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THE SCULPTURE OF VIBRATIONS

TREASURES
OF
WORLD ART

39

Punic pendant

This little masterpiece of paste jewellery (actual size shown on right) is a necklace pendant fashioned by a craftsman of ancient Carthage in the form of a mask whose white face contrasts sharply with the deep blue tones of the eyes, hair and beard. Founded by the Phoenicians about 750 B.C., Carthage quickly became the greatest commercial power in the western Mediterranean, exporting to its overseas trading posts a wealth of "mass produced" objects which, as we may judge from this pendant, did not debase the ancient Phoenician tradition of elegant craftsmanship.

Bardo Museum, Tunis. Photo © Luc Joubert

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Cover photo

Cymatics is a new field of research which studies the effects of rhythmic vibrations in nature. It reveals an ever-changing world of unusual forms in which figures appear, currents and eddies are set in motion, structures take shape and pulsating patterns materialize. The curious forms shown here dance and leap upwards when vibrations are transmitted to a viscous liquid (see also photos pages 13, 14, 15).

Photo © J.C. Stuten, Dornach, Switzerland

CYMATICS

THE SCULPTURE OF VIBRATIONS

This photo shows neither a duck nor a swan about to plunge. It is one of the extraordinary patterns sculpted by high-frequency sound. It was produced by placing a plastic mass in a magnetic field and subjecting it to vibration. The masses form sculptural shapes reflecting the characteristics of the magnetic field.

Photo © J.C. Stuten, Dornach, Switzerland

Throughout the living and non-living world we find patterns of recurrent rhythms and periodic systems in which everything exists in a state of continual vibration, oscillation and pulsation. These rhythmic patterns can be observed not only in the beating of the heart, the circulation of the blood and the inhaling and exhaling of breathing, but also in the recurrent formation of cells and tissues, in the rhythmic movements of the oceans, the wave motion of sound and hypersonic vibrations, and in the vast universe extending from the cosmic systems of solar systems and galaxies down to the infinitesimal world of atomic and nuclear structures. In the following article, Dr. Hans Jenny, a Swiss scientist and artist, describes some of the experiments he has carried out in a long study of these rhythmic vibrations and presents some of the extraordinary results which this new field he has termed "Cymatics" (from the Greek *kyma,* wave) already reveals to us. Dr. Jenny believes that these experiments will give us new insight into the world of vibrations —terrestial and extra-terrestial—and eventually serve fields of research as diverse as astrophysics and biology.

by Dr. Hans Jenny

Photos — J. Christiaan Stuten
Hans Peter Widmer

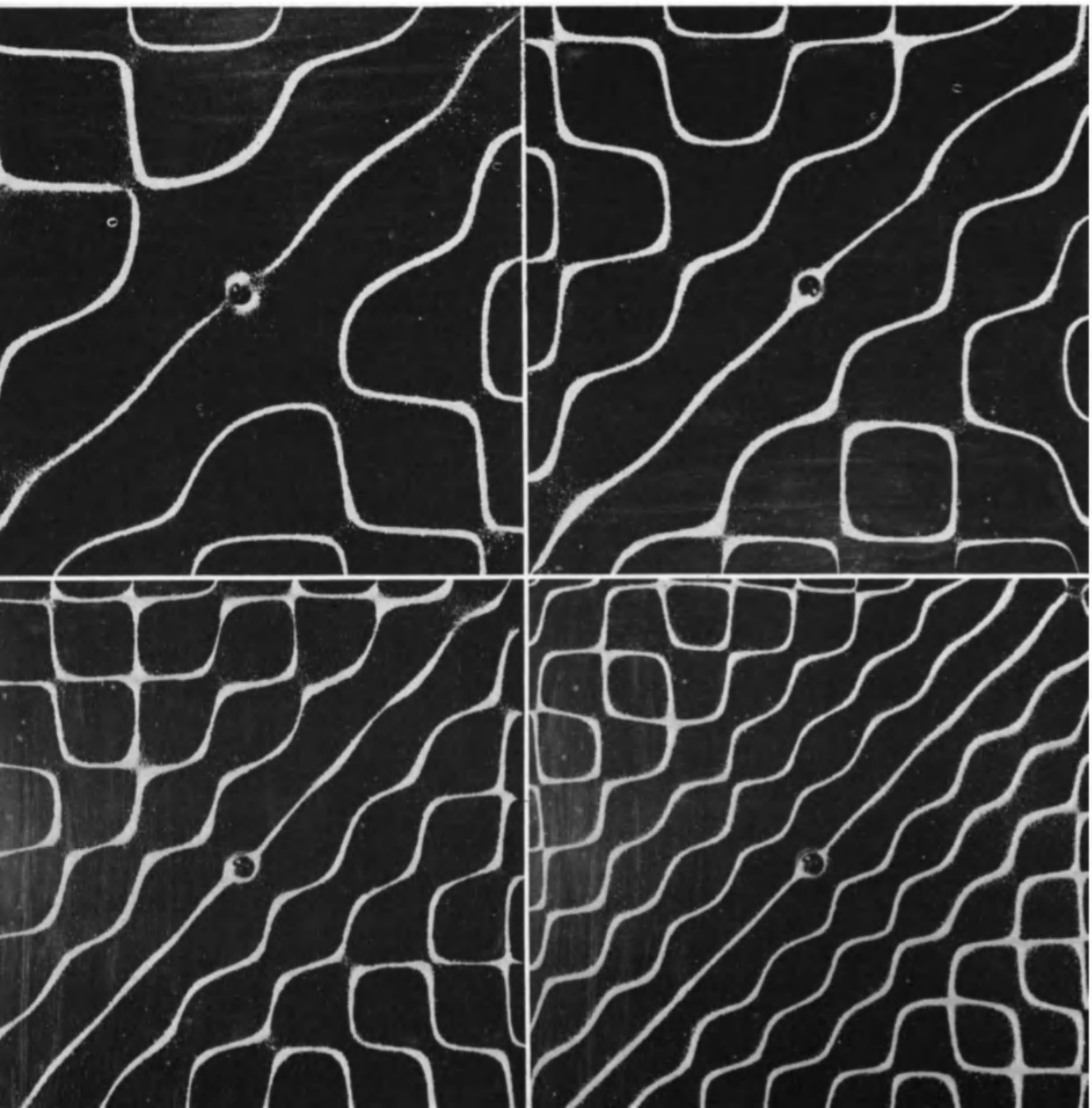
CYMATICS

1 - Patterns of a world permeated by rhythm

OUR world is permeated throughout by waves and vibrations. When we hear, waves travelling through the air impinge on our ears. When we speak, we ourselves generate air waves with our larynx. When we turn on our radios and televisions, we are utilizing a waveband. We talk about electric waves and we are all familiar with waves of light. In an earthquake the whole earth vibrates and seismic waves are produced. There are even whole stars which pulsate in a regular rhythm.

HANS JENNY *was born in Basel, Switzerland, and studied natural sciences and medicine. For many years he has been in medical practice at Dornach, near Basel. He is a naturalist and painter and has undertaken extensive research into zoological morphology. The problems of modern physiology and biology led him to study the phenomena of experimental periodicity, a field of research that was extended to include the effects of vibration, a new field he has termed "Cymatics." Dr. Jenny's article reports on more recent experiments carried out since he published his original study, "Cymatics, the Structure and Dynamics of Waves and Vibrations," highly illustrated with bilingual German-English text, published by Basilius Presse, Basel, Switzerland, 1967.*

But it is not only the world we live in that is in a state of vibration (atomic vibrations are another example) for our body itself is penetrated by vibrations. Our blood pulses through us in waves. We can hear the beat of the heart. And above all our muscles go into a state of vibration when we move them.



QUARTZ QUARTET

How cymatic experiments visualize sound is shown in photos left. Quartz sand strewn on a steel plate is "excited" by vibrations from a crystal oscillator. Approximately the same configuration is seen in all four illustrations, but the pattern becomes more elaborate as the pitch of the acoustic tone rises. Frequencies used here, left to right and top to bottom, are: 1,690 hertz (cycles per second), 2,500, 4,820 and 7,800. (See also centre colour pages, photo No. 5).

Photo © J.C. Stuten

BIRTH OF A VORTEX

This photo, with its graceful curves and shimmering movements, is a detail of a vortex in the course of formation. The pattern of flow of the vortex is clearly visible because of the use of coloured dyes by the experimenter which delineates each current sharply (see colour photo No. 7).

When we flex the muscles of our arms and legs, they actually begin to vibrate. It is even possible to hear these muscle sounds and record them with a telephone. All this means nothing more or less than that the many complicated chemical, energetic, bioelectric processes in the muscle fibres take place in a series of vibrations.

This raises a problem: What tangible effects do wave and vibrational processes produce in a specific material, in a particular milieu? The purpose of the studies reported here is to provide an answer to this question. Experiments have been devised to display a whole world of curious phenomena in which figures appear, currents and eddies are formed, structures take shape, harmonically pulsating patterns can be seen, and so forth.

Our first reaction to this whole world of wave phenomena is one of astonishment; its features excite the wonder of both the scientific investigator and the artist. In studying all these phenomena, however, we are concerned not only with completed forms but also with the ways in which they come into being. Movement is annexed to form. Thus we may be said to have the whole phenomenon before our eyes.

This is something that can have a particularly productive effect on the mind of the creative artist. Not only does the realized form appeal to us through its beauty, but it also presents itself to us as a living pattern of motion which is revealed in, say, a heap of sand. The vibration lays hold of the

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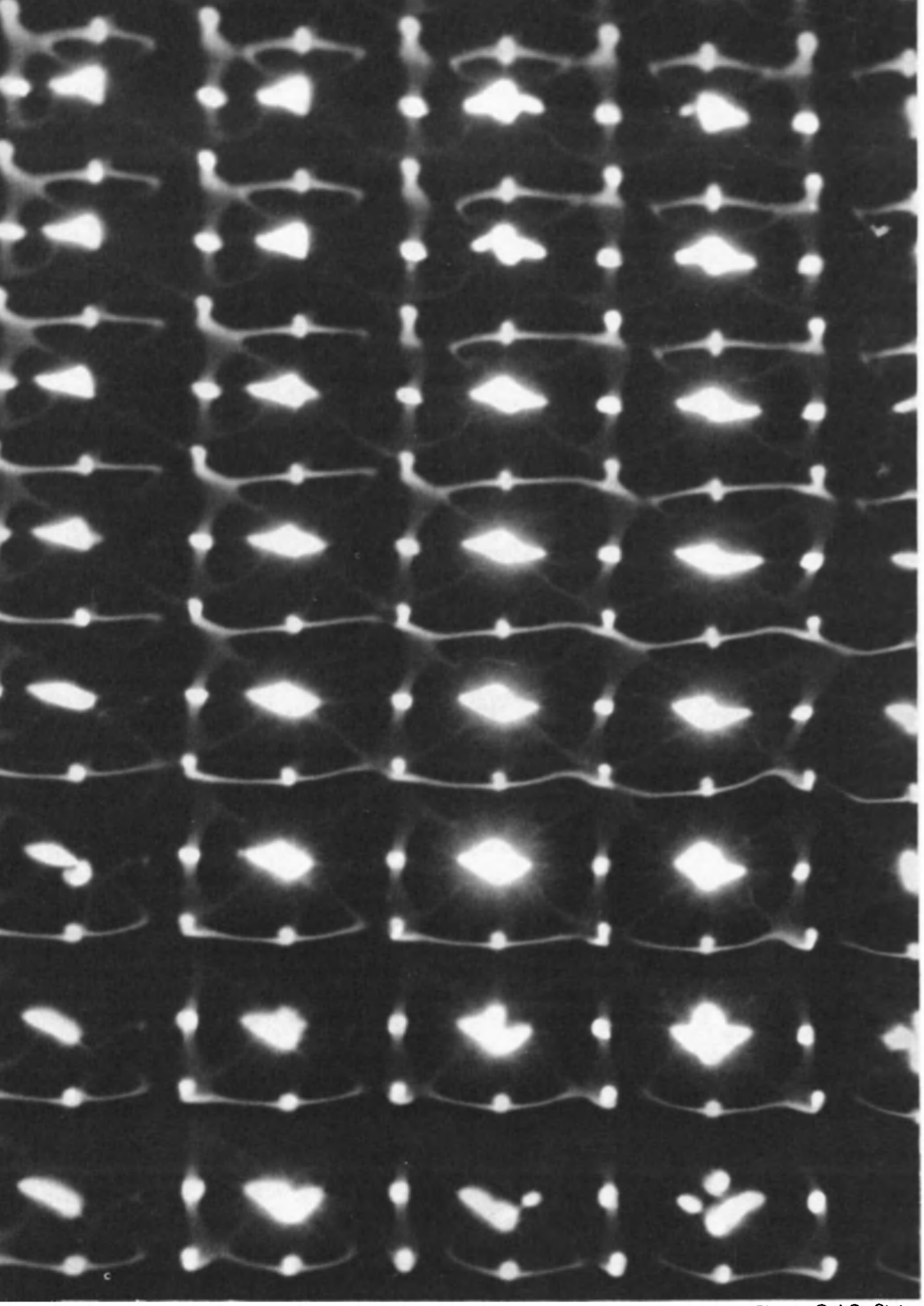
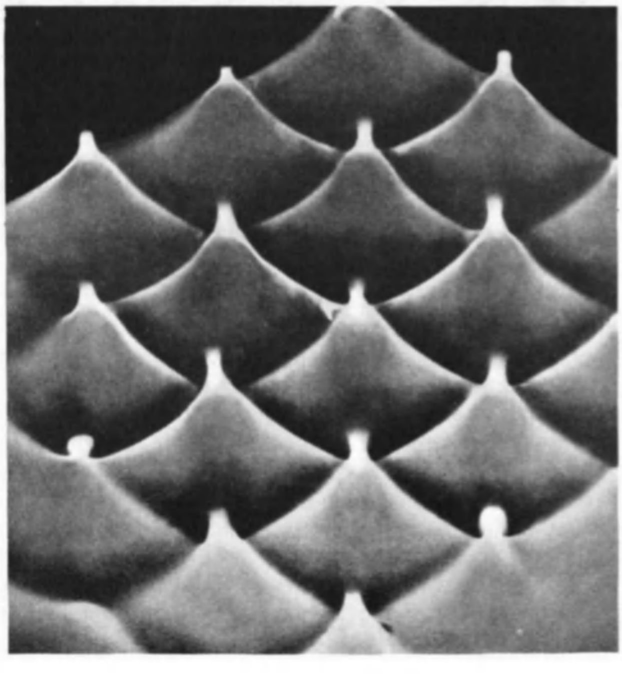


Photos © J.C. Stuten



WEAVING BY SOUND

When liquids are made to vibrate, very unusual patterns result. Above, a cellular pattern, not unlike those found in nature. Right, scale-like structures (technically know as imbricate). When the materials and frequencies are changed the patterns change and we see beautifully structured arrays, hexagonal, rectangular and overlapping patterns in the form of honey-combs, networks and lattices. Sometimes the texture itself undergoes a marked change and the most astounding displays result.

grains of sand and transports them in a way determined by the arrangement of the vibrational field.

