, and the instruments were manufactured by their families. It has been impossible, during the last hundred-and-fifty to two hundred years, to improve on or even to approach the quality of violins of the Stradivarius or Guarnerius type. This is particularly surprising because the material used is wood. Today such a wide selection of materials is available that it is of great interest to discover why wood is still preferred. In addition, the early, great violin makers had no physical measuring equipment and no theories on the nature of sound; their only criterion was the ear.

Now, stringed instruments must first satisfy the performer; second, the conditions of the concert room; and third, the listener. These three requirements ask for very, very different achievements from exactly the same instrument. That the violin was able to satisfy these various demands is extraordinary.

Viola da gamba LEFT *by Ventura di Francesco Linarol, Venice, 1582; lute* RIGHT *by Andrea Harton, Venice, ca. 1515; from the exhibit for the Conference on Scientific Aspects of Stringed Instruments.*

The Capabilities of the Human Ear

Even today, in a period of almost unbelievable development in methods of transmitting information, the human ear can still be considered an impressive organ. It has a threshold so low that it almost competes with the best microphones. The vibrations the eardrum can detect are smaller than the diameter of some molecules. But, in spite of this tremendous sensitivity, the ear is able to stand a sound pressure of the order of 1 gram per square centimeter. This incredible range of correct functioning is seldom reproducible in even the most modern electronic equipment. Very little internal noise disturbs the

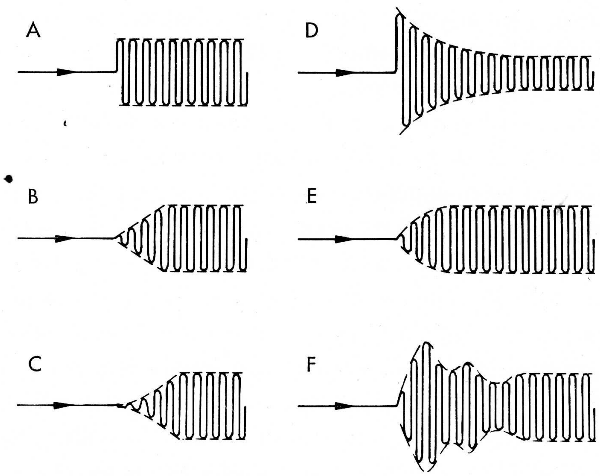
transmission, and very little distortion is produced during the perception of pure tone.

Another feature of the ear is frequency analysis. It can pick up one particular sound from a large set of sounds, and sometimes can determine pitch in a time interval much less than a hundredth of a second. It can follow in a few milliseconds the onset of the sound produced by an instrument, and also the decay of that sound. Thus, besides a pitch analysis, the ear also performs an onset analysis.

There are some small variations in sound amplitude for which the ear is extremely sensitive and which we can call "roughness." This roughness plays an important role in judging the quality of sound and the quality of instruments. Furthermore, the ear can precisely localize sounds with a high pitch. The click, for instance, is sharply localized as to the direction from which it comes; it is not so sharply localized as to distance. But localization of a sound source seems to be something so basic in human hearing that we seldom make a mistake, even under difficult conditions — as, for instance, when we are enclosed in a room with walls that reflect sound. The ear has this potential because it is able to inhibit phenomena that come later. In this way it can pick out the first sound-intensity change that reaches it.

A few decades ago it was discovered that the difference between a flute and a violin consists mainly of a difference between onset and decay phenomena. If we cut out from a tape all the sections in which the sounds start and leave just the continuous tone, it becomes difficult to discriminate between the two instruments. Furthermore, physiological experiments all seem to indicate that the human nervous system is triggered mainly by changes. For instance, electrical recordings from the cortex show very little activity for a pure tone. Any change in pitch or amplitude immediately produces electrical potential changes.

The different types of onset phenomena can be seen below. A represents a sudden start of a more-or-less periodic vibration. B is a continuous linear onset to a certain amplitude. C is an onset that starts slowly and then rises fast. D is just the opposite — it starts with a large amplitude and then drops. E is an onset that starts rapidly and then stays constant. The F onset phenomenon is the type generally found in instruments. It is either a combination of all the five types or of some of them. This last is the type we have to consider in judging the quality of stringed instruments.



The different forms of onset of the sound pressure of a pure tone.

To investigate musical instruments we need as simple an onset phenomenon as possible. The easiest way to produce it seems to be to pluck a string. The top photograph on page three shows how the vibration amplitude and the sound produced by a cheap violin change with time after the string is plucked. It starts with a large amplitude; then, since amplitude is related to energy, it decays rapidly with time as the energy is dissipated. By recording this type of amplitude decay, we can analyze many important qualities of the stringed instrument.

At the conclusion of The Rockefeller University Concert Series this spring, a conference was held on Scientific Aspects of Musical Stringed Instruments, with a concurrent exhibition of rare 16th-18th century Italian instruments from the Laurence C. Witten Collection. The conference — which was organized by Professors Theodore Shedlovsky and Gerald M. Edelman — explored the history, acoustical aspects, and new experimental designs for the violin family and the guitar. These were played and their qualities were compared. The role of sensory feedback and inhibition in judging the quality of a musical performance was discussed by Nobel Laureate Georg von Békésy, Professor of Sensory Sciences at the University of Hawaii, who is the author of this article.

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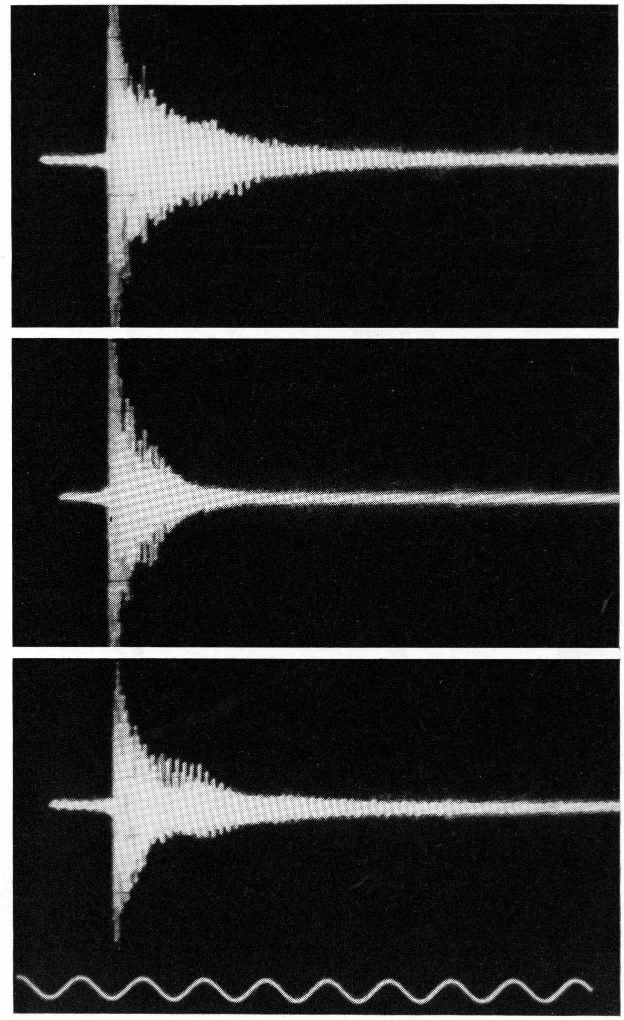
In the upper recording, at the right, the string was plucked without a finger on the string. In this situation, the plucking supplies the string and the whole violin with a certain starting mechanical energy, which diminishes with time. The loss of mechanical energy is partially due to the sound radiation of the violin. In addition, it is caused by loss through friction. We have friction in the string itself; we have friction in the wood of the whole violin. By studying the decay times of various violins, we can determine how much friction is present in different instruments for different situations at different frequencies.

If we put our finger on the string, we immediately introduce one more friction — that of the fingertip. This friction absorbs quite an amount of energy. It is interesting to observe various people and to compare decay times when they touch the same string in what seems to be exactly the same way. By simply recording the decay of the sound near the violin we discover that every musician has his own touch. That touch is not always exactly reproducible, but each individual can develop it to become typically his own style.

The energy loss produced by friction in the violin is unimportant to the listener — he is only interested in the energy loss produced by radiation. Now, the loss by radiation in most stringed instruments is small. There are many ways to determine this loss — the effective part of the whole mechanical process. In a highly reverberant room we can measure the whole sound output produced when a violin is plucked. We can also calculate the amount of energy transmitted from the violin to the room.

A second method, which, in many cases — especially in the laboratory — is more simple, consists of putting the violin in a vacuum, where there is no sound radiation, and plucking it. By comparing the decay time of the plucked string in the vacuum with a plucked string under normal conditions we can determine how much energy per second is radiated into the air.