Those artists in particular who are interested in kinetic art will find here a domain of nature in which kinetics and dynamics have free play until a configuration emerges. This highlights a very important characteristic of wave and vibrational processes: on the one hand, there is movement and an interplay of forces; on the other, the creation of forms and figures.

But invariably both the kinetic and the structural elements are sustained by the vibrational process. Thus we are always confronted by these three components: vibration or wave which is manifested in figures and in dynamics and kinetics. It is hardly an exaggeration, then, to speak of a basic triple phenomenon of vibration.

How are such experiments performed. The German scientist E. Chladni (1756-1827) was the first to show how solid objects vibrate. He scattered sand on a metal plate, making it vibrate with a violin bow, so that the sand formed a definite pattern of lines characteristic of the sound heard. The vibration transports the sand from specific areas called loops into certain linear zones. But the conditions of the experiment could not be selected at will nor could the results be seen as a whole until new methods were found.

One of these will be described by way of example. What are known as crystal oscillators were used. The lattice structure of these crystals is deformed when electric impulses are applied to them. If a series of such impulses is applied to the crystal, it begins to oscillate and the vibrations actually become audible. These vibrations can be transmitted to plates, diaphragms, strings, rods, etc. (photo page 6 and colour photo number 5).

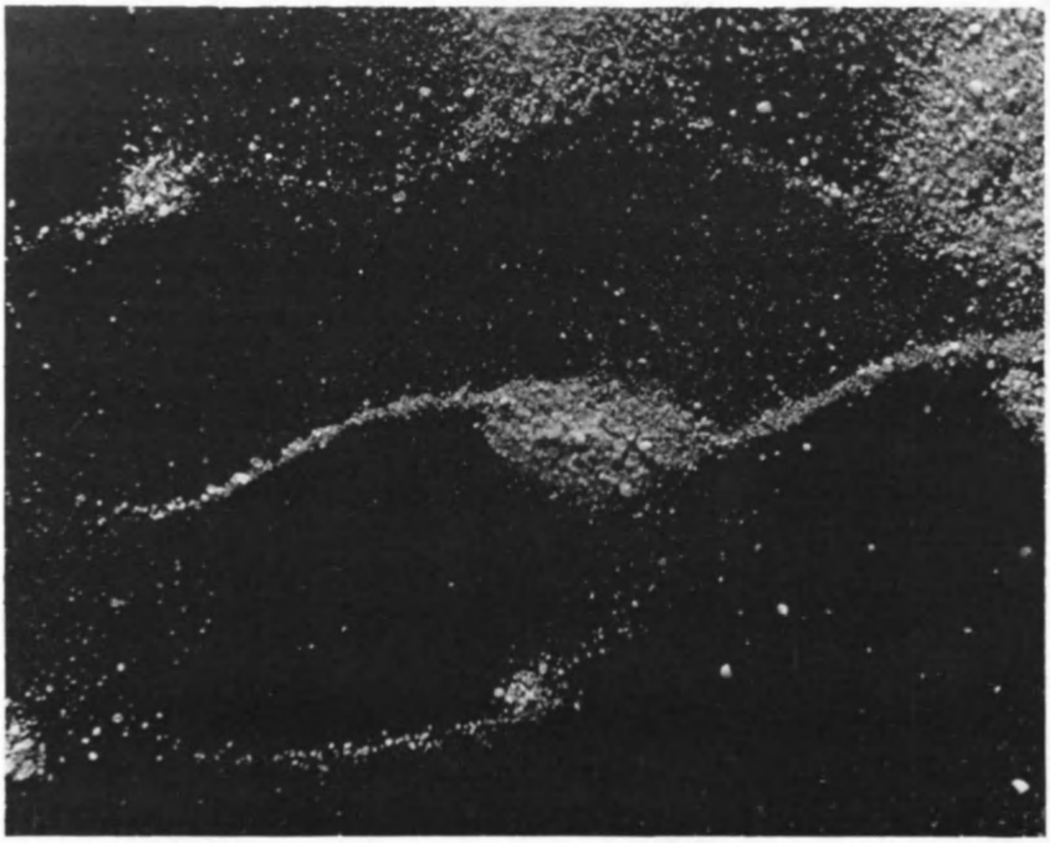
By means of this method conditions can be freely selected and accurately determined: the number of vibrations per second (frequency), the extent of the vibratory movement (amplitude), and the exact point of excitation are all known with precision. Several acoustic tones can be experimented with at one and the same time; the scope of the experiment can be extended at will and, above all, each experiment is precisely reproducible.

With the aid of such methods, research can reveal a whole phenomenology of vibrational effects. The name "cymatics" was chosen for this field of study (*kyma*, Greek for wave, *kymatica*, things to do with waves).

CONTINUED ON PAGE 10

SPIRALLING SANDS

Photos right and below show how vibration produces rotational effects. Here we have a steel plate strewn with quartz sand. On right we see piles of sand rotating under vibration. Sand is flowing river like, toward the centre pile, in long, narrow arms coming from various directions. These forms strangely recall the rotating, spiralling masses observed by telescopes in nebulae and other galactic phenomena. Below, two disc-shaped piles of sand have been formed by the flow of the sand streams. Each disc is constantly rotating and has a nipple of sand like a nucleus in the centre.



Photos © J.C. Stuten

2 - Music made visible in a film of liquid

IT is possible to generate vibrations systematically through a continuous series of tones and to transmit them to any object at will. Consequently sonorous figures are not the only phenomena produced (photos page 6). Vibrational conditions are found, called phases, in which the particles do not migrate into stationary figures but form currents. These currents run side by side in opposite directions as if in obedience to a law. The whole vibrational pattern is now in motion.

These continuous waves also provoke rotary movement. The sand begins to turn round a point. These rotary processes are continuous. The masses are not ejected. If coloured grains of sand are used to mark rotating piles, the movement pattern revealed is continuous and due entirely to vibration (photos page 9).

It is interesting to note that all the phenomena of cymatics have not only been photographed but, since movement is invariably involved, also filmed. Still and motion pictures complement each other as documentation.

Just as vibration can be transmitted to solid particles (sand, powder) it can also be communicated to liquids. Once again we find the whole spectrum of cymatics. A richly diverse field of structures appears. Delicate lattices are generated. Then hexagonal, imbricated (scale-like) and richly curved patterns (photos pages 8 and 28) appear. If the exciting tone is removed, all the formations naturally vanish.

Currents also occur in liquids. In a film of liquid, bilaterally symmetrical pairs of vortexes like those discovered in the ear by Georg von Békésy rotate in contrary directions (photo page 7 and colour photo number 7). These pairs of vortexes are formed charac-

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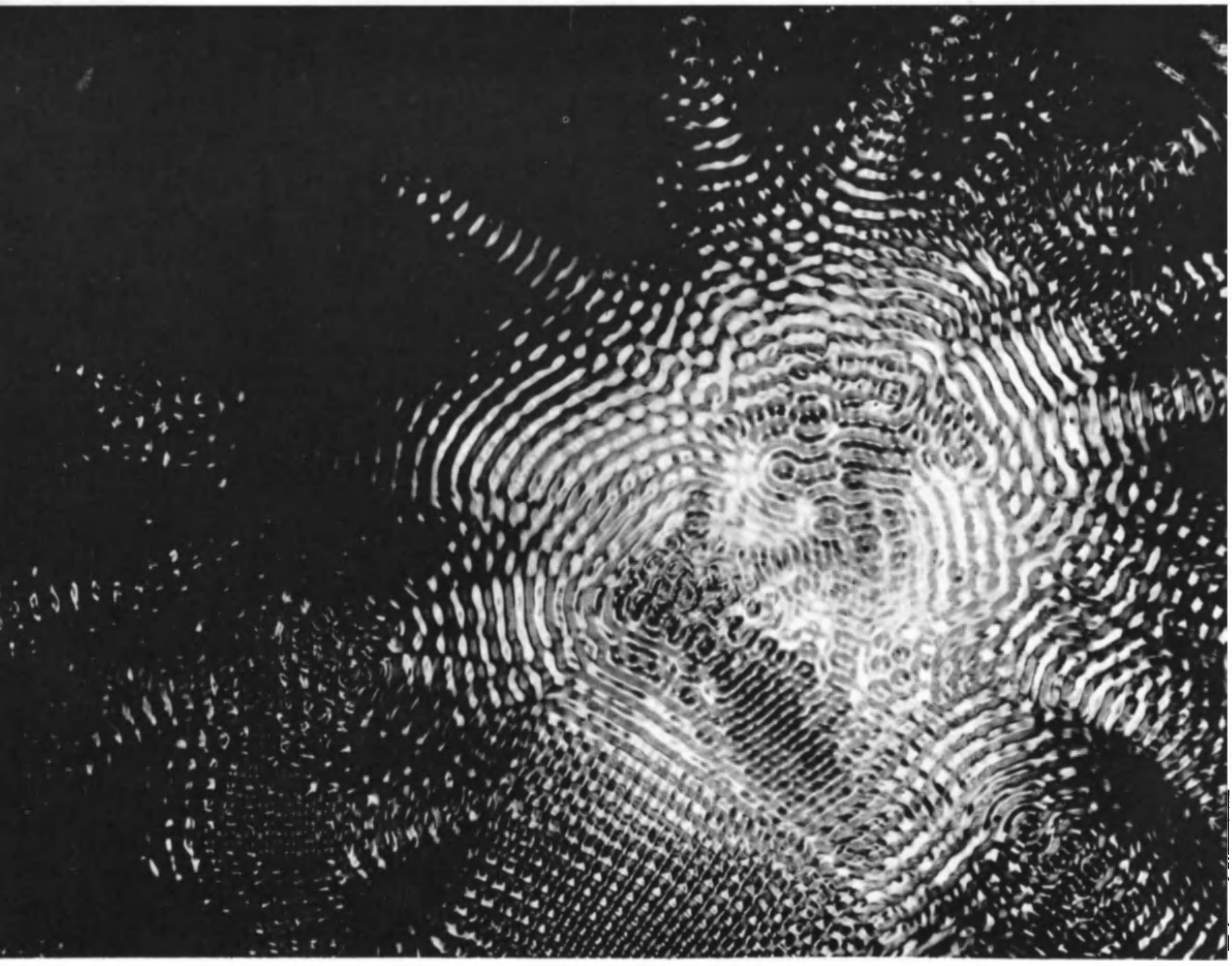

Photo © H.P. Widmer

Photo © J.C. Stuten

MOZART'S 'DON GIOVANNI'

Pattern (left) is a musical sound from the 27th bar of the overture of Mozart's opera "Don Giovanni". The sound has been made visible by impressing the sound vibration patterns on a film of liquid. Not only the rhythm and volume become visible but also the figures which correspond to the frequency spectrum exciting them. The patterns are extraordinarily complex in the case of orchestral sound. See also Bach photo next page.

CRESTS OF THE WAVE

Above, suggestive of gaping mouths in some bizarre mask of Antiquity, these orifices are actually a series of wave crests (photographed from above) produced when a viscous liquid is irradiated with sound. When poured onto a vibrating membrane, the fluid becomes a flowing, pulsating mass in which wave formations soon appear. Changes in the amplitude and frequency of vibrations and modifications to the viscosity of the liquid produce further strange effects (see photos pages 13, 14, 15).

CYMATICS *(Continued from page 10)*

teristically in the cochlea of the ear by the action of sound. The vortexes appearing in the liquid can be made visible by adding a few drops of marker dye. They rotate continuously. The louder the tone, the more rapid the rotation.

Turbulences or unstable waves deserve special mention (bottom photo page 16). In the marginal areas of a wave field or when two trains of waves are contiguous, agitated wave formations appear which are constantly changing. Vibration causes "turbulence" in liquid. It is a characteristic of such turbulences that they sensitize a medium (liquid, gas or a flame) to the action of sound.

For example, it is only when a gas flame is made turbulent that it becomes receptive to irradiation by sound, i.e. it is only then that it forms into sonorous figures. These turbulences are important in the design of wind instruments, e.g. the mouthpieces of trumpets.

Since these experiments entail the transmission of vibrational processes in conformity with natural laws, it was a logical step to attempt to visualize music (photos pages 10 and below). It is in fact possible with the aid of diaphragms to make the actual vibrational patterns of music visible in films of liquid. One and the same vibrating diaphragm is used to radiate the music and also to visualize the musical processes in the sonorous figures appearing in the liquid. In this way, we see what we hear and we hear what we see.