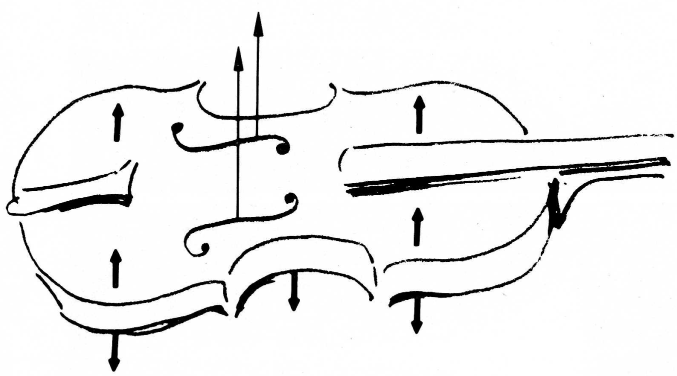
The wavy line at the bottom, right, represents a time scale. The distance between two maxima represents two milliseconds, and it is surprising to see how long a string vibrates until it loses its energy. The question now arises: "Is the ear able, in these few milliseconds, to determine the difference between different decay shapes?" Maybe one of the best ways to find out is to pluck the eardrum, just as we did the string. This can be done easily on the ear of the human cadaver. By using a different method we can do the same thing on a living person, and the decay curve looks very similar. It is surprising that the decay time is so short. The period of the vibrations is one millisecond, and in three or four milliseconds the amplitude drops strongly. This means that any energy stored suddenly in the middle ear is absorbed very quickly. Thus we can say that the damping of the ear is much stronger than that of stringed instruments, and that, as a result, the ear is able to detect and to follow changes of amplitude during even the short decay time of a plucked string.



The sound pressure of the violin produced by plucking a string. The middle recording shows the same string plucked with a finger pressed on it. The bottom recording is the same as the middle one but for a different performer.

It is a physical problem to find out why the violin's

energy loss through radiation is relatively small. The kind of violin vibrations a physicist would like to have is seen schematically below. The two sides of the violin body vibrate in opposite directions so that the surrounding air is pressed simultaneously out and in around the whole violin. The same holds for the sound produced and forced out through the two sound holes. This is called a "pulsating" vibration. No violin does this. Therefore, the sound radiation of the violin is always less than we can obtain in the optimal condition shown below. In general, one part of the plate vibrates in the opposite direction from another section of the plate. The air then will only be pushed from one side of the plate to the other, and will not be forced outside into the room. This reduces the over-all radiation for that particular vibration.



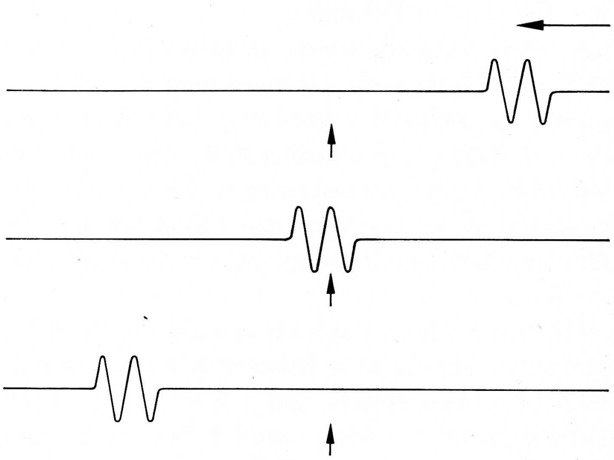
The ideal vibrations that would produce the maximum sound pressure.

These vibration patterns are different for different frequencies, which is why the radiated energy of some violins changes to a large degree with the frequency of the string vibration. The ideal violin represented above would radiate about the same way for all frequencies, or at least there would be a continuous change in the amount of the sound emitted with the frequency. But if vibratory nodes are formed, there are disturbing peaks. I have the impression that the good violin differs from the poorer violin in that its peaks are much less pronounced. Different sections of the panel can vibrate almost independently, so the energy loss and the radiation of the violin are complex phenomena. One section of the violin may have a pronounced resonance frequency which picks up parts of the energy from the neighboring sections of the vibrating wood. Therefore, it is difficult to damp.

Immediately the question arises of how it is possible for the ear to have such highly developed damping and no problems of long decay time. The reason for this exceptional quality is that there are traveling waves in the ear. These waves run along the basilar membrane where the hair cells with nerves are located. A traveling wave has most peculiar features. Waves traveling along a rope are illustrated below for two single vibrations. They move along with a certain speed, from right to left. Only the section with the two vibrations contains the vibrating energy, and this energy moves along the rope. Therefore, if we fix our attention on one section of the rope we can see that, at the moment the two vibrations arrive, we immediately have the full onset of the vibration; after the vibrations have passed that section, the section's whole energy disappears. Therefore, we have an almost immediate damping. This unique feature of the traveling wave enables the inner ear to follow the fastest changes in the sound produced by the stringed instrument.

Capabilities of the Violin

A violin cannot utilize all the potentials of the human ear. Its range of sound intensity is much less than the sound intensity the ear can discriminate. The same holds for the frequency range. The ear is made so that it is insensitive to low frequencies. In the range from one thousand cycles to fifty cycles the



Schematic drawing of a wave traveling along a rope.

sensitivity drops about ten thousand times. This drop is necessary for the ear, because, if it were not so, we would hear our own pulse with a tremendous intensity. The blood flow through the inner ear cannot be reduced; if it were possible, the nerve system in the inner ear could not be supplied with the necessary oxygen, and so on. Therefore, there are capillaries in the inner ear through which the heart beat is transmitted to a certain degree. Because of this, the inner ear must reduce its sensitivity, and nature has developed maximal sensitivity for the higher frequencies; in this range no heart sounds are transmitted to the ear.

As a consequence, the stringed instrument must produce a large sound pressure for lower frequencies; that pressure is determined by the number of liters moved per second. A small violin is not able to produce enough sound, so a larger instrument is needed. As a result, a series of stringed instruments has been developed – the violin, the viola, the cello, and the double bass. From the physical point of view, this was the only way to extend the high performance of the violin type of instrument into the lower frequency range.

To make the string vibrate with a bow seems to be an extremely simple exercise. Physically, it is one of the most complicated. The vibrations are produced by friction between the string and the bow. Primarily, the so-called starting friction determines the vibration amplitude of the string. This starting friction is that between two solid bodies, such as the string and the hair, when there is no relative displacement. A force between the two solid bodies is needed to release their contact. This is a surface phenomenon with sheering forces that depend on the roughness of the surface, its adhesion, and many other factors that are not completely understood, even today. (Little research has been done in this field.) It is primarily the starting friction that determines both the smallest sound we can produce and the largest vibration amplitude, for the speed at which we can move the bow has a relatively small range. I think the range produced in vibratory amplitude is not only defined by the quality of the violin, but is also dependent on the musician and his ability. I almost feel it can be used to discriminate between a beginner and a well-trained musician.

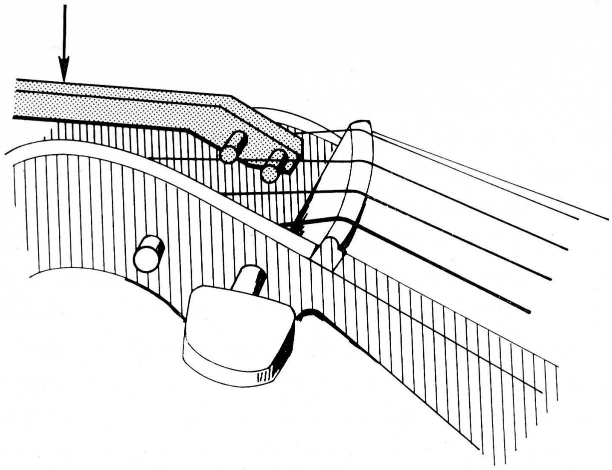
The simple fact that the maximal vibration amplitude is determined by the friction and by the maximum speed with which we move the bow gives a certain limit to the radiation the violin can produce. If we must fill a whole concert hall with the sound of a violin, it is of utmost importance to make sure of the direction in which the sound is radiated. If it radiates straight to the ceiling, where we may have some sound absorption, the audience will hear much less than if it radiates only horizontally, exposing the audience to the sound waves equally. From this we can see that we expect a good violin to radiate in a certain more-or-less restricted horizontal angle. Furthermore, this limited angle of radiation should hold for all frequencies – something that is hard to achieve – and a good violin is one from which the radiation angle does not vary too much with the frequency of the sound. An even more complicated matter – which, as far as I know, has not really been investigated – is the radiation of the transients, since they seem to be so important for the quality of performance. This applies especially to large concert halls.

Feedback Between Violin and Musician

Just as when we speak, sing, or walk, the performer adjusts his muscle behavior to the sensations produced on the surface of his skin and to the sounds he hears. This is highly important in violin playing, because it leads the artist to alter the frequency, his finger pressure and movement, etc. Therefore we have a constant interaction between the musician and his instrument.

We would like to think that this interaction is an almost instantaneous feedback. Naturally, the feedback in a living system takes a certain amount of time; the fastest takes about 0.2 seconds. This does not depend too much on training. What does depend on training, however, is a violinist's ability to tell the direction in which to make the adjustment. It is well known that if a small frequency change of a pure tone is produced, that change can be recognized easily. However, it is not possible to say in which direction it was made. Was it an increase or a decrease in pitch? A much larger change is required before we can identify the direction of the pitch change precisely and quickly.

To a certain extent, we can test the ability of a musician by asking him to play a tune with a constant



The use of a lever permits sudden change in the longitudinal tension of a string.

loudness and a constant pitch. It is surprising to what degree a tune can be kept constant by good musical technique, even when played on a poor violin. It is largely the speedy action of the ear that makes the precise feedback condition so effective.

The feedback relation between the musician and the violin can be investigated further by using the equipment shown above. A lever is installed on the left side of the peg box in such a way that a small rotation of the lever will produce a longitudinal stress on the string as it runs between the pins. By pressing the lever down sharply, we can suddenly increase the tension of the string. In this way we can change the pitch of the produced sound without any movement of the fingertip. We can ask the musician to keep the pitch constant by compensating the change of string tension by an appropriate finger movement. These tension changes can be produced very neatly at given time intervals by having the lever moved by an electrodynamic device.

The result of such small changes and their compensation by the feedback system are interesting, because they indicate clearly that the smallest change immediately produces a large variation of the whole system. The figure at top of page seven shows the variation of the sound pressure and frequencies when the lever was pressed down suddenly.

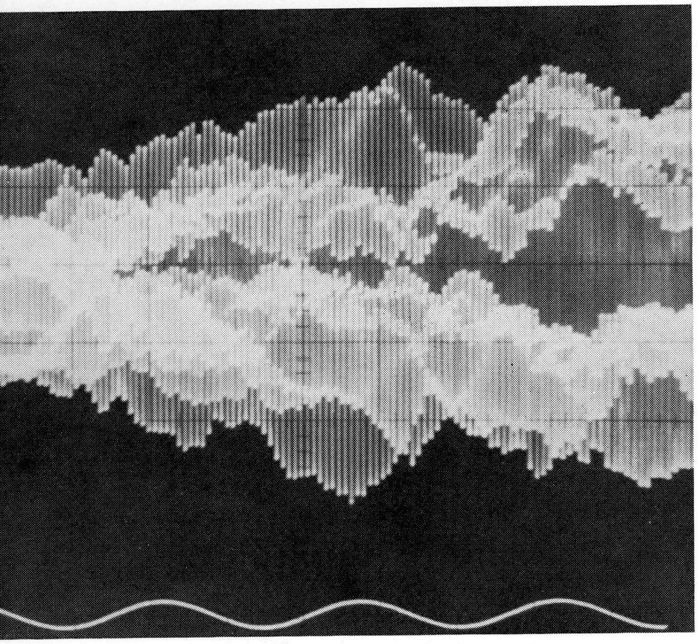
A poor violin was used, however. With a good violin and a musician with long training the changes are less. This is because the good violin has fewer resonance peaks; therefore the amplitude and the frequency changes occur in a more continuous way. The variations can be recognized much more easily, because any resonance leads to a wrong estimate of the frequency. The modesty of this transient is always an indication of the good musical instrument and the good musician. The wavy line at the bottom of the figure is a time scale. The time difference between two maxima is ten milliseconds.

As several experiments have indicated, the investigation of the feedback, its time delay, and its overshoots and undershoots can be used effectively to investigate the fitness of the performer and his speed, especially if they are extended to different conditions and different frequency and amplitude ranges. We can develop a set of data that give us a hint about the violin and the musician. At the moment, there is no way to make an absolute judgment, but, by comparing ten different musicians on the same instrument or one musician on several different instruments, we can at least rank-order them according to the quality we expect them to have.

To demonstrate how this method of feedback investigation works, I would like to refer to a recording of the vibration amplitude in a piano body during a period of about a minute. (See page seven.) The recording at the top was made by a well-known pianist playing in a room that virtually lacked sound absorption in the walls. It shows an extremely large reverberation; therefore, the pianist played as softly as he could. The middle recording shows a reduced reverberation time; the pianist immediately began to play with a much larger vibration amplitude and adjusted it so that the whole musical performance seemed pleasant to him. The bottom section shows the results when we repeated the same recording in a room that was damped too much. The musician tried to compensate for the damped sound by playing louder, and the vibration amplitude increased. It is interesting that if the musician plays a simple, familiar piece he has time to listen to his performance and adjust it, so that the performance sounds relatively the same for different room dampings. In this case, the musician controls the situation completely.

However, if he plays a more difficult and less familiar selection, he cannot concentrate his attention completely on the acoustical problems of the room. Instead, he is concentrating on his performance. Therefore, he will not vary the vibration amplitude to the degree he would have done for a piece he knows well.

If we give him an extremely difficult section of a



Sound pressure produced by a violin at the moment the performer tries to compensate for a sudden change in string tension.

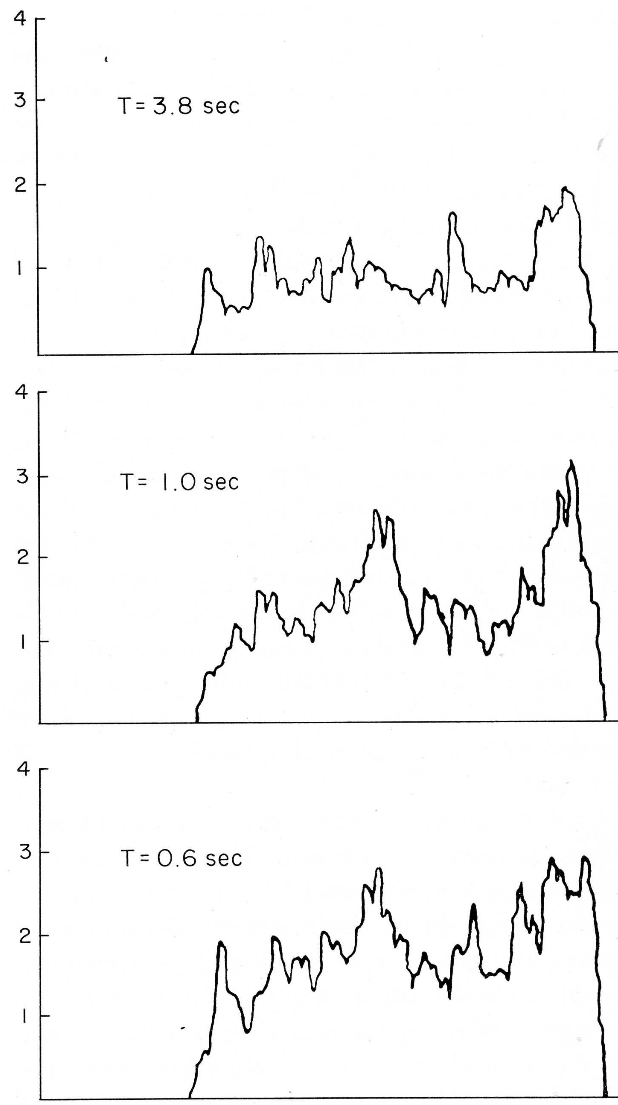
piece, he has no more time to listen to room acoustics, and there is no difference between the recordings of the vibration amplitude in a highly reverberant room and a highly damped room.

By repeating these observations, it was easy to find one number that was just difficult enough for the performer to control; he could adjust the important sections to the acoustical environment of the room. By comparing beginners and well-trained artists, we had no difficulty in rank-ordering them. The famous musicians always were able to adjust the vibration amplitudes to the room acoustics, whereas some beginners forgot the room completely after they had played for ten seconds. (I think you will agree with me that only scientists could test musicians so cruelly!) It is a peculiar fact that our rank-ordering was identical with the rank-ordering that the musicians themselves made regarding the technical abilities of each artist.

The Acoustical Delights of Small Changes

For physical experiments, it seems to be necessary to replace the bow of the violin with a friction wheel to produce enough constancy in the vibration of the string. By listening to such a sound produced by a friction wheel, the surprising and generally accepted feeling is that it is dull compared with that produced by a bow. From this we must conclude that completely constant sound production is not pleasing to our ears. We like small variations. Perhaps we would like to have the loudness stay constant, but we would also like to have the frequency spectrum change a little. These small changes make the tune alive and colorful.

The same situation exists in our reactions to paintings. We can dip our brush into a watercolor paint

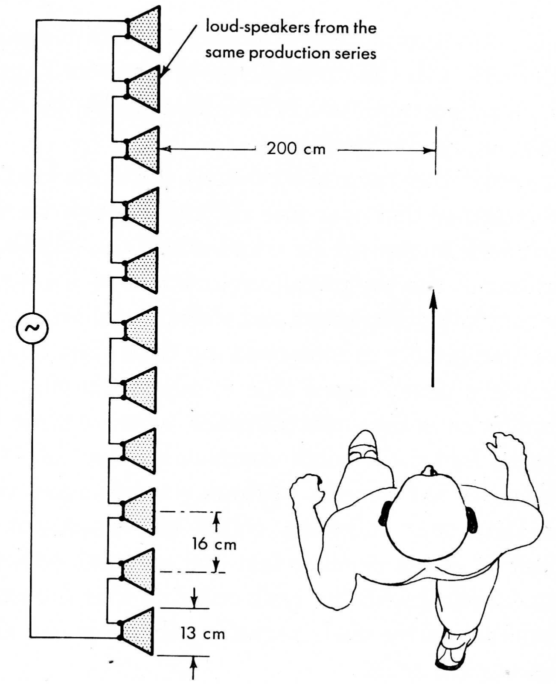


Vibration amplitude of a piano when played in rooms with different reverberations. The larger the reverberation, the more the pianist tries to reduce the force with which he plays.

and put it on paper with a single stroke. But a real artist does not do that. For instance, a Chinese artist puts a little India ink on one side of a tray; he then adds a few drops of water and produces a mixture that has more ink on one side than the other. He now immerses his brush in his peculiarly set solution and makes a stroke. The intensity of one side is already different from that of the other, but by further rotation of the brush he can make the whole stroke come alive. This effect can be enhanced by using India ink sticks that cost hundreds of dollars. Other sticks cost 59 cents, and the difference between them is that, according to the degree of dilution, the good stick changes its color. When it is very much diluted, the stroke has a bluish tint, but in a higher concentration the stroke appears more brownish. In this way, one stroke can produce a whole melody of discrete colors.