The eye is, of course, unaccustomed to "seeing Mozart or Bach"; if films of this visible music are shown without sound, it is by no means apparent that what can be seen is, say, Mozart's Jupiter Symphony. It is only when the music is switched on that the aural impression can be experienced visually.

The question whether it is feasible to visualize the human voice is a particularly interesting one. A specially designed apparatus called the tonoscope (sound-seer) makes it possible to produce without intermediate agency the actual vibrational pattern of a vowel (see colour photo number 6). The figures reveal characteristic features which reflect the spoken vowel and its frequency spectrum, the pitch of the vowel, and the individual voice of the speaker. If conditions are constant, precisely the same form appears.

For deaf-mutes this visible speech is a substitute for the normal person's ability to hear himself. The deaf-mute sees what he says. He can practise producing in the tonoscope the same forms as those made by persons with normal hearing. If he succeeds in doing so, this means he is producing

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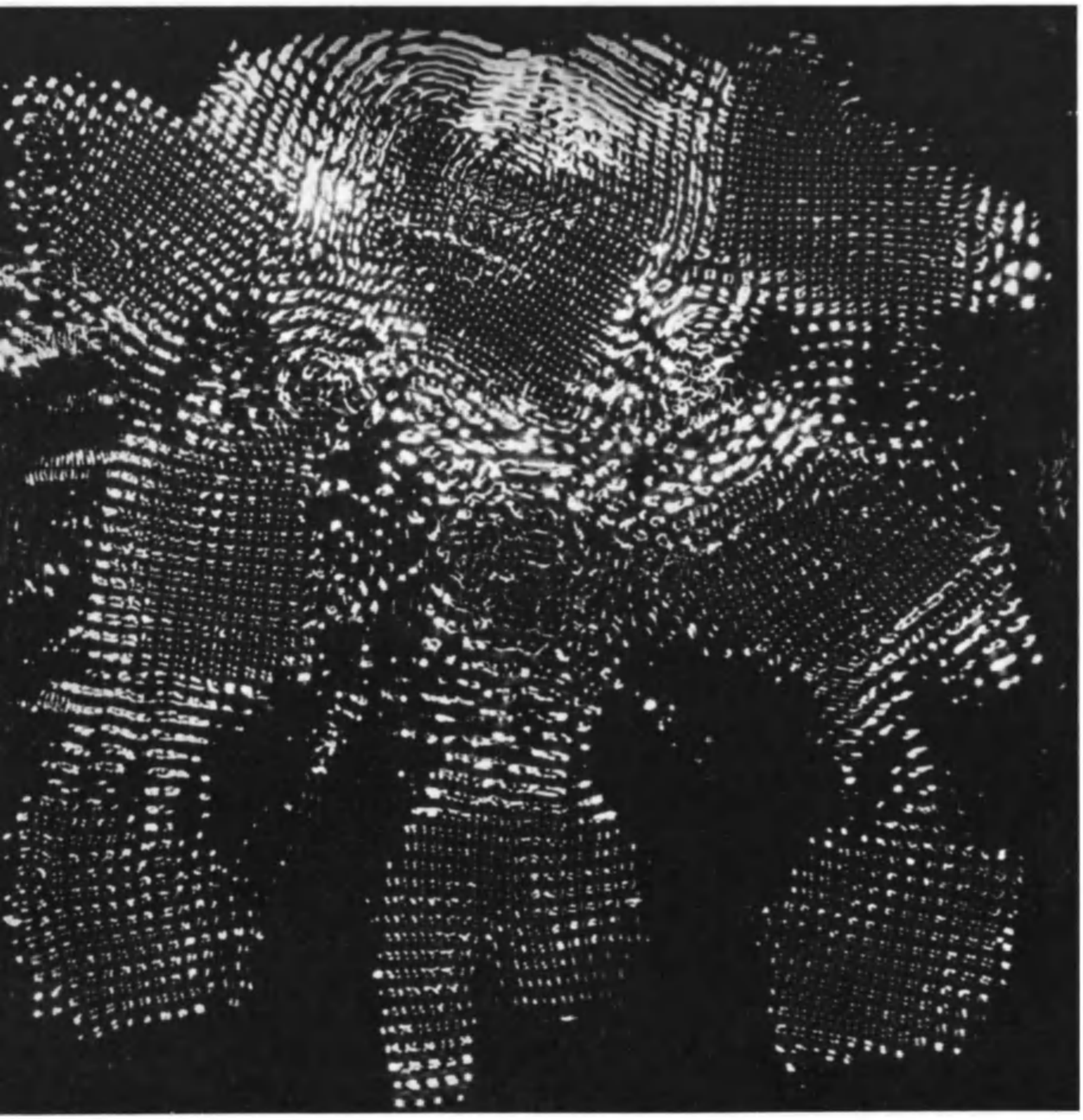


Photo © J.C. Stuten

BACH'S TOCCATA IN D MINOR

The musical notes shown in tiny photo below are a sound from the 28th bar of the famous Toccata and Fugue in D minor (ist movement) for the organ by Johann Sebastian Bach. Photo left shows the same musical note as revealed by cymatics. Vibrational figures reproduce all music precisely, but if we look at these passages on a silent film, we can at first make nothing of them, the eye being unaccustomed to "seeing" music without the guidance of the ear. When the music is heard simultaneously, the aural impression quickly becomes a visual one.

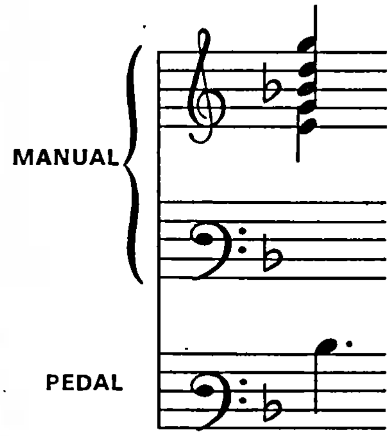


Photo © H.P. Widmer

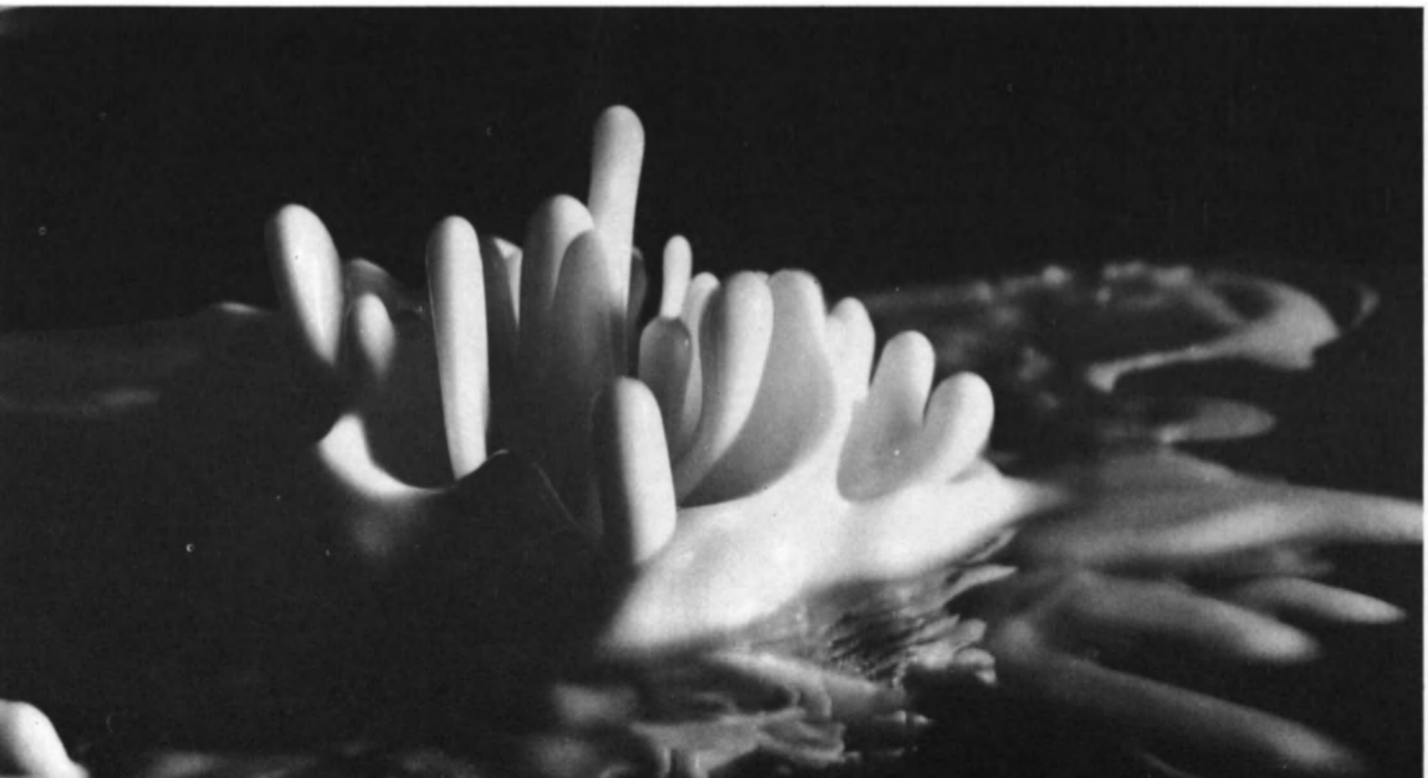
FRENZY OF A CYMATIC BALLET

These shapes, leaping and gyrating like dancers in a frenzied ballet, are some of the dynamic "sculptures" created during a series of experiments that demonstrate the amazingly diverse effects produced by vibration under certain conditions. In these experiments, a viscous fluid is poured onto a vibrating membrane, producing first one and then a series of annular waves. By modifying the frequency, and the viscosity of the liquid, a changing world of new forms is created, some of which are shown on the following page.

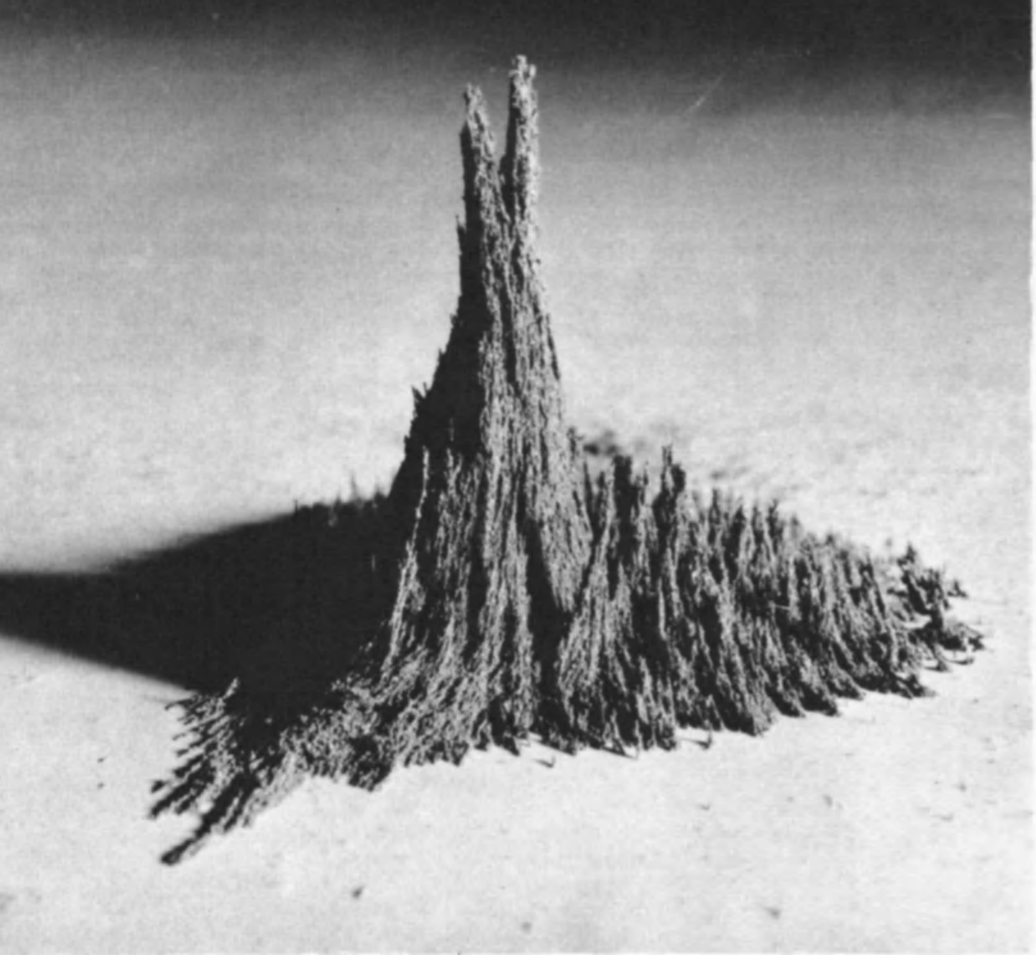
THE SOUND AND THE FURY

Suggesting the storm-tossed waves of an ocean or a sea of molten lava surging under the impact of volcanic forces, these remarkable photos show a laboratory-size storm, created by vibrating a liquid with the aid of sound waves. Increasing the vibrations produced by an oscillating diaphragm conjures up iceberg-like waves (right). When the liquid is made more fluid and greater vibrations are used, the waves rise still higher, lifting into plates, pillars and peaks (below left). Finally, the mass of liquid, filled with pulsations, currents and turbulences, flings up with dynamic force tiny droplets that form a curtain of flying spume (below right). The experiment can be continued until the liquid is completely transformed into spray.