As I have already mentioned, the cortex apparently reacts more to changes than to a constant stimulus. But it is easy to realize that our interest in small changes makes it extremely difficult for a physicist to investigate a phenomenon properly. Most physical instruments work in a linear manner. Their indication is proportional to a certain input. This does not seem to be the case with living and thinking human beings, in whom small changes can produce large effects. I feel that a violin with steel strings does not sound as good as one with gut strings. The reason may be that the steel wire is mathematically, precisely round, whereas the gut is not. This tiny change in the roundness of the wire produces a change in adhesion and friction, so that it will alter the damping of the string. Naturally, an elaborate physical setup would be needed to record numerical values for these small variations.

To illustrate what a small change can do, I would like to describe an experiment. The sound output of the violin is relatively small, so we were interested to see how much we could increase the output by having several violins playing exactly the same thing. To duplicate that situation in the laboratory, we set up a group of loudspeakers in a highly damped room, as shown at right. All the loudspeakers were supplied by exactly the same electric current, were of the same size, and built by the same manufacturer. Even the manufacturing number was the same. The general opinion was that, under this condition, we would hear a sound that would have a large longitudinal extension — a sort of elliptical sound source. This was not the case. If a person stands next to that row of loudspeakers he hears — for all practical purposes — only *one* loudspeaker, and localizes all the sound into that single source. The apparent loudness of this one speaker is related to the number of speakers involved. If we move along the row, some peculiar phenomena are manifested. For instance, we receive the impression that someone is carrying a loudspeaker at our side. If we move faster, it moves faster, and, if we stop, suddenly the loudspeaker will stop, too. A highly sensitive person can be made extremely unhappy and nervous by being "followed" in such a precise way. However, if we now introduce a little change in the loudspeakers, the whole picture changes. When the speakers are slightly randomized, we are able to localize most of them separately. They do not merge into one loudspeaker. The same holds for a series of violins. We do not transmute all the violins into one instrument; instead they sound enlarged, as we know from listening to an



A series of loudspeakers does not produce a longitudinal sound image, if all the loudspeakers are equal and are supplied with the same current. But the smallest change in the loudspeakers can increase the operant size of the sound image, as is the case with a set of stringed instruments.

orchestra. The reason for this is that no violin plays precisely like another. This little change in phase and amplitude and in onset and offset phenomena alters the whole reaction to the sound source; a small, concentrated source is broadened to a widespread, flatter source.

There are many reasons why physics has difficulties in making useful contributions to the problems of music. One of them is of some special interest. If we produce a pure tone, as we can do today very easily with the sine-wave generator, that tone is completely defined in physics by three variables — sound pressure, frequency, and phase on the surface of the eardrum. If we listen with only one ear, the phase does not play a role, so we have only two variables to take into consideration — the sound pressure and the frequency. Therefore, the pure tone seems simple to describe physically.

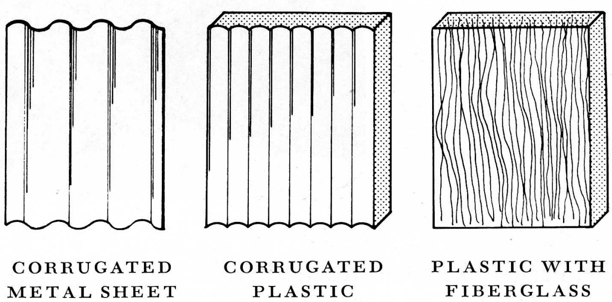
It is different if we ask an observer to describe the qualities of the pure tone. He will tell us a pure tone has a loudness; it has a pitch; it has a certain tone volume; it has a tone density; it has a smoothness; it has a certain range of pleasantness if it is not too loud and not too weak. Two ears can recognize a phase difference and localize a sound source. Therefore, the psychological observer has some six or seven variables by which he can discriminate a pure tone, whereas a physicist has only two or three. Naturally, we could say that the psychological variables are not independent; that there are only three independent variables. This is correct, but if we have, instead of one single tone, two tones together, the dependent variables will behave together in a complex way and will produce quite different sensations. This combination of dependent variables turns sound into music.

Music is far removed from the dull and tiresome sounds we can produce in a laboratory. However, taking all the dependent variables and their combinations together, we can produce a set of pictures of completely different patterns. This is at the heart of what makes music entertaining and interesting.

The New Possibilities

Today there is general agreement that a violin made by Stradivarius sounds better than modern violins. Therefore, it is not surprising that so many efforts have been made during the last two centuries to copy the fine, earlier instruments. Such attempts led to research on the nature of stringed instruments — research that has not yet been particularly fruitful. However — as so often happens — it is more difficult to copy something than to start afresh. It would seem better to try to make the best-sounding violin with readily available tools and materials.

As an admirer of old art objects, I feel that the continuous reverence for early violins has presented a handicap to the development of new instruments. I believe that with all the new plastic materials available we could construct panels with the qualities of earlier woods. Beyond that, we could produce qualities that would be unobtainable in wood, even with the most sophisticated fillers. We can change the density, the elasticity, and the inner friction, almost *ad libitum*. As shown below, we can imitate or even



Different possibilities of making the elasticity of the panel softer in the horizontal direction than in the vertical direction, as compared to wood with its well-developed fibers.

exaggerate the fiber structure of wood, so that the elasticity will vary in different directions. I am aware that modern methods and new products often cannot compete with natural materials. For example, the fibers in a spiderweb are objects of wonder even when compared with the best steel wire. But I do not think this necessarily holds for wood.

If we forget the history of violins and start building them as a new engineering problem, I am confident we will end up with instruments with magnificent sound qualities which may satisfy our musical taste even better than the old ones do. At the same time, I am sure they will not have the beautiful look and feel of a Stradivarius. That would be asking too much of an engineer. But the sound production seems to me to be a clear-cut research project.

DR. SEITZ TO SUCCEED

DR. SEITZ

Dr. Frederick Seitz, President of the National Academy of Sciences in Washington, D.C., has been elected President of The Rockefeller University. He will succeed Dr. Detlev W. Bronk who has reached the University's retirement age.

Dr. Seitz will take office as President on July 1, but will divide his time between the University and the National Academy until 1969, when he will assume his educational duties on a full-time basis. In 1962, Dr. Seitz succeeded Dr. Bronk as Academy President after the latter had served in that position for twelve years.

"We are privileged to have an outstanding leader of the scientific stature of Frederick Seitz as our new President," said Mr. David Rockefeller, Chairman of the Board of Trustees, in commenting on the election.

Dr. Seitz is a member of the President's Science Advisory Committee as well as of the Defense Science Board of the Department of Defense, whose chairmanship he held for four years until March 1st of this year. He is also a member of the Committee on the National Medal of Science, of which he was chairman in 1962 and 1963, and of the Naval Research Advisory Committee of the Office of Naval Research, a committee which he chaired from 1960 to 1962.

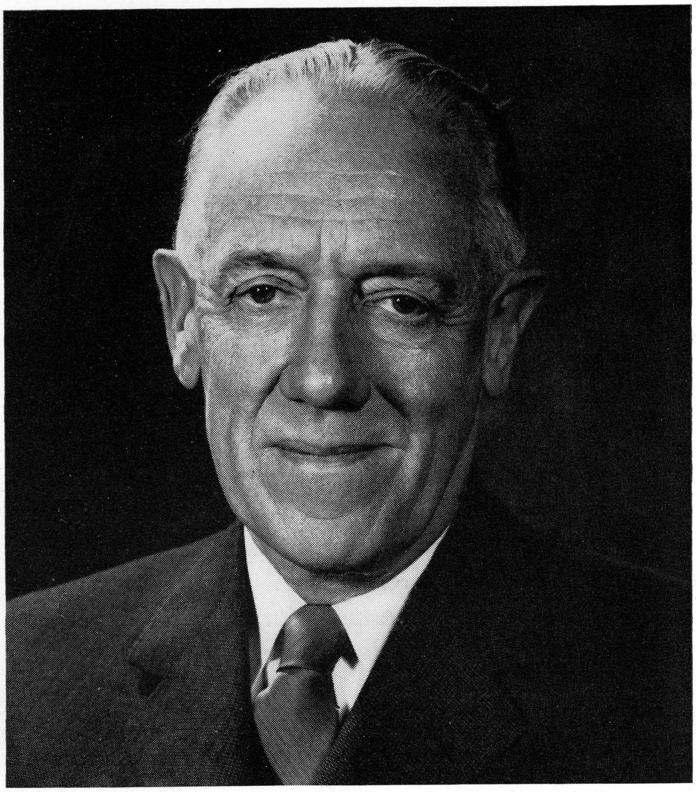
He served as Dean and Vice President for Research of the University of Illinois in 1964 and 1965 and was Science Advisor to the North Atlantic Treaty Organization (NATO) in 1959 and 1960. He is a Trustee of The Rockefeller University.

His major scientific research interest has been in the theory of solids and nuclear physics, and he is the author of *The Modern Theory of Solids,* published in 1940, and *The Physics of Metals,* issued in 1943. In addition, he is co-editor of volumes on solid luminescent materials and solid-state physics and is an editorial board member of several European physics journals.

Dr. Seitz is a member of the Governing Board of the American Institute of Physics, of which he was chairman from 1954 to 1959, and is a past president of The American Physical Society.

Born in San Francisco on July 4, 1911, he attended

ESIDENT BRONK



PRESIDENT BRONK

San Francisco schools and received the A.B. degree in mathematics from Stanford University in 1932. After receiving the PH.D. in physics from Princeton University in 1934 he remained there for another year as a Proctor Fellow. He has since served on the faculty of the University of Rochester, as a research physicist at the General Electric Company, as a faculty member of the University of Pennsylvania, as Professor and Chairman of the Physics Department of the Carnegie Institute of Technology (now the Carnegie-Mellon University), and as Professor and head of the Physics Department of the University of Illinois.

In World War II, Dr. Seitz was a civilian member of the National Defense Research Committee and a consultant to the Secretary of War, serving as director of the training program in atomic energy at the Oak Ridge National Laboratory in 1946 and 1947.

He is a member of the International Union of Pure and Applied Physics, the Committee on Science and Technology in Developing Countries of the International Council of Scientific Unions, the American Academy of Arts and Sciences, the American Crystallographic Association, the American Philosophical Society, the American Society for Metals, and the Optical Society of America.

His board memberships include many universities and foundations and he is a member of the Executive Committee of the Board of Trustees of The Rockefeller Foundation. He is a member of German and Swiss academies of science, Phi Beta Kappa, Sigma Xi, and Tau Beta Pi, and holds honorary degrees from 14 universities.

In announcing the new president's election, Mr. Rockefeller went on to say:

> In President Detlev W. Bronk we have an educational and scientific statesman who has transformed a famous scientific research center into an eminent university in just fifteen years. This has been the most constructive era in the history of the University.
>
> Dr. Bronk has had the ability to attract a most distinguished faculty and graduate student body so that The Rockefeller University is now regarded by many as a model of graduate education throughout the world.

President Bronk's career has been highlighted by his leadership in education, science, and government. He served as Chairman of the National Research Council from 1946 to 1950. In 1950 he was elected President of the National Academy of Sciences and held this position for an unprecedented three terms until 1962. During this period of time, he guided the Academy when it multiplied its activities and national influence in such vital matters as the biological effects of atomic radiation, the observance of the International Geophysical Year, important research in oceanography and astronomy, problems of scientific communication and research, transportation, and space science.

Dr. Bronk was one of the original members of the National Science Board, the supervisory group for the National Science Foundation, and served as its Chairman from 1956 to 1964.

He also was a member of the President's Science Advisory Committee from 1957 to 1963 and has served as Chairman of its Panel on International Science since 1957 and a Consultant-at-large since 1963.

The holder of 51 honorary degrees from colleges and universities in this country and abroad, Dr. Bronk is Chairman of the Board of Trustees of Rensselaer Polytechnic Institute and a Trustee of Bucknell University, The Johns Hopkins University, Rockefeller Brothers Fund, the University of Pennsylvania, and many other institutions. He is a member of seven foreign academies of science.

He has been given many medals and awards from governmental, scientific, and educational organizations in this country and overseas. Last Fall, Dr. Bronk received the Benjamin Franklin Gold Medal of The Royal Society of Arts from Prince Philip at the annual dinner of the Society in London. This was only the third time that the medal has been awarded to an American. It was conferred, Prince Philip said, in recognition of Dr. Bronk's many contributions to forwarding Anglo-American relations and to science, for which Dr. Bronk had already been decorated with the Order of the British Empire, elected to The Royal Society of London, awarded honorary degrees from Cambridge, London, and Belfast, and elected to honorary membership in many British societies.

"Detlev W. Bronk personifies the unity of all science," stated a citation of the City Club of New York in awarding its Distinguished New Yorker Medal to Dr. Bronk at its 75th anniversary dinner. "He achieved distinction as a physicist, biophysicist, and physiologist. He has served as the director and coordinator of efforts in all scientific fields. ...We salute him as New York's man of science."

Among his many honors, Dr. Bronk has received the Presidential Medal of Freedom, the nation's highest civilian honor, the Award for Exceptional Civilian Service of the U.S. Army Air Force, the Public Welfare Medal of the National Academy of Sciences, and the Franklin Medal of the Franklin Institute for distinguished contributions to the physical sciences, a medal also held by Dr. Seitz.

The Rockefeller University was founded in 1901 by Mr. John D. Rockefeller, Sr. "for the furtherance of medical knowledge and related fields of natural science." The University formerly was known as The Rockefeller Institute and, prior to that, as The Rockefeller Institute for Medical Research. In 1953, with the election of Dr. Bronk to the newly created office of President (he had been President of The Johns Hopkins University), an extensive reorganization took place.

The Rockefeller charter was amended by the University of the State of New York (the State Education Department) and given authority to grant doctoral degrees; in 1965 the name was changed officially to The Rockefeller University.

Under Dr. Bronk's guidance, the University established a graduate student body now numbering approximately 150 Fellows, and expanded research and teaching activities from the life sciences to physics, mathematics, philosophy, and psychology. The faculty has tripled in size and the ratio of faculty members to students is almost three to one. In addition, the endowment has doubled and the budget has increased sixfold.

Physically, laboratory space has been doubled during his administration. Nine new buildings have been erected, increasing the number to fourteen. Additional land has been acquired for future expansion in the vicinity of the University, which is located between 62nd and 68th Streets, and York Avenue and the Franklin D. Roosevelt Drive. A new 17-story laboratory building is now being constructed.

THE UNIVERSITY'S CLINICAL RESEARCH CENTER

BY MACLYN MCCARTY

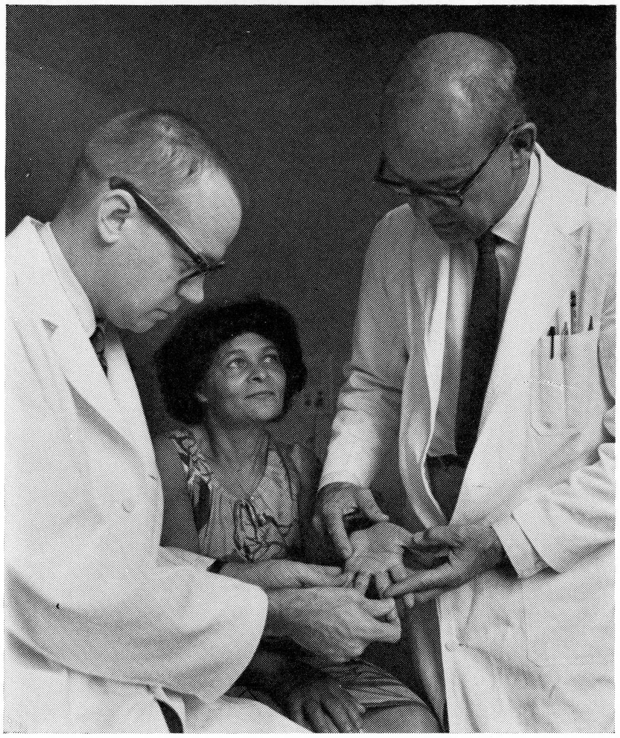
THE ESTABLISHMENT of a research hospital came under consideration in the early stages of the organization of The Rockefeller Institute for Medical Research. It is important to remember the setting in which these discussions took place. The idea of staffing medical schools with full-time faculties had as yet made only limited headway, and there was no experience with clinical investigation as we know it today. It is no surprise, therefore, that some of the advisors conceived of the research hospital as a place where practitioners of medicine could study disease on a part-time basis. It was a layman, Mr. Frederick T. Gates, who, more than any one person, influenced the planning of the hospital along more innovative and soundly scientific lines. Gates, it will be remembered, first became acquainted with John D. Rockefeller, Senior, during the negotiations to create the University of Chicago, and subsequently became his chief advisor, not only in philanthropy but in investments as well. With vision and intuitive grasp of the real needs, such as he had shown in initiating the founding of The Rockefeller Institute, Gates insisted that the hospital be staffed by full-time medical scientists who could devote all of their efforts to the development of a scientific approach to the study of disease.