Photo © J.C. Stuten

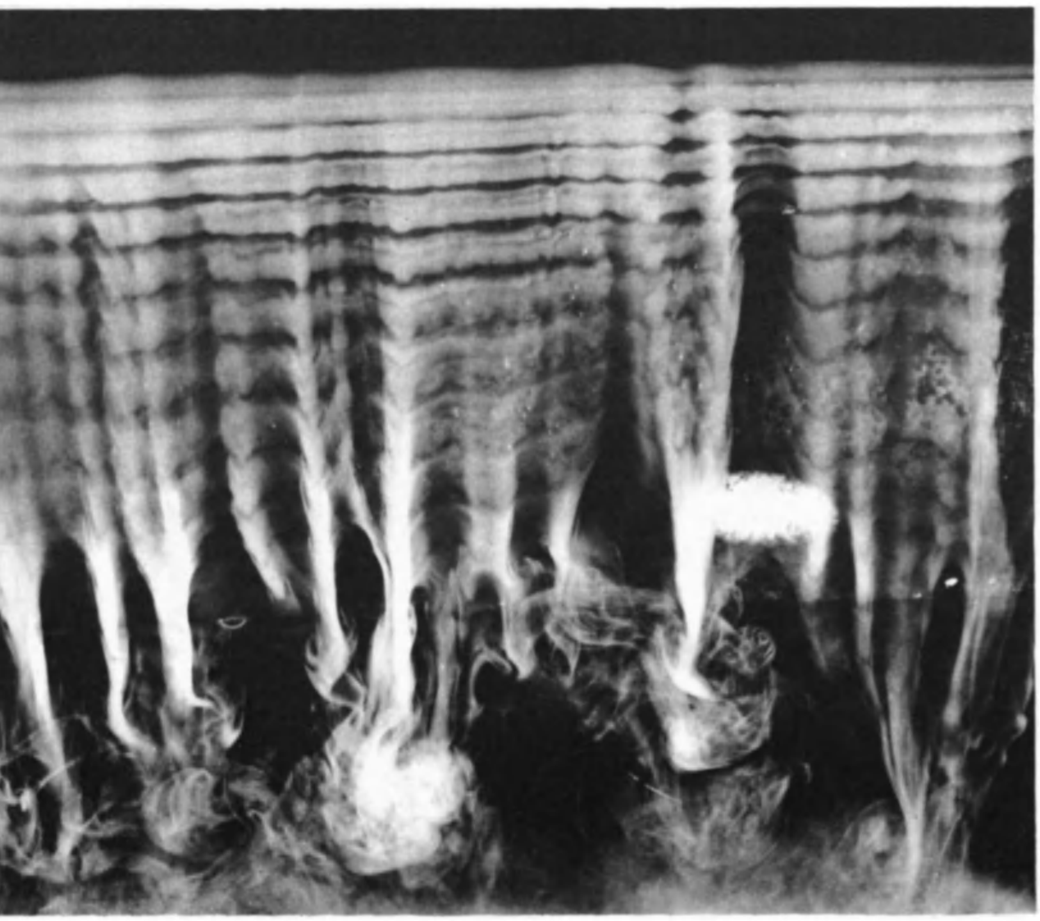


Photos © H.P. Widmer



IRON FILINGS AND SMOKE IN HIGH PITCH

Iron filings when vibrated in a magnetic field produce the craggy peak effect seen above. Oscillation reduces the adhesion between the particles, providing them with extra freedom of movement. Filings thus strewn in a magnetic field subjected to vibration form mobile shapes which seemingly dance in the vibrational field. Here, camera has temporarily frozen the dance of the iron filings. Below, a downward stream of smoke takes on a fabric-like appearance when irradiated by high frequency sound. Becoming turbulent, the gas is sensitized to sound; structures appear, their form depending on the sound waves.



Photos © H.P. Widmer

CYMATICS *(Continued from page 12)*

the sounds correctly. In the same way he can learn to pitch his voice right and consciously regulate his flow of breath when speaking.

To give some idea of the richness and diversity of cymatic effects we will look at one example more closely. If vibration is applied to lycopodium powder (spores of the club moss), the results are curious and specific. The particles of this powder are very fine and of even consistency. If a plate or diaphragm on which the powder has been uniformly strewn is excited by vibration, a number of circular piles of powder form (photo below right).

This clumping in circular heaps is extremely characteristic of cymatic effects. These piles are in a constant state of circulation, i.e. the particles are transported from the inside to the outside and from the outside back to the inside by the vibration. This circulation is particularly typical of the action of waves.

If the tone is intensified, which is perceived by the ear as a crescendo, the circular heaps gravitate together and unite in a larger heap, which, however, continues to circulate (photo above right and centre spread, colour photo number 4). If the tone is intensified still more, the masses are flung into very violent motion. They are thrown or even hurled out, yet the process of circulation still continues.

ACTUAL currents can also be produced in lycopodium powder. The powder rushes along precisely defined paths (photo page 30). If new material is cast into such an area of currents, the result is not chaos; instead the freshly added masses are immediately assimilated into the system of the vibrational field. Throughout all the changes and transformations the dynamics of the figure and the figuration of the dynamics are preserved.

When these conglobations move, they do so in a characteristic manner. They invariably move as a whole, and if a process is put out, the rest of the heap creeps after it just like an amoeba. There is no crumbling or disintegration. Whether the heaps unite to make larger ones or whether they break up into a number of smaller piles, they invariably form *whole* units. Each of them is participative in the *whole* in regard to both form and process.

This brings us to a particular feature of vibrational effects: they may be said to exemplify the principle of wholeness. They can be regarded as models of the doctrine of holism: each

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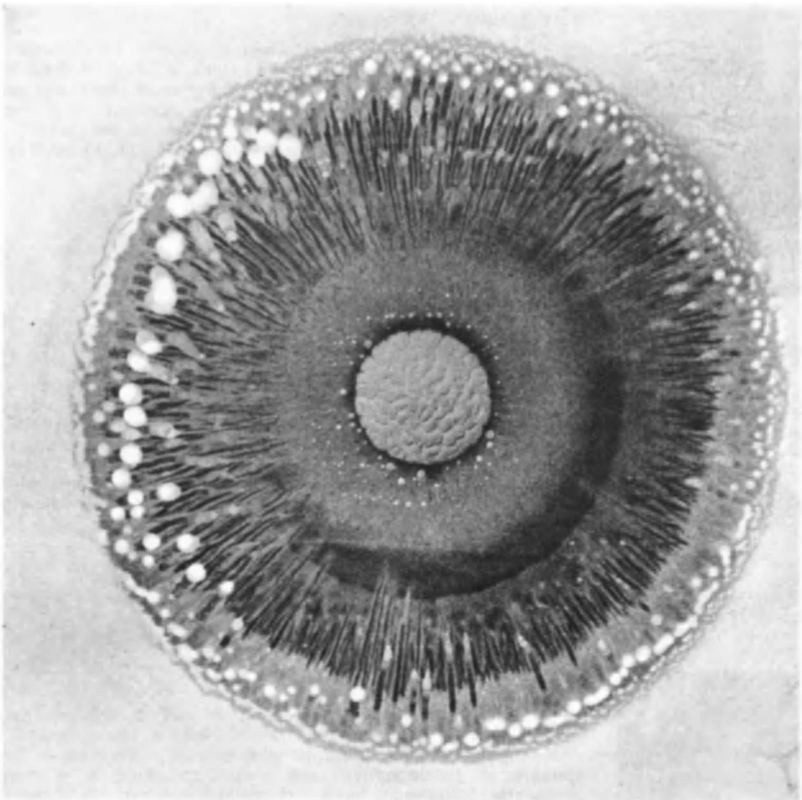
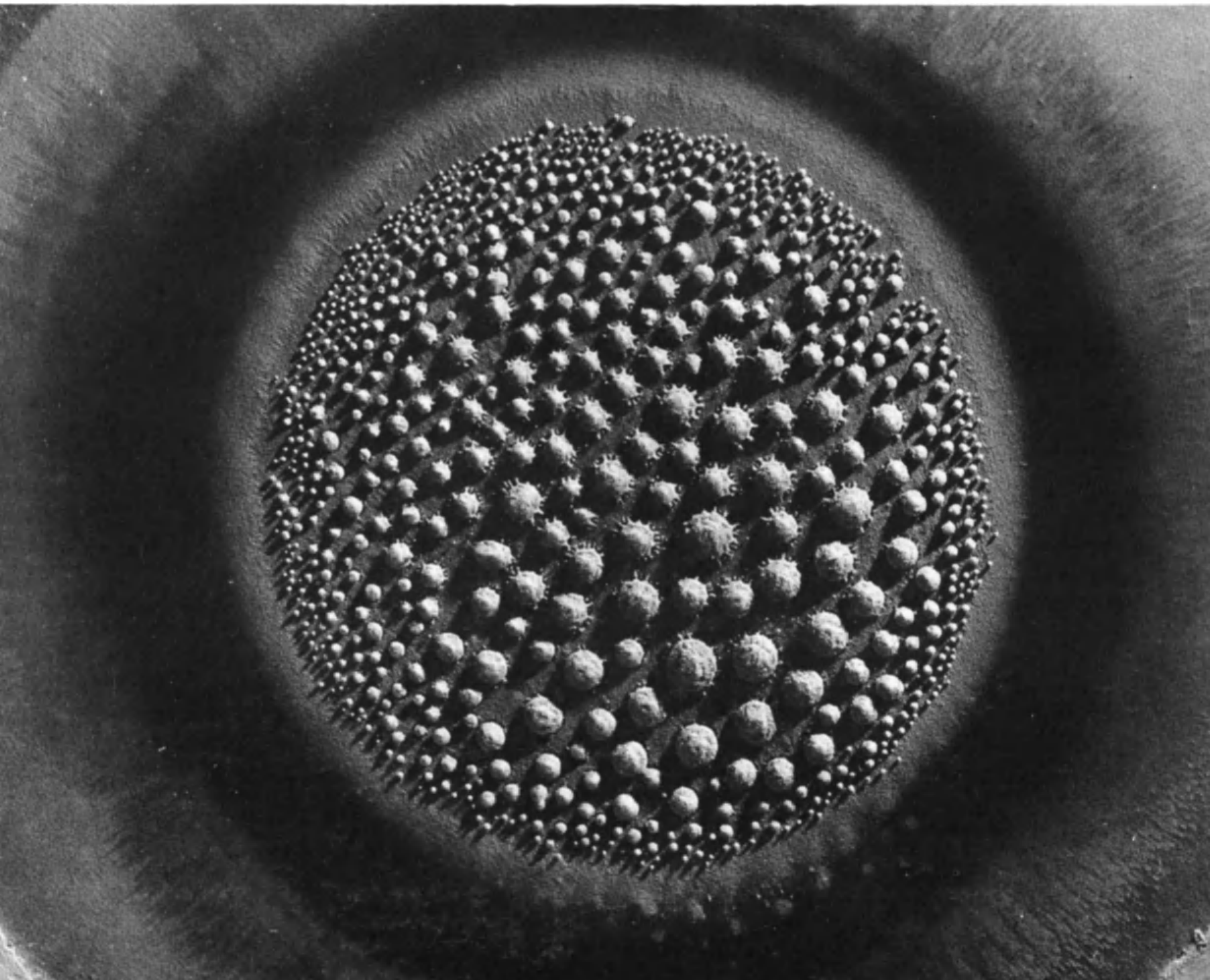


Photos © J.C. Stuten

MIGRATION TO THE CENTRE

When the spore powder of the club moss (lycopodium) is spread evenly on a vibrating diaphragm, it forms a galaxy of tiny piles (photo below). Each pile rotates on its own axis and also rotates as a single body like the elements of our solar system. When the vibrations are increased the piles migrate towards the centre (photo left) in which the paths of migration can be seen as streaky lines. While forming large central pile, they continue to rotate on the diaphragm.



single element is a whole and exhibits unitariness whatever the mutations and changes to which it is subjected. And always it is the underlying vibrational processes that sustain this unity in diversity. In every part, the whole is present or at least suggested.

To study vibrational effects in space, first of all drops were made to vibrate. Experiments with mercury showed that the oscillating drops moved in regular forms. Systems in arithmetical series of 3, 4, 5, 6, 7, etc., appear, so that it is legitimate to speak of harmonics and symmetry. Pulsating drops of water also reveal this polygonal arrangement with the difference, however, that the liquid travels regularly from the centre to the periphery and from the periphery back to the centre.

It must be imagined, then, that these vibrations take place roughly in systems with 5, 4, and 3 segments. The pictures formed are strikingly reminiscent of the shapes of the flowers of higher plants. Thus a true harmony becomes apparent in the series of cymatic processes.

WE are taken still further into the three-dimensional when soap bubbles are excited by vibration (colour photo number 8 and photos page 27). These reveal a regular pulsation and might be visualized as "breathing spheres" The higher the tone producing the oscillation, the larger the number of pulsating zones.

Curious phenomena result from the fact that adhesion between materials and the supporting surface of plates or diaphragms is reduced by vibration. The particles or masses acquire a certain freedom of movement as a result of the reduced adhesion. If, for example, iron filings are placed in a magnetic field on a vibrating diaphragm, adhesion between the filings and the surface is reduced and they become to some extent mobile. They form figurines which appear to dance in the magnetic field and by their motion reveal its density and configuration (top photo page 16).

Changes in the state of matter are also strangely influenced by vibration. For instance, if a blob of hot, liquid kaolin paste is allowed to cool while being vibrated, it does not solidify in a uniform mass but is so twisted and churned that curious branch-like structures are formed which are due simply and solely to vibration.

The experiment results in a whole array of structured elements which eventually solidify (colour photo number one).