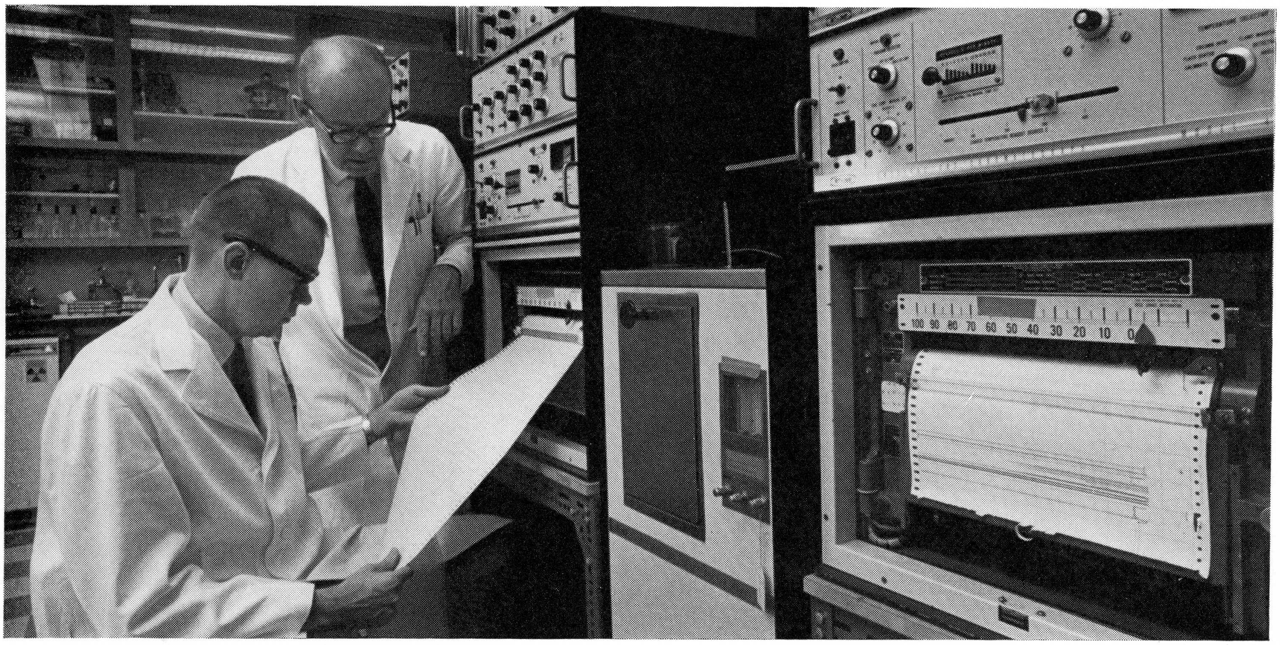
From the outset of the planning, there was concern about the cost of operating a hospital engaged solely in research, and the possibility was entertained of charging patients for hospitalization during their admission for study. Mr. Gates's influence was again crucial in this matter, since he saw clearly the importance of divorcing the research hospital from the usual type of fee-for-service operation; he championed the policy that no charge should be made to patients, regardless of economic status. Rufus Cole, who was appointed the first Director of the Hospital prior to completion of the building and who thus participated in the planning, concurred with the principles agreed on by the Board of Scientific Directors and was responsible for putting them into practice. His success can be measured by the fact that these principles continue to guide the operation of the Hospital today and have been in force throughout its long history of accomplishment.

The Hospital of The Rockefeller Institute for Medical Research opened its doors in the fall of 1910 with a staff of ten physicians who had the courage to participate in this pioneering venture in medical science. For those who deplore the "recent" emergence of labor problems as a complication in University construction, it can be recorded that completion of the building was delayed for some five months by a strike of steam fitters.

One miscalculation in the planning of the Hospital became apparent very soon after it had begun operation. Although it was recognized that laboratory facilities were essential and integral parts of the Hospital, the space devoted to patients in ratio to that of laboratories had been greatly overestimated. Experience showed that one does not require large numbers of patients for the intensive study of a given disease. Indeed, if the need for clinical care of patients assumes too great a portion of the investigator's time, his progress in the laboratory exploration of problems

Clinical expertness RIGHT *still sets the stage for good questions in clinical research. Professor Ahrens demonstrates an unusual deposition of lipid in the palm creases of a patient likely to suffer the premature onset of the complications of atherosclerosis. Dr. Scott Grundy, M.D.* LEFT, *received his Ph.D. from the University this June, after six years of clinical research on cholesterol metabolism in Dr. Ahrens' laboratory. Clinical research* BELOW *combines modern-day laboratory technology with bedside observation. In their gas-liquid chromatography laboratory Dr. Grundy discusses with Professor Ahrens the excretory pattern of sterols in his patient. The record Dr. Grundy holds demonstrates how the excretion of sterols changed when his patient was given a cholesterol-lowering drug.*





posed at the bedside will be impeded. The conversion of bed space to laboratory space was accomplished with remarkable economy, as judged by present-day standards. When I came to the Institute in 1941, the sixth floor of the Hospital, which housed the laboratories of Dr. Oswald T. Avery and Dr. Homer F. Swift, bore the unmistakable stamp of its original construction as a patient facility. The conversion had been carried out with a minimum of structural alterations: auxiliary rooms, kitchens, and wards were converted to laboratory space simply by moving in the necessary furniture and equipment. My desk (which also served as the bacteriological laboratory bench) was placed against one of the marble fireplaces which had been included in each of the wards.

In the formative years, a successful pattern of continuing interaction between basic laboratory studies and clinical observations at the bedside was established. When he retired as Director in 1938, Dr. Cole described the situation in the following terms: "No restrictions have ever been placed on the nature of the investigations or methods to be employed; they

could be as fundamental as the training of the man permitted, but it has always been felt that workers in the hospital should have in the backs of their minds (though it might be far back) the relief of suffering and the cure of disease. This has resulted in the choice of large problems, the solution of which might require the efforts of many men over long periods of time, even many years. This program has not prevented the discovery of many new facts along the way, but it has tended to produce a continuity of effort, and it has discouraged merely opportunistic and fragmentary investigations which in my opinion are today all too common and which are responsible for the enormous bulk of publication, some of which is unnecessary." This statement retains its pertinence thirty years later.

The individual research groups were organized for the study of the pathogenesis of a specific disease or group of diseases, and patients suffering from these diseases were selected for admission to the hospital. For the most part, patients were referred by practicing physicians in the Metropolitan area who were notified of the nature of the diseases under study. The young medical scientists charged with the care and observation of these patients were concurrently involved in the laboratory studies designed to elucidate the mechanisms of the pathological process. Information derived from the study of the patient posed problems which were brought to the laboratory and, in turn, new concepts emerging from research in the laboratory were brought back to the bedside for clinical application.

Students and the Hospital

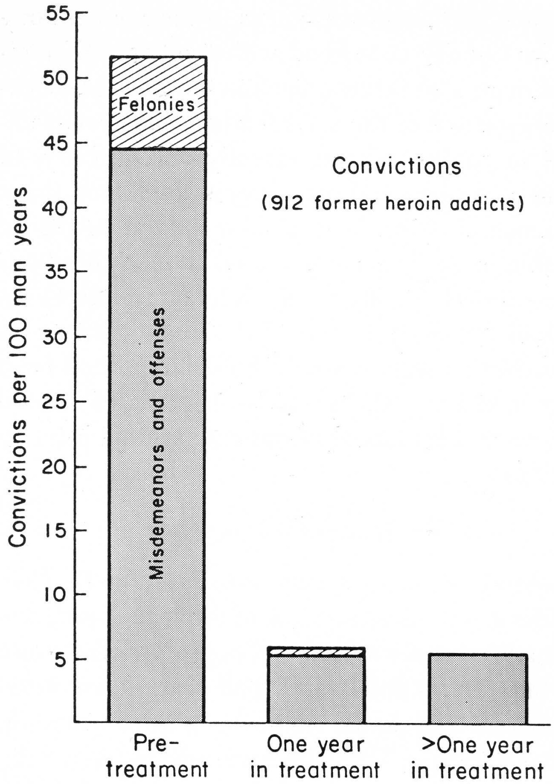
The essential interdependence of clinical investigation and experimental pathology was decisively proved during the early decades of the hospital. And there are fundamental techniques and basic science methods developed today in various hospital groups, which have direct application to the work of graduate students who are not in the medical field: for example, the immunochemical methods in Professor Kunkel's laboratory; the lipid separation methods developed in Professor Ahrens' laboratory; the studies of cell size and shape developed by Professor Jules Hirsch; and the research on action of steroids on cells in tissue culture systems by Dr. Kappas.

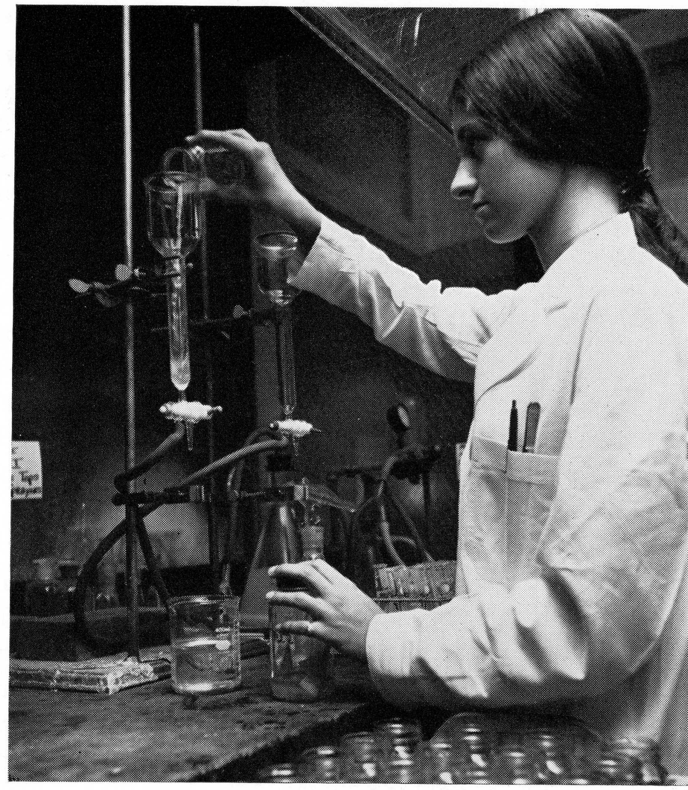
It is also apparent that the investigator attempting to explain pathological changes in the human body must be equally concerned with the "normal" biology of man. This is recognized in the present collective designation of the several laboratory groups engaged in studies related, directly or indirectly, to human physiology and pathology as the Laboratories of Human Biology. In a similar vein it might be desirable to apply some name other than "hospital" to the research facility to which human subjects are admitted for study in one of the investigative programs. In this way, it would be distinguished from the general hospital, in which diagnosis of disease and care and treatment of patients are the primary functions.

The Research Spectrum

The study of lobar pneumonia initiated by Dr. Cole provides an excellent example of the type of program he visualized, since it extended over a period of more than thirty years and included all of the interrelated components that should comprise an investigation in depth of a disease. Thus, there were extensive and detailed observations on the characteristics and course of the human disease; a comprehensive examination of its bacteriology; a varied group of experimental pathological studies in laboratory animals directed toward elucidation of pathogenesis; basic investigations of the biology of the pneumococcus that contributed a major portion of the impressive body of knowledge accumulated concerning this organism; and, based on these various studies, the introduction of new methods of treatment as exemplified by specific serum therapy. In addition, this program is the source of the most dramatic demonstration that disease-oriented studies can make major contributions to biology in general, namely, the demonstration that polysaccharides are antigens, and the identification of the pneumococcal transforming agent as DNA.

During the early decades, other studies of similar breadth included the pioneering developments from Donald D. Van Slyke's laboratory of biochemical methods applicable to human physiology and disease and their use in the study of kidney disease; investigation of the pathogenesis of rheumatic fever in Homer Swift's laboratory and the associated work on the biology of the streptococcus; and studies on the circulation and on heart disease in the laboratories of Alfred E. Cohn. In the intervening years, the em-



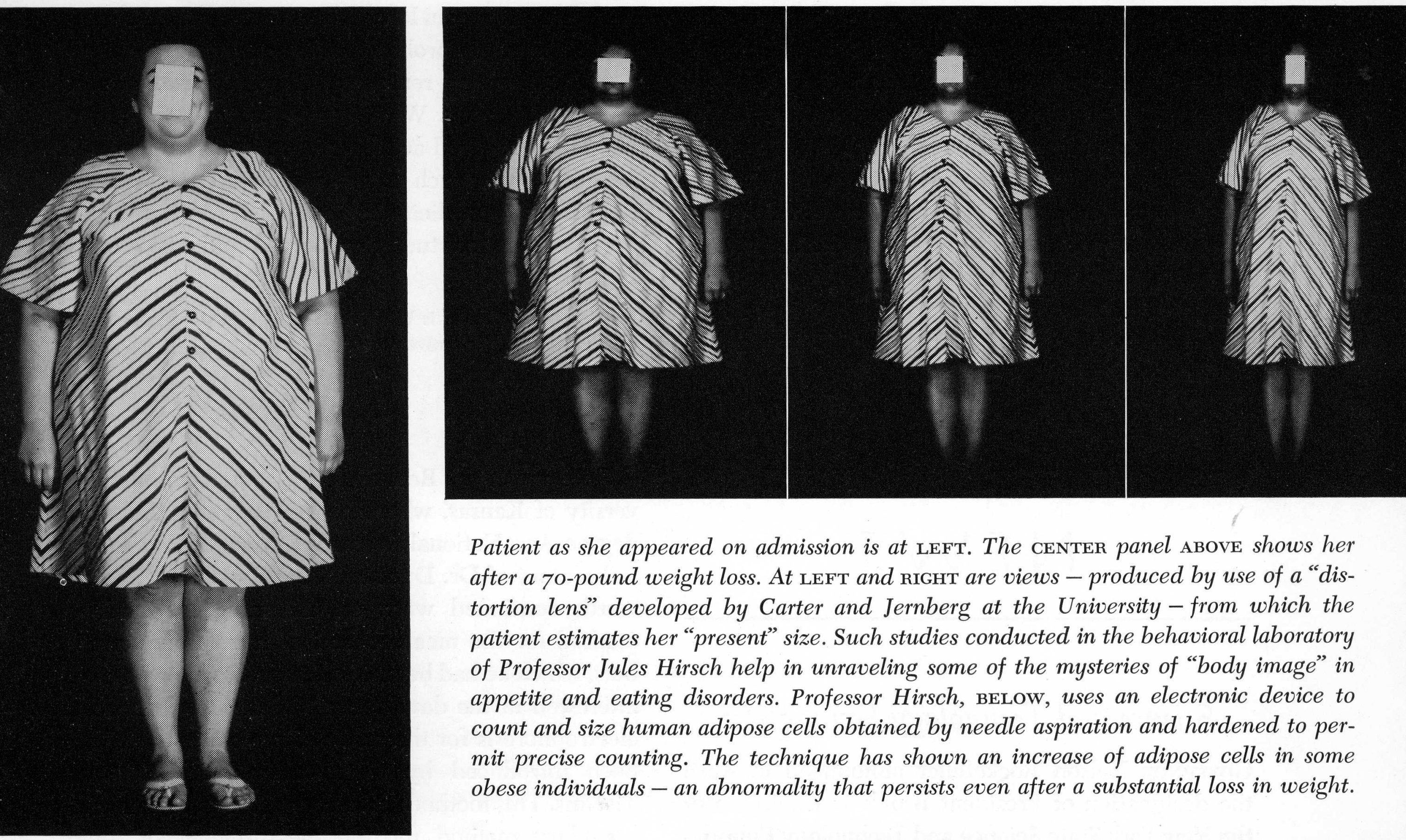


Graph illustrates crime reduction among those addicts who have received methadone treatment. The total conviction rate of former heroin addicts has been reduced to 10 per cent of the rate that prevailed before treatment, and serious crimes (felonies) have almost vanished. Frequent analysis of the urine of patients for narcotics and other drugs is essential in treatment RIGHT. *Both the methadone therapy and analysis techniques were developed at The Rockefeller.*

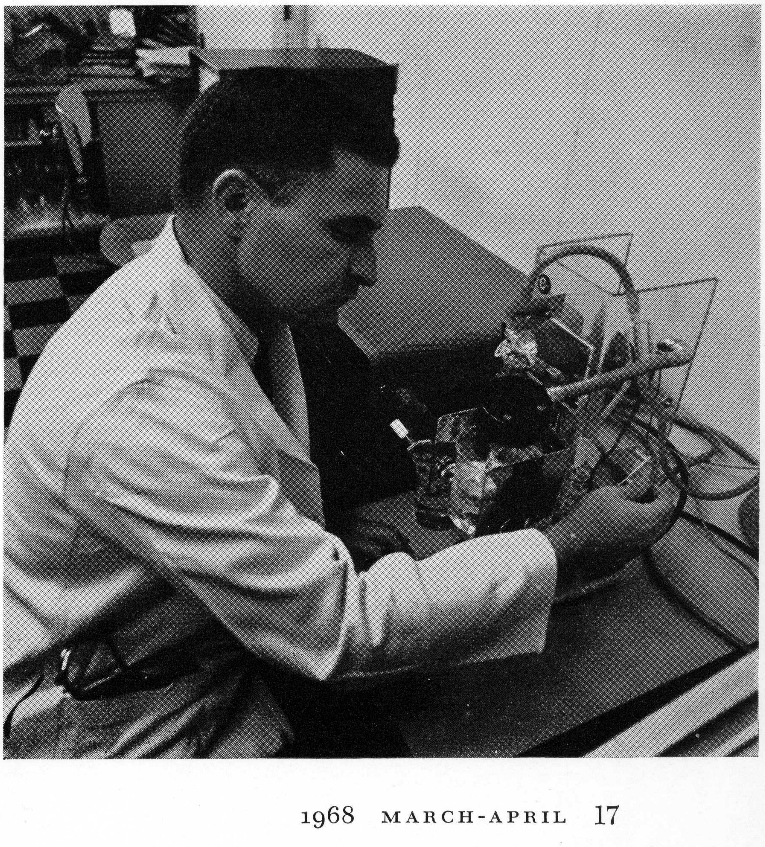
phases have changed, although the pattern of long-term, multifaceted attack on problems of disease has been retained.

Today, there are some direct ties with these earlier studies, as in the continued investigation of the pathogenesis of rheumatic fever, but for the most part new areas of exploration have been selected. For example, atherosclerosis, one of the major medical problems of our time, with its serious consequences for the circulatory system, is being attacked in Edward H. Ahrens' laboratory in pioneering studies of lipid metabolism in man. New programs introduced in recent years reflect the changing times and also illustrate the important principle of permitting the trained investigator to focus his research efforts on any problem that captures his attention. In this connection, one can cite Jules Hirsch's laboratory, where the approach to the study of obesity involves combined behavioral and metabolic studies, and the intensive attack by Vincent P. Dole on one of today's most distressing social and medical problems, narcotic addiction.