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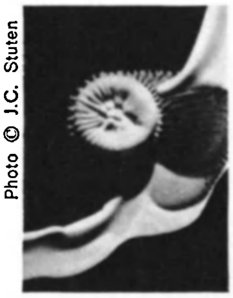

Photo © J.C. Stuten

1. KAOLIN CAKE

Curious configurations occur when a material is vibrated while it is changing from liquid to solid. Here a blob of heated kaolin paste forms a ribbed cake-like structure as it cools and solidifies. The ribbed pattern pulsates and pushes currents of plastic kaolin up the sides and down through the centre of the "cake". As the kaolin grows rigid, branch-like formations begin to appear on the outer ribs of the vibrating mass.

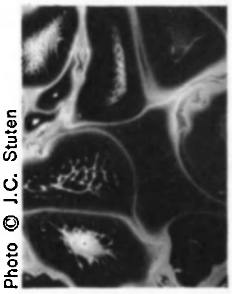

Photo © J.C. Stuten

2. THE RHYTHM OF INDIA INK

These flowing whorls and meandering currents, made by drops of red emulsion placed in a solution of black India ink, show a periodic process in which no outside vibration is used. The emulsion slowly diffuses into the ink with a periodic, rhythmic to and fro movement, creating a pattern of thick serpentine spurts and delicate formations that vanish like wisps of mist. It must be imagined that everything is not only flowing, but actually flowing in patterns and rhythms.

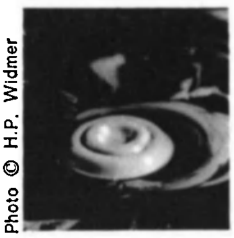

Photo © H.P. Widmer

3. PHANTOM POTTER

This perfectly shaped double ring is not a finished design in porcelain turned on a potter's wheel. It is a "fluid figure" formed when highly viscous liquid is vibrated on a diaphragm. Its static appearence is deceptive. The entire structure is in movement, constantly rotating, with material flowing to the centre and back again, the whole generated and sustained entirely by vibration. (Other shapes created in this experiment are shown on pages 11, 13, 14 and 15.)

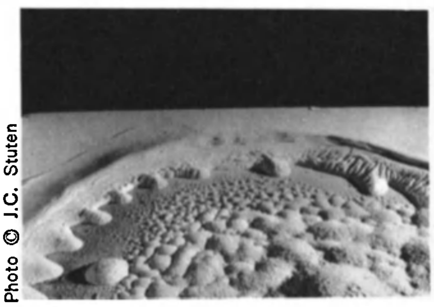

Photo © J.C. Stuten

4. LANDSCAPE IN THE ROUND

This dusty, petrified looking landscape, recalling photos of the moon's surface, is composed of spores of the club moss (lycopodium powder) set in motion by vibration. Each circular mound of fine powder, both large and small, is rotating on its own axis and the whole surface is in itself rotating and pulsating. Patterns change according to the frequency of vibration. Increasing it can create "sand storms" or unite tiny mounds into a single large one, as seen in photos on page 17.

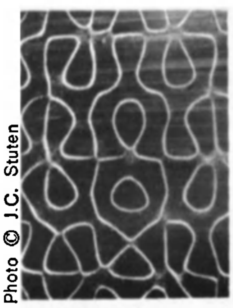

Photo © J.C. Stuten

5. THE SOUND OF COPPER

Inspired by the research of Ernst Chladni, the 18th century German physicist and musician, who first demonstrated the modes of vibration of solid objects, Hans Jenny, using more sophisticated techniques, has assembled a collection of "sonorous" figures. Sound pattern shown here was created on a steel plate strewn with copper filings, and corresponds to a frequency of 2,200 cycles per second.

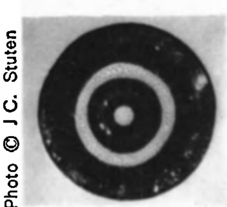

Photo © J C. Stuten

6. VOWEL 'O'

The vowel "O" produces this vibrational pattern when spoken into the tonoscope, or sound-seer, an apparatus designed to visualize the basic components of human speech. Using the tonoscope, deaf and dumb persons can familiarize themselves with normal patterns of speech and practise producing the same sound forms.

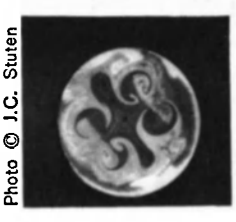

Photo © J.C. Stuten

7. SOUND PATTERNS IN THE EAR

In these vortex patterns we see a vibrational model of the hydrodynamic behaviour of the cochlea, (the conical spiral tube where hearing takes place in the inner ear, and where vortexes are formed by the action of sound). Vortexes, made visible by adding marker dye to liquid, are rotating continuously in opposite directions. The louder tone, the more rapid the rotation.

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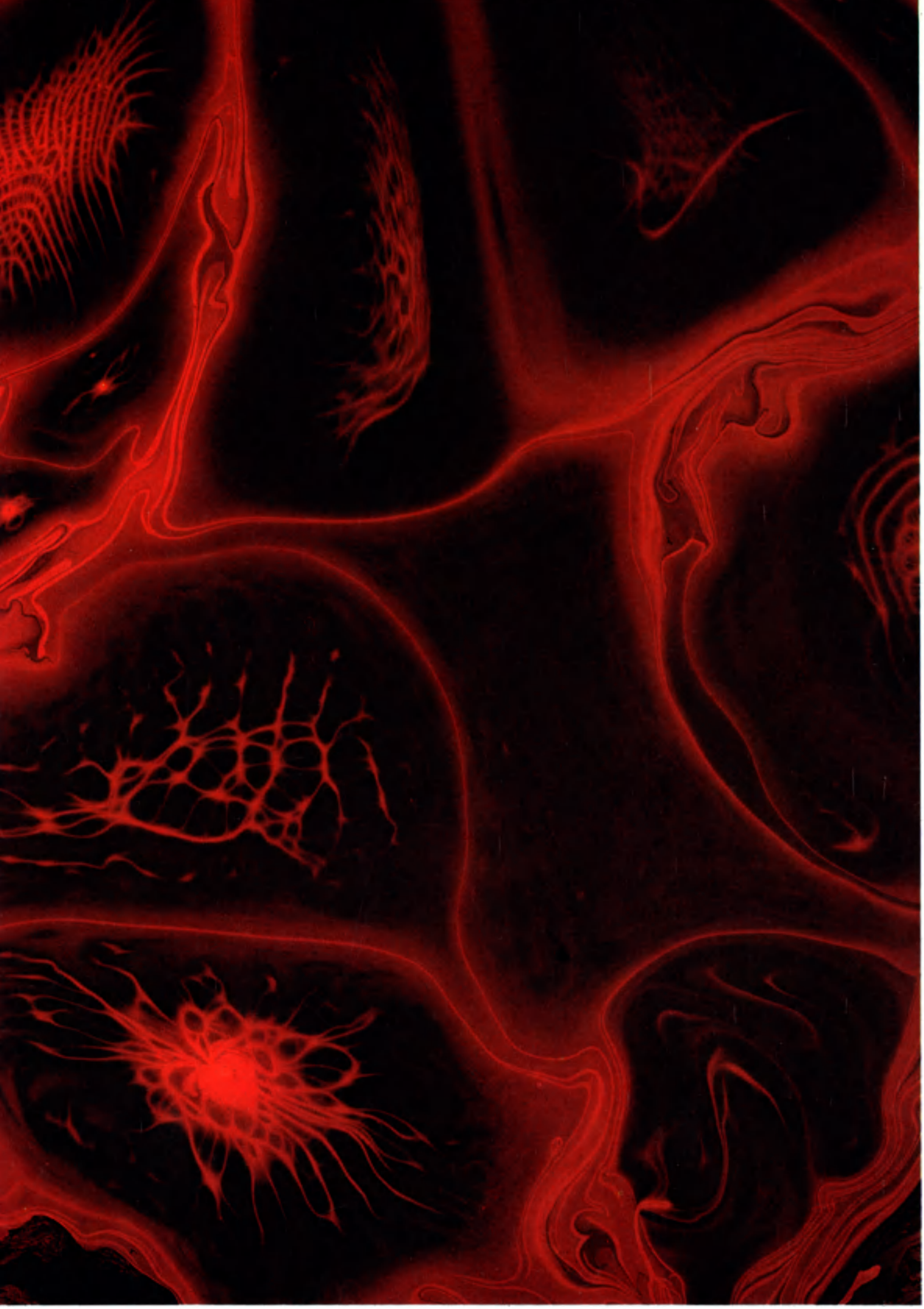

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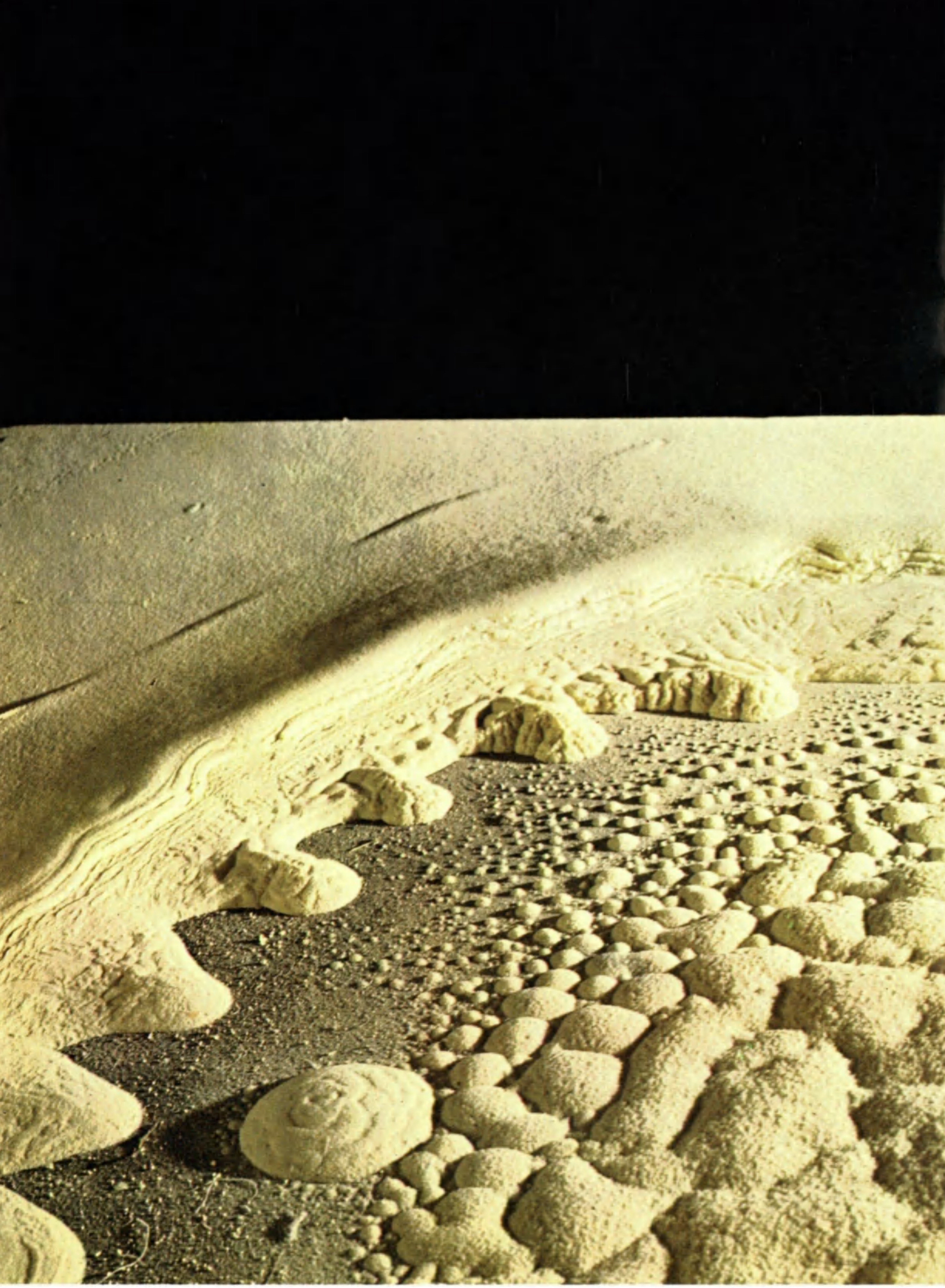

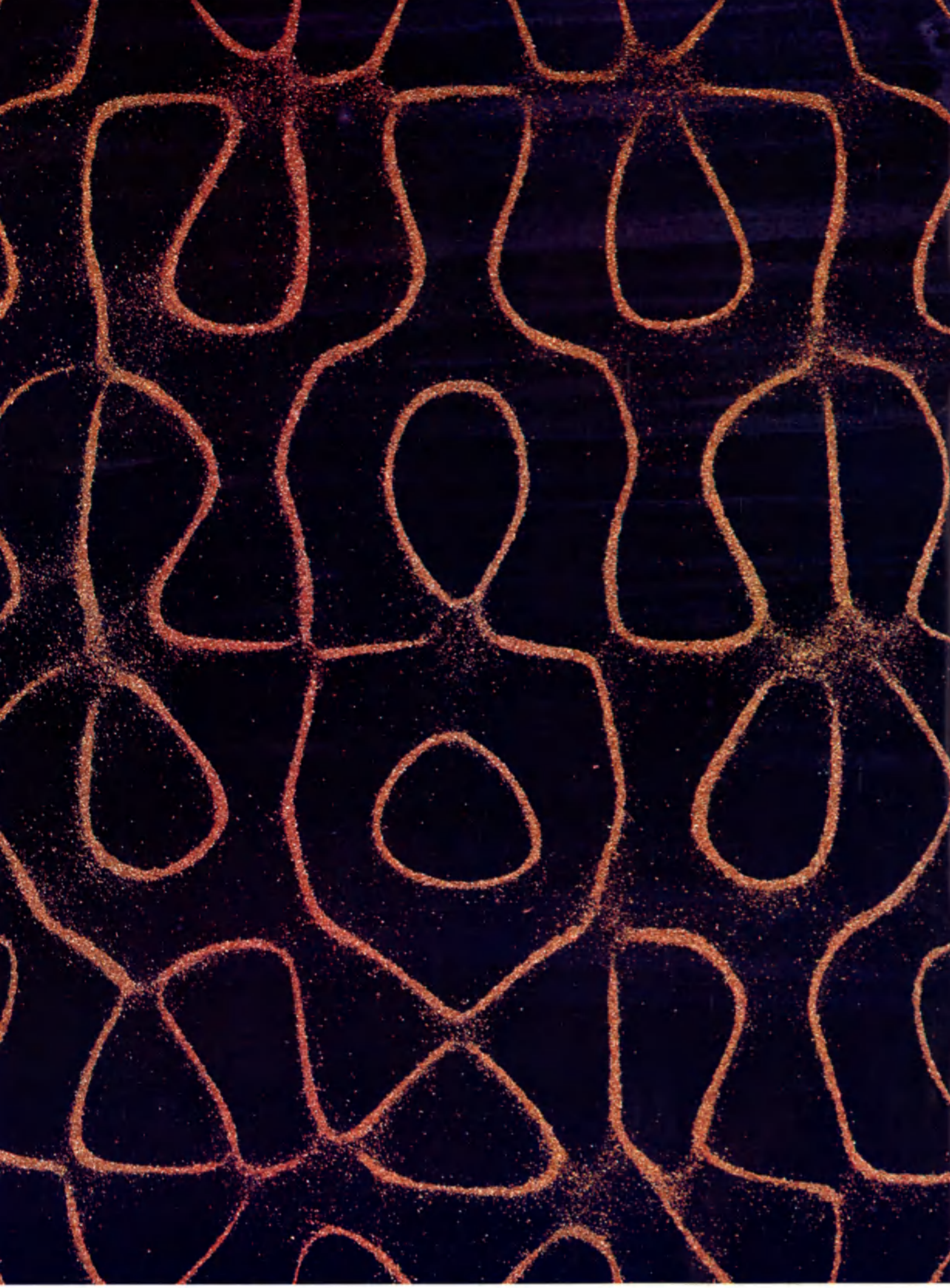

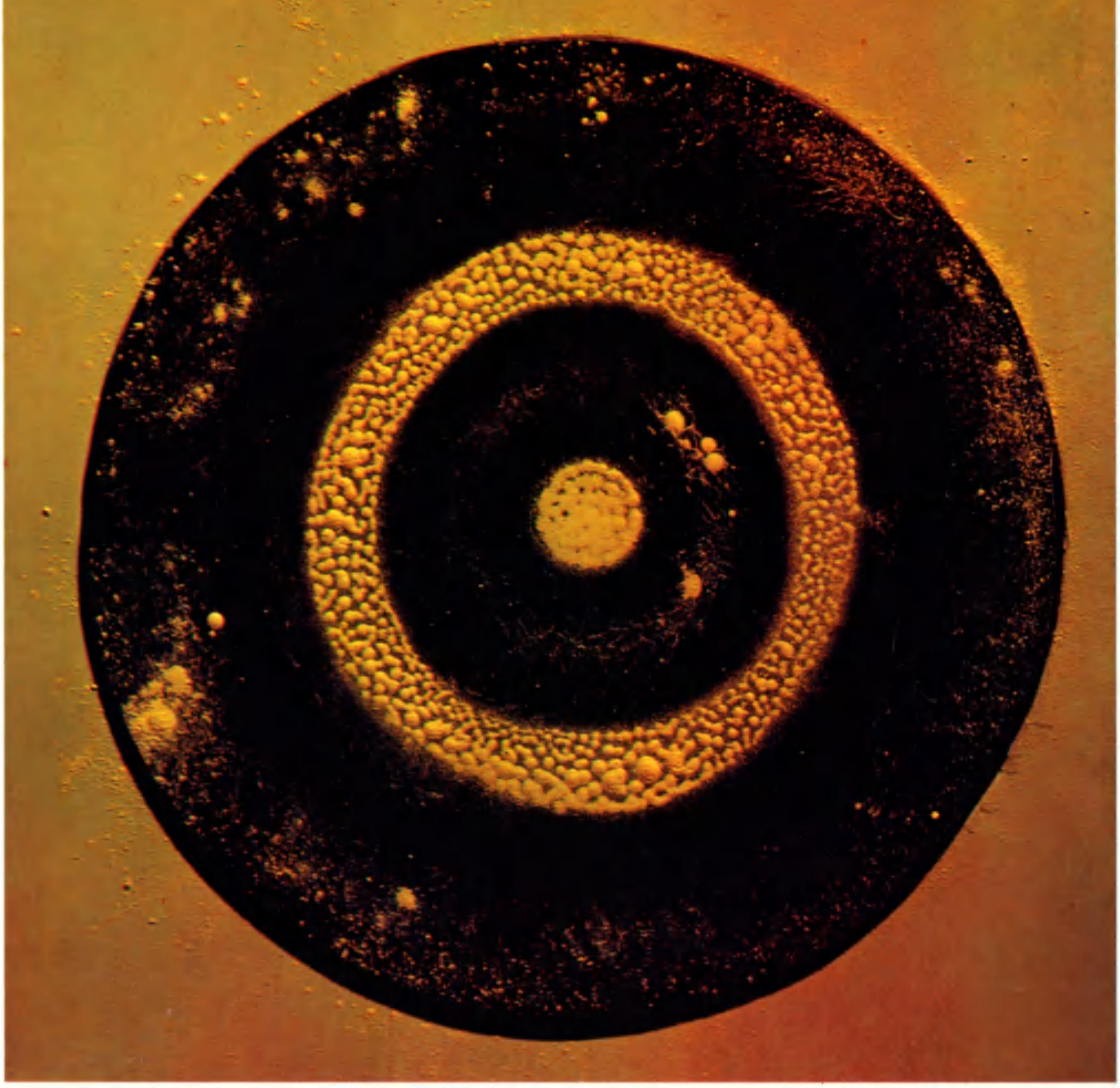

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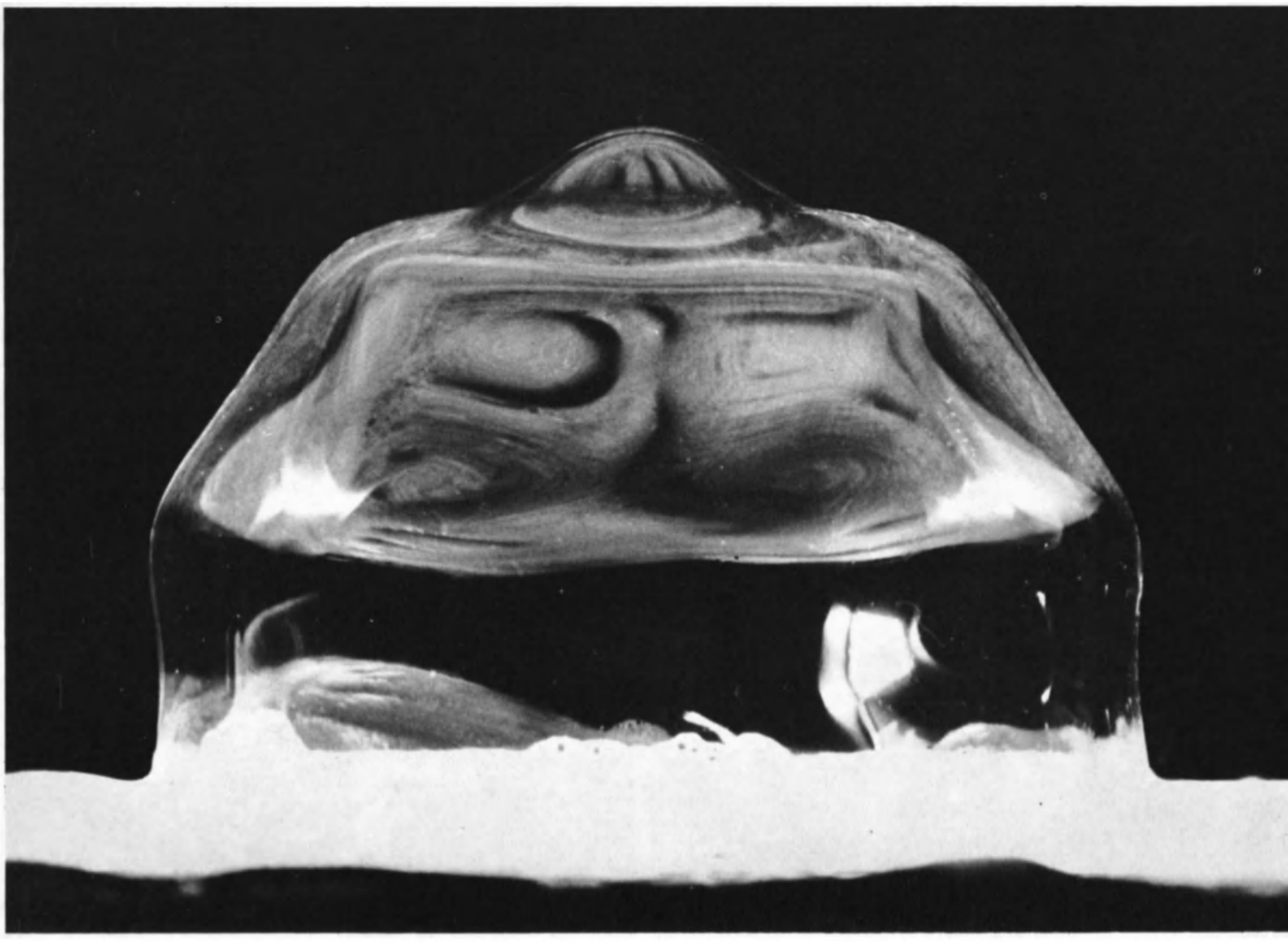
BUBBLE DANCE

Some strange things can happen to an ordinary soap bubble when it is made to vibrate on a diaphragm. One can almost say that it starts to "breathe" as rhythmic pulsations gather strength inside its surface. The original sphere begins to change shape. Photo right shows an early stage of pulsation, becoming more complicated, below, as vibrations increase. Pulsations occur in regular zones. Colour photo, opposite, shows whole soap bubble, resembling a lovely crystal wine-glass, in full oscillation. They show how three-dimensional shapes are structured by vibration.

Photos © J.C. Stuten



DOES SOME UNIVERSAL LAW GOVERN FORMS IN NATURE?

The forms and configurations resulting from experiments in varying the pitch of vibration often bear so strong a resemblance with structural patterns found in nature, be it in plant or animal life or the world of minerals, that one is tempted to see here some fundamental law governing the creation of all forms in our universe. The perfect honeycomb structure, left, was obtained by vibrating a liquid with high frequency sound waves. The sculptured form resembling a growing bud or coral formation, below, was created by varying the frequency of vibration of a viscous liquid. The fishbone pattern, bottom right, was made by sound vibrations in a film of glycerine. Cowrie shell or bean shape, bottom left, was produced when a paste-like substance was made to vibrate.

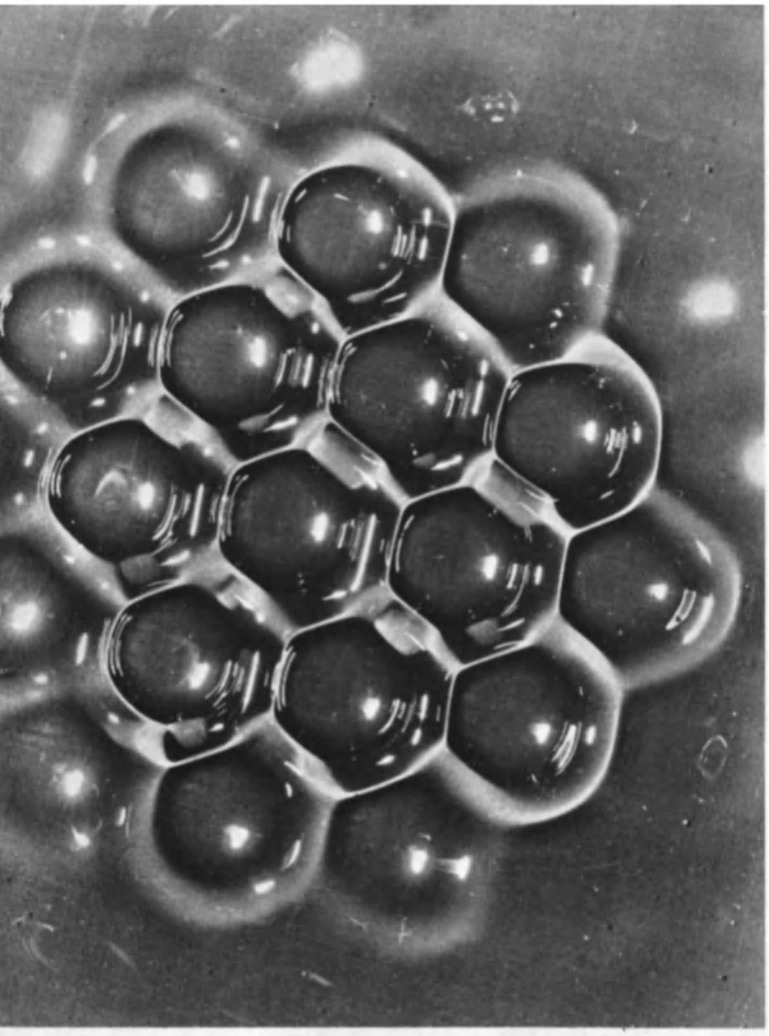
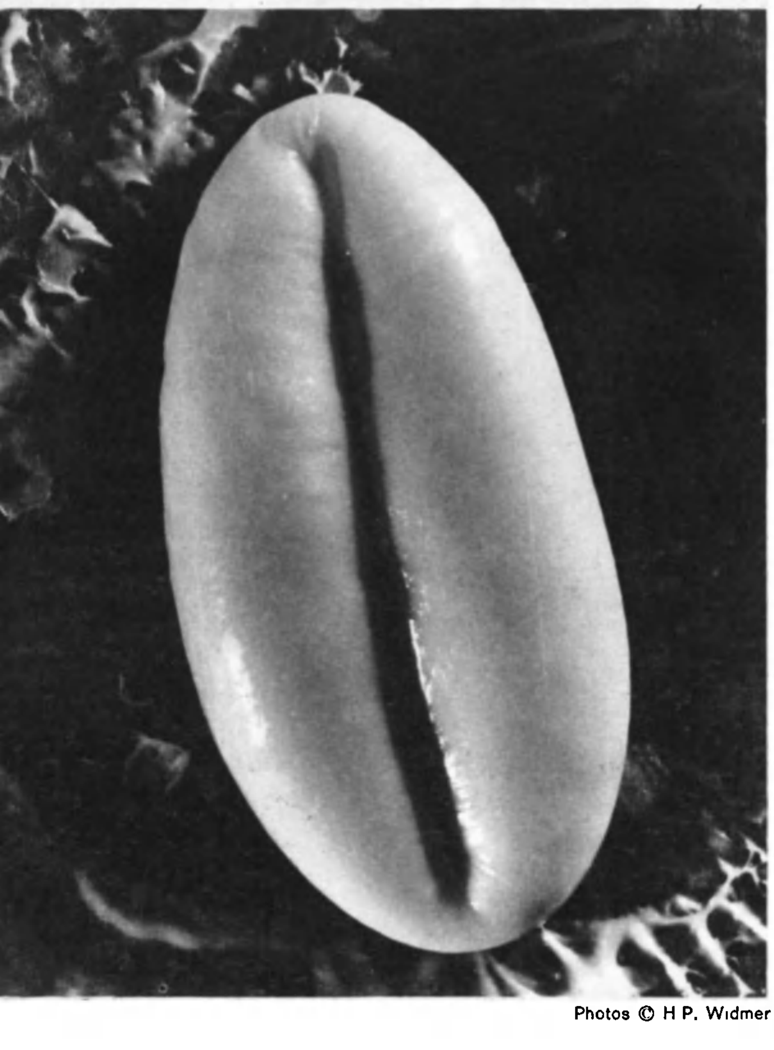
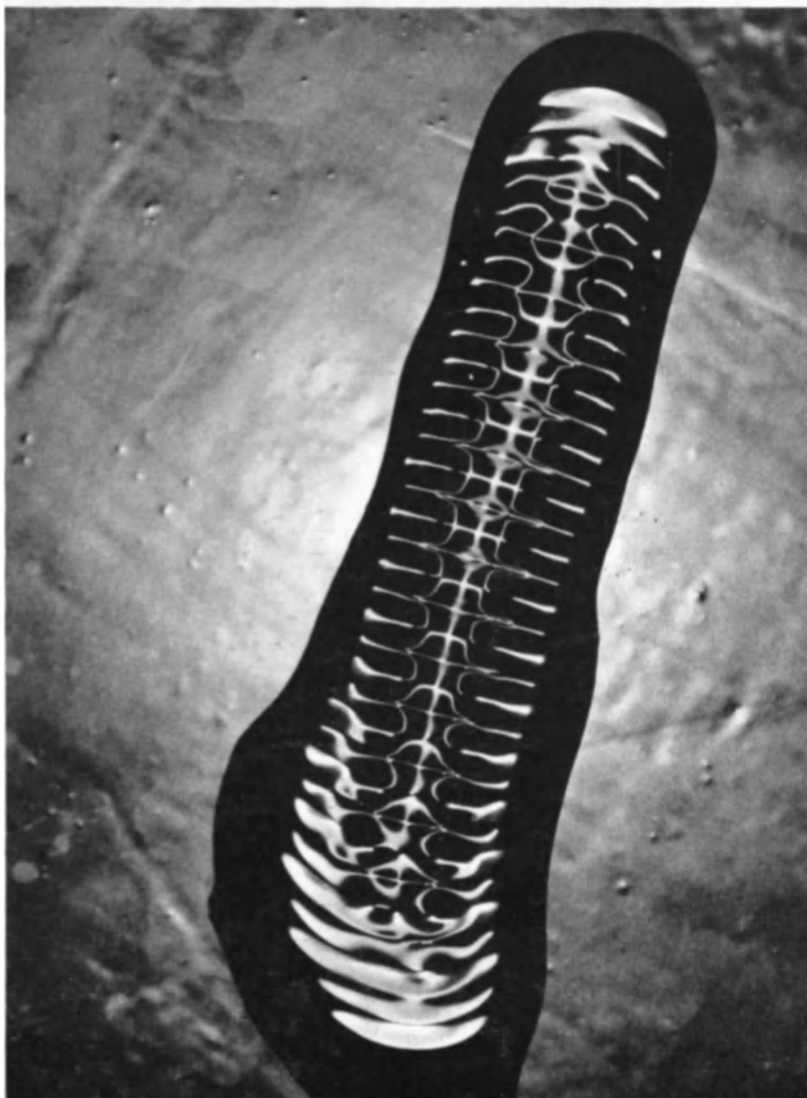


Photo © J.C. Stuten



Photos © H P. Widmer



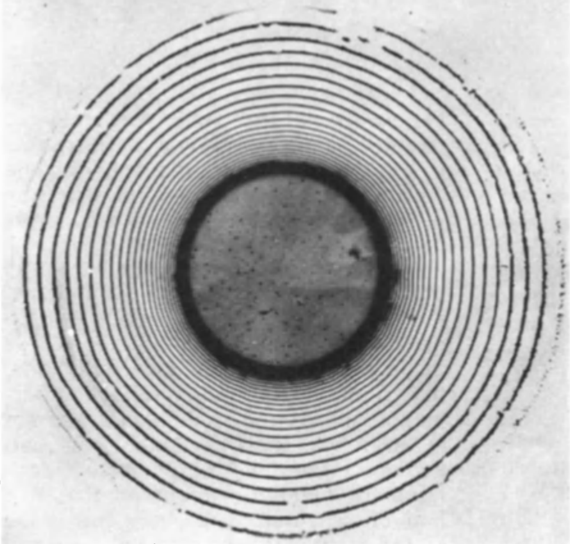


Photo © H P. Widmer

Nature is permeated by periodic and rhythmic processes in many of which no actual vibration is involved. Circles, left, known as "Liesegang rings", demonstrate one well known periodic process in the field of chemical reactions. When potassium bichromate is combined with silver nitrate it forms silver chromate in a remarkable way: concentrating the silver chromate in a series of concentric rings proceeding from the centre to the periphery in ever larger circles.

3 - The vast spectrum of cosmic vibrations

THE examples we have given will afford some idea of the wide field of research opened up by vibrational effects. By scrutinizing these curious structures, figures, flows and movements, we widen our range of vision. We are alerted to many things which had hitherto gone unnoticed. Suddenly we realize to what extent nature is permeated by rhythms and periodicities.

It will be recalled that periodicity is characteristic of organic cell tissue. The elements of organisms are repeated as fibre networks, as space lattices, and quite literally as woven tissues with an infinite diversity. The rhythms of these forms are apparent to the naked eye. The leaf patterns of plants are an example. But in both the optical and the electron microscope the law of repetition still prevails.

In everyday life we meet with other examples of rhythm, seriality and periodicity. Every water jet, every water surface, every drop of water reveals complexes of a cymatic nature. Whole oceans of wave trains, wave fields and wave crests appear in cloud formations. The smoke rising from a chimney forms vortices and turbulences in a periodic manner. Wave formation, turbulence, pulsation and circulation are to be found throughout the fields of hydrodynamics (colour photo number 2) and aerodynamics.

By seeing all these phenomena as an integrated whole the observer comes to develop what is really an intuitive faculty for rhythmic and periodic things. He begins to appreciate the cymatic style of nature. This applies with particular force to the creative artist. Numerous contacts with architects, painters, graphic and industrial designers have shown that for them cymatics cannot be merely a matter of copying sonorous figures or adopting them purely as decoration.

A productive confrontation with cymatics lies rather in this: let us suppose that someone is working with geometrical shapes, say with squares or circles. Using these elements he constructs his designs. But the forms he is handling are finished and complete: the nascent element is absent. Yet he must be aware that everything has its origin and genesis.

Now this generative process is one that he can experience particularly well in the field of waves and vibrations. On seeing a sonorous figure take shape, one cannot help but say: the creative process is just exactly where "nothing" can be seen, and the points whither the particles of sand and powder are carried are the very places where there is no movement. The figure must take shape out of its environment; bound up with the finished form is the circumambient space creating it. With each thing shaped goes the experience of that which shapes it; with each thing fashioned, of that which fashions it. In this way the space round things becomes vitalized for the sculptor, the architect and the painter. The rigid form is seen in terms of that which gave it birth.

But the converse case is also illuminated by the study of cymatic processes. Let us suppose someone's interest is focused on kinetics, on moving elements and the interplay of forces. Then he is confronted by the problem of how a configuration can emerge from such a mobile system. How is a dynamic process related to form, to a specific figure? Here again, thinking of the problem in terms of vibration provides the answer, for however great the changes and transformations, precise figural aspects prevail in the vibrational field. Even turbulences, for all their instability, have a formative, repetitive element.

Hence wave phenomena and vibrational effects form a kind of totality (colour photo number 3, and photos pages 11, 13, 14 and 15). They throw an explanatory light on the process of formation as much as on that which ultimately takes shape; they illuminate movement as well as the stationary form. And here again it is a question of looking behind these fixed forms to see what generative process leads to them. The obvious procedure is to find out what stages precede the figured shapes and to scrutinize them closely. And this brings us to the significance of cymatic phenomena.

First of all it must be said that mere similarity between natural phenomena and the results of experiments do not warrant the conclusion that there is any essential identity. Undoubtedly many wave effects look like various natural phenomena. But interpretation and analogizing lead nowhere; they miss the heart of the matter.

What is involved here is this. The observation of vibrations and waves yields a whole series of specific and particular categories of phenomena. It also shows that these diverse elements appear in a vibrational system as a whole. In one and the same vibrational system we find structural, pulsating, and dynamic-kinetic features, etc. Thus we can say that when dealing with vibrational systems, there will appear in them, appropriately transformed, the cymatic effects we have observed in our experiments.

Experiments thus provide us with conceptual models which can stimulate research. Needless to say, each field must be understood in its own terms. However, experience with cymatics tutors the intuitive faculty in such a way that attention is drawn to many interrelated facts which would previously have gone unheeded. Thus while it must be firmly reiterated that all interpretation is pointless, it must be borne in mind that in actual fields of experience the effects of natural cymatics must be apparent.

Let us take the example of astrophysics. There can be no doubt that in this field specific vibrational effects must appear on the lines we have indicated. A compilation of cymatic phenomena embraces a whole range of features and relationships for which appropriate verification must be discoverable in astronomy, whether

CONTINUED ON NEXT PAGE

planetary, solar, or galactic. From this point of view it is self-evident that in the vast energy processes of the cosmos, oscillating and vibrating systems must become manifest in conglobations, rotations, pulsations, circulations, interferences, vortexes, etc.

In this connexion, for instance, experiments have been made in which materials reacting to magnetic influences have been observed under the action of vibration in the magnetic field (photo page 4). Thus in magnetohydrodynamics remarkable elements appear which owe their character entirely to vibration. In both structural and dynamic respects these magnetohydrodynamic events are characterized by vibration. It would be legitimate to speak of magnetocymatics. What has to be done is to find corresponding phenomena in cosmic magnetic fields.

It is certainly not our intention to encroach on the preserves of astronomers and astrophysicists. Our only purpose is to report on the results of this or that series of experiments. How the corresponding patterns take shape in the cosmos can only be determined by research in that particular field.

Biology might also be adduced as a further example of the way in which conceptual models can be abstracted and serve for research purposes. In particular, cymatic research can penetrate into the very heart of the biological field. The phenomena reported in this study are all macroscopic. However, it has proved possible to demonstrate cymatic effects in the microscopic dimension, i.e. it is possible to apply the cymatic method in all its variations to cell processes.

These current investigations open the way not only to observing cell processes with respect to their rhythmic and oscillatory characteristics but also, and more importantly, to studying the influence of vibration and its effects on healthy and sick tissues and on normal and degenerate cells. That the carcinomatous (cancer) process should loom large in the field of study follows inevitably from its very nature.

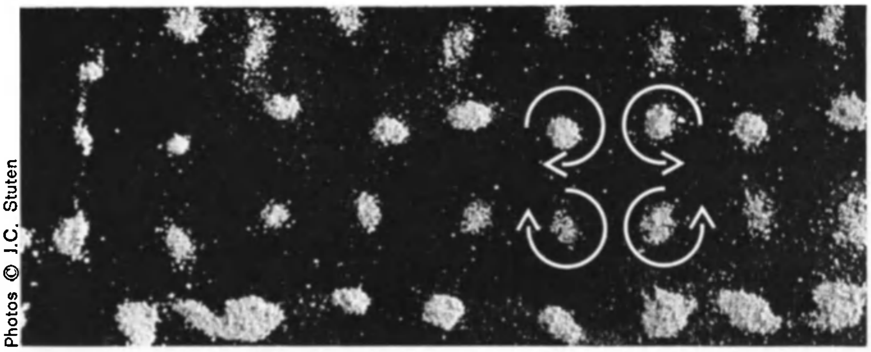
The task confronting us, then, is to induce specific vibrational effects in cellular events and to scrutinize the structural and functional results with respect to cell division, cell respiration, tissue growth, etc. selectively.

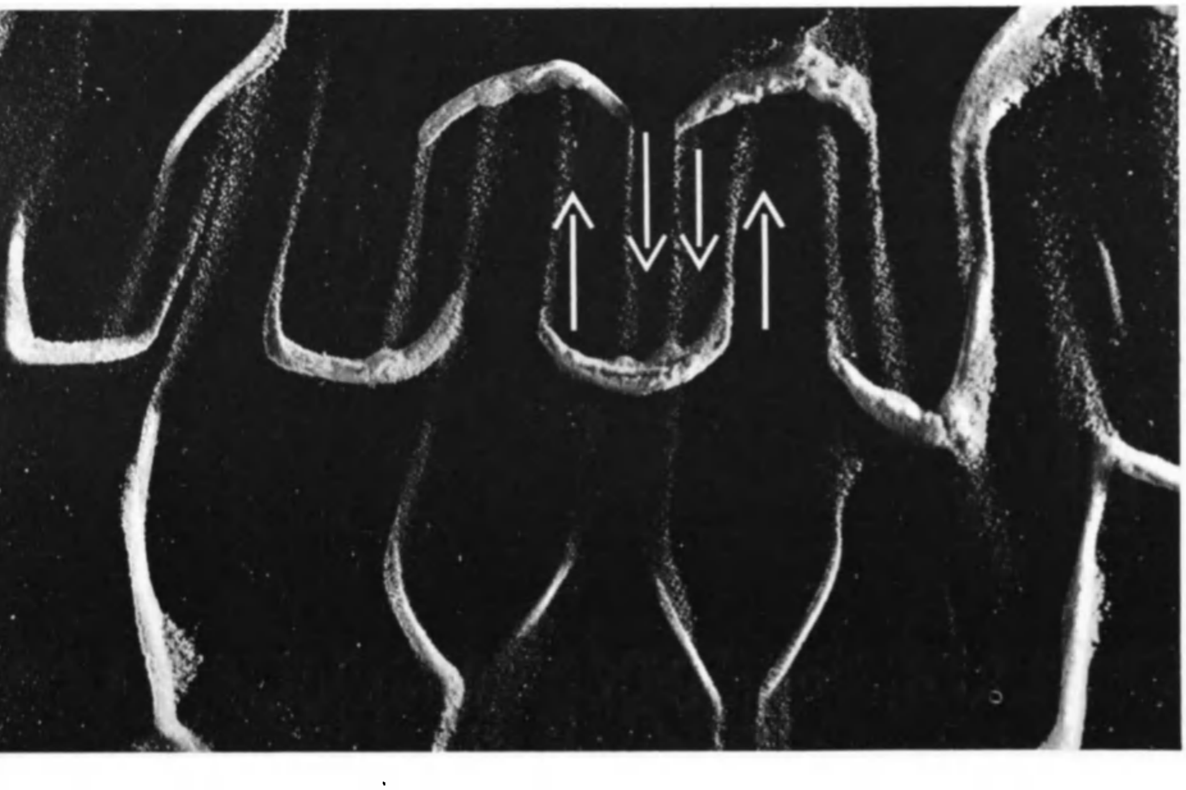
In this way the models and basic phenomena of experimental physics are brought into conjunction with ideas of vibration as a cosmogenic element which Rudolf Steiner, inspired by his research in the sphere of the mind and spirit, formulated 60 years ago regarding astrophysics and biology.

The work summarily reported here is in full swing. One series of experiments is followed by another. It lies in the character of the subject that each experiment points the way to the next; the investigator is led by Nature from one stage of study to another. And on the way he observes a number of periodic phenomena which are not produced by vibration in the strict sense of the word.

In this connexion we might single out rhythmic chemical precipitations, the so-called Liesegang rings (photo page 29) rhythmic crystallization, rhythmic processes in colloidal solutions, the periodic formation of semi-permeable membranes, etc. Thus there is evidence that periodicity is also active in the field of chemical reactions. (It might be intimated that this line of research is bringing us close to the problems of catalysis).

Where do all these experiments lead? What significance can they have for human life in general? Quite apart from all the many practical applications adumbrated by these studies, one aspect is paramount: they teach us to observe the world in such a way that our experience of it is stimulated, enriched and deepened. But besides its richness, this experience enables the scientist and the artist, the investigator and the designer, and thus basically every man, to develop his own essential being and personality. ■



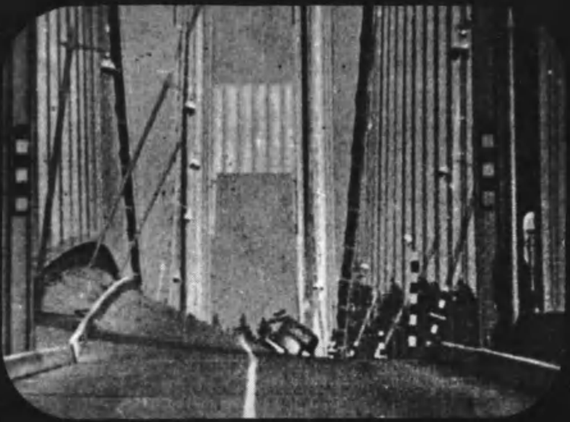


These two photos (above and left), are not only interesting graphically in themselves, but show a most extraordinary phenomenon of our vibrating whirling universe. In each photo granulated substances —quartz sand above, lycopodium left—have been made to vibrate on a steel plate. Note especially the arrows showing small round areas and streams of particles rotating and flowing in clockwise and counterclockwise directions. Vibrated at 8,500 cycles p/sec, the lycopodium forms into moving streams. Vibrated at a higher frequency, 12,460 cycles p/sec, the quartz sand moves into round heaps that rotate. The reason for the contrary rotations and flow is not precisely known, but the currents would seem to be moving as if in obedience to a law of physics.

1

DEATH OF A BRIDGE BY VIBRATION

Like a violin string vibrated by a bow, a suspension bridge strung between its high towers is vibrated by winds. Soldiers crossing a bridge in column always break step to prevent the bridge from "entering into vibration" as the second prong of a tuning fork does when the first prong is struck. Vibrations can reach the point where they set up strains and stresses powerful enough to bring a bridge crashing down. These spectacular photos show in sequence the disastrous effects of the Tacoma bridge in vibration (State of Washington, U.S.A.), when its main span collapsed on November 7, 1940. (1) A 70 km. (45 mph) wind sets the bridge vibrating, causing it to twist and sway. Twisting effect worsened when a suspension cable came loose. (2/3) As vibrational forces increase, roadway is twisted and wrenched upwards (about 35 degrees from the horizontal) as shown by automobile being tilted first one way then the other. (4/5) Vibrations have built up to a critical pitch, tearing away the whole centre span. Below, the main span has disappeared; only a jagged section of side wall remains. Another spectacular example is Venice, where vibrations from waves and tidal currents during many centuries and more recently from ocean-going ships and power boats have inflicted grievous damage on the city's ancient buildings and monuments.



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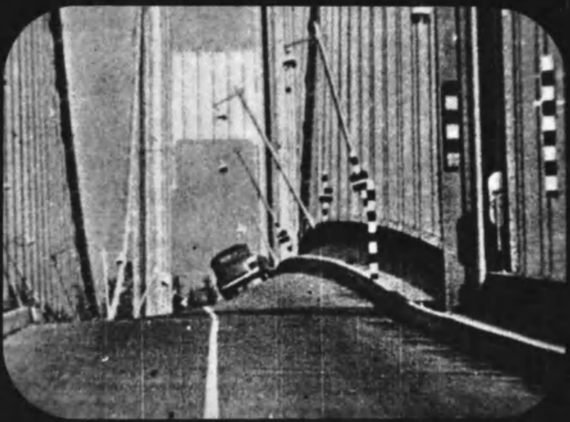

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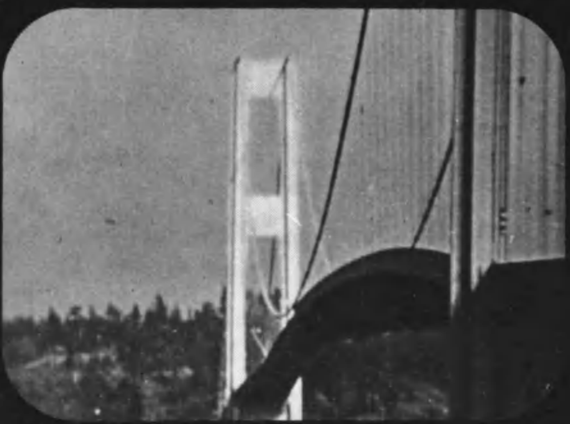

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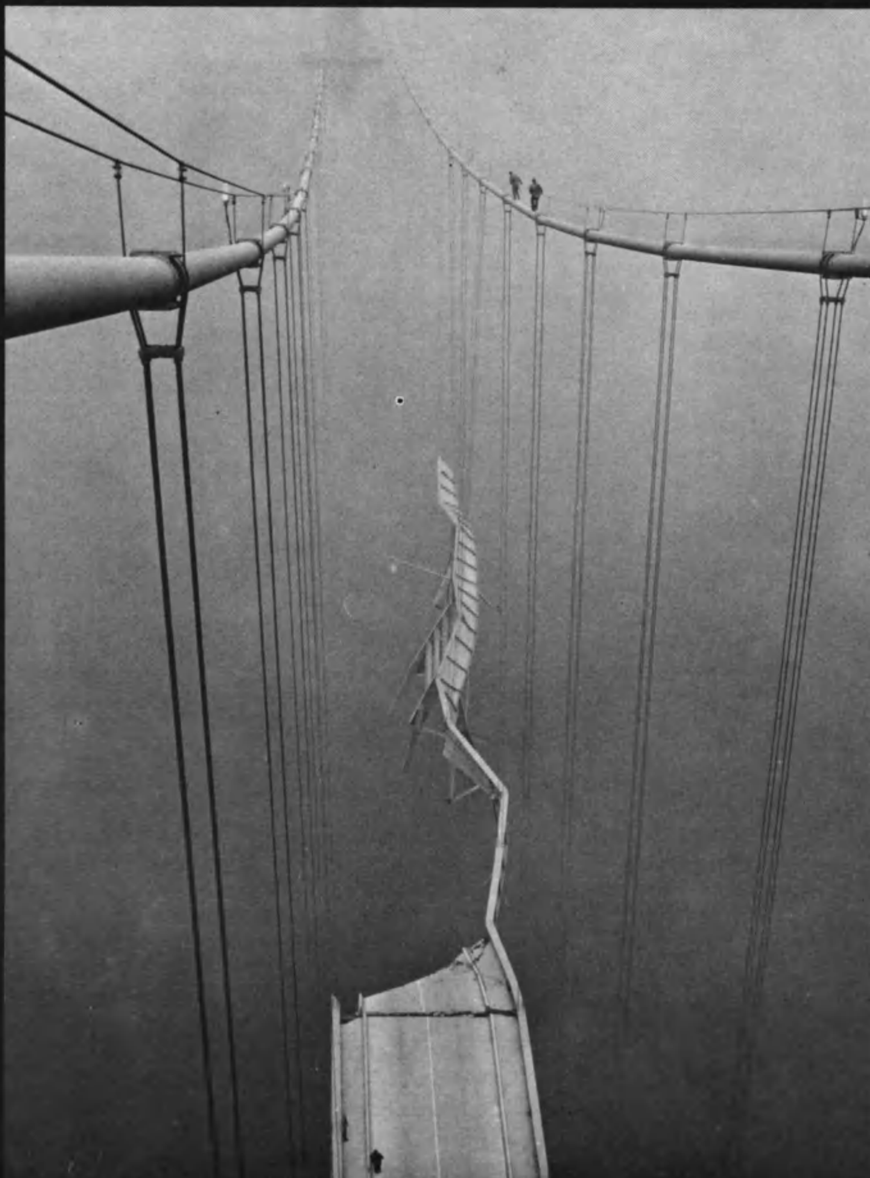


Photos © F.B. Farquharson, Engineering Experiment Station, University of Washington, Seattle, U.S.A.

QUASARS AND THE BIRTH OF THE UNIVERSE

by György Marx

LOOKING upwards on a clear night, we see myriads of stars, thousands upon thousands of them twinkling in the dark sky. The brightest stars are visible to the naked eye up to some thousands of light-years away. With the aid of telescopes they can be distinguished at distances thousands of times greater, up to some millions of light-years.

At a greater distance still, individual stars can no longer be distinguished, although they can be seen as galaxies, similar to our own of which the sun is part. These galaxies comprise thousands and hundreds of thousands of millions of stars. The total light emitted by such galaxies can be recorded up to distances of some thousands of millions of light-years. The light we register on a photographic plate began its journey at a time when life had barely commenced on earth.

And yet we can probe in this way only a minute portion of the universe. We should have to penetrate much further into the depths of space and time to discover the structure and the history of the universe. The heavenly bodies, stars and galaxies we can see now began to form more than ten thousand million years ago. It would therefore be necessary to go back at least ten thousand million years into the past in order to understand the history of the genesis of matter.

Before Copernicus, man had a simple picture of the universe. Its centre was the earth, the natural focus for the condensation of matter. Copernicus removed the terrestrial globe from this privileged position.

The Neapolitan philosopher Giordano Bruno, an admirer of Copernicus and friend of Galileo, had already conceived the notion of an infinite number of worlds all of equivalent importance. From then on the universe was represented as being full of heavenly bodies distributed uniformly in space and time and of homogeneous density, in the same way that the molecules