There have been great changes both in medical education and in the scientific study of disease since the opening of the Hospital in 1910, and clinical investigation has gradually become broadly based in medical centers throughout the country. Beginning with the introduction of the full-time system and with the subsequent establishment of metabolic wards and increasing emphasis on experimental pathology, there has been a progressive increase in the national effort to solve some of the most pressing problems of human disease. After World War II, this trend received a major additional impetus from the federal government's support emanating from the growth of the research grant program of the National Institutes of Health, the creation of the Clinical Center in Bethesda, and, most recently, the introduction of the Gen-



Patient as she appeared on admission is at LEFT. The CENTER panel ABOVE shows her after a 70-pound weight loss. At LEFT and RIGHT are views — produced by use of a "distortion lens" developed by Carter and Jernberg at the University — from which the patient estimates her "present" size. Such studies conducted in the behavioral laboratory of Professor Jules Hirsch help in unraveling some of the mysteries of "body image" in appetite and eating disorders. Professor Hirsch, BELOW, uses an electronic device to count and size human adipose cells obtained by needle aspiration and hardened to permit precise counting. The technique has shown an increase of adipose cells in some obese individuals — an abnormality that persists even after a substantial loss in weight.



eral Clinical Research Center grant. The Rockefeller University Hospital now receives generous support from one of these General Clinical Research Center grants of the National Institutes of Health.

Thus, in the medical community today The Rockefeller University Hospital no longer stands, as it did at its inception almost 60 years ago, as the only hospital devoted solely to clinical investigation and one of the very few places in which human studies can be pursued. However, it retains certain unique features that permit it to make a special contribution to human biology and pathology. Just as the absence of a categorical departmental structure adds strength to the University in general, it also provides an unusually favorable setting for the long-term, comprehensive study of a specific disease process. It makes possible a high degree of continuity in clinical studies associated and correlated with the complementary approaches of experimental pathology and basic labo-

ratory investigation. The types of problems selected tend to be different from those of the clinical research center housed in a medical center, and programs under way here are rarely undertaken elsewhere.

It is apparent that a clinical research facility organized as an integral part of a graduate university will be and should be quite different from one that is part of a medical school or a general hospital. The university setting influences the nature of the research programs, and has the additional advantage of providing for an unusual degree of interaction with research in the basic sciences in laboratories throughout the campus. In turn, the problems of human biology have a potentially strong representation in the program of graduate training. While this potential has not yet been fully realized at Rockefeller, the emergence of new disciplines such as behavioral science and environmental biomedicine indicates that there will be a broader base for studies concerned with the human organism.

PROFESSOR MCCARTY is Vice President and Physician-in-Chief of The Rockefeller University.

THE ROCKEFELLER UNIVERSITY NEWS

Science and Technology Foundation

GOVERNOR Nelson Rockefeller announced in April the designation of President Bronk as Chairman of the New York State Science and Technology Foundation, effective May 15. Dr. Bronk, who has served as Vice Chairman of the Foundation since 1965, succeeds Eugene J. McNeely—former president of American Telephone and Telegraph Company—who will continue to serve on the Board of Directors. The New York State Science and Technology Foundation was created in 1963 to promote and sustain excellence in science and technology in New York State, and it makes grants to university and engineering schools for projects intended to raise their academic and research programs to the highest levels.

Chromatography and Electrophoresis

PROFESSOR Lewis G. Longsworth received the $1,000 American Chemical Society Award in Chromatography and Electrophoresis at the 155th national meeting of the Society in San Francisco in April. Dr. Longsworth is internationally known not only for his work in electrophoresis but also for his earlier classical experiments on the moving boundary method for the measurement of ionic transference numbers.

He came to the Rockefeller in 1928 from the University of Kansas, where he had received the PH.D. degree. As a National Research Council Fellow in the Laboratory of Dr. Duncan A. MacInnes, Dr. Longsworth continued work on the moving boundary method for the measurement of transference numbers, which he had begun at Kansas. He later became interested in the development of moving boundary electrophoresis for the study of proteins, which had been introduced by the Swedish scientist Arne Tiselius. This method is closely related to the moving boundary method for the measurement of ionic transference numbers for which Longsworth is internationally known. His introduction of the schlieren optical technique in the 1940's has contributed in a most important way to the practical use of moving-boundary electrophoresis for new approaches to important problems in biological research.

Two Cultures Award

BY VOTE of the four thousand students of Flushing High School, Professor René J. Dubos was chosen the first recipient of the Two Cultures Award, to be presented each year "to that American citizen whose life and work best exemplify the bridging of the worlds of the sciences and the humanities."

The scroll was engrossed by Louis Wai Ling—student chairman of the selection committee—who presented the award to Dr. Dubos at a special assembly program on March 26. The citation stressed Dr. Dubos' "distinguished research, his lucid writing, his lectures to high school students at The Rocke-

Louis Wai Ling LEFT *Dr. James J. O'Connell, Principal* CENTER *and Professor René Dubos*

feller University, and his studies of the relationships between man and his environment." In his response, Dr. Dubos referred to the Award as "the one recognition of my effort that has been the most meaningful to me.... I shall find it a continued inspiration for communicating to others...."

◖ Professor Theodosius Dobzhansky was awarded the degree of Doctor of Humane Letters by the University of California at Berkeley in March:

His brilliant studies, over many years, have led and inspired the science of population genetics; his breadth of knowledge and grasp of significance have produced great syntheses during an age characterized by fragmentation of knowledge; his profound understanding of human evolution has illuminated the biological basis of the case for the universal dignity of man.

and the degree of Doctor of Biological Science by the University of Padua, Italy, in April:

For his classical research which has exercised a profound influence on the present direction of evolutionary biology.

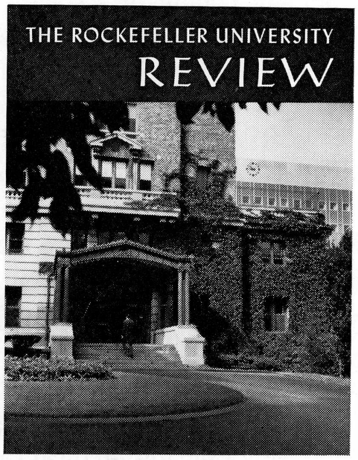
◖ President Bronk gave a dedicatory address in April on the campus of the University of Indiana at ceremonies honoring the new visual science building.

◖ The tenth anniversary of the successful launching of the first Vanguard satellite was celebrated in March at a dinner in Washington, attended by leaders in government, science, and industry. Dr. Bronk was the featured speaker and reviewed the early history of the space program.

◖ The 105th Annual Meeting of the National Academy of Sciences this spring was the last annual gathering of the Academy at which Dr. Frederick Seitz would preside as President before assuming the presidency of The Rockefeller University in July. Three featured symposia included a session chaired by Professor Vincent P. Dole on The Persistent Effects of Narcotic Drugs, at which Dr. Dole presented a paper on Clinical Implications.

◖ Over 500 civic, government, and business leaders joined the Boston Junior Chamber of Commerce, at its annual dinner this spring, in honoring Alan R. Adolph PH.D. 1963 as one of the Ten Outstanding Young Men of greater Boston. Former recipients of the award include the late President John F. Kennedy and symphony conductor Leonard Bernstein. Dr. Adolph, who is Research Associate in the Institute of Biological and Medical Sciences of the Retina Foundation, was cited for his "work of fundamental importance to the understanding of the processes involved in vision and his unusual contribution toward understanding, curing, and preventing some of the now incurable blinding eye diseases." The panel of judges who selected the ten outstanding young men was headed by Arland Christ-Janer, President of Boston University, and included The Honorable Joseph Tauro, Chief Justice of the Massachusetts Superior Court, and Dr. Samuel Proger, Chief Physician of the New England Medical Center.

◖ The New York Botanical Garden presented a two-day symposium this spring on the theme "Challenge For Survival." The general chairman was Professor René J. Dubos, and the first day's proceedings were held in Caspary Auditorium. Late that afternoon, President and Mrs. Bronk were hosts to the participants at a reception in the President's house. Among the distinguished guests and speakers were Lewis Mumford, author; The Honorable August Heckscher, Commissioner, Recreation and Cultural Affairs Administration, New York City; Dr. David Gates, Director of the Missouri Botanical Garden; and Dr. William C. Steere, Director of the New York Botanical Garden.



THE COVER shows the entrance to the University Hospital and clinical research center, a small but superbly equipped laboratory of human biology. Story on page 13. The upper part of South Laboratory is visible in the background at right. Photograph by Joseph Barnell.

ACKNOWLEDGMENTS: Pages 1, 11, 16 (left), 17 (top), and 19 illustrations by The Rockefeller University Illustration Service. Pages 2-9 illustrations courtesy of Dr. Georg von Békésy. Page 10 photograph by George Tames. Page 14 photographs by Albert Fenn. Page 16 (right) and 17 (bottom) photographs by Joseph Barnell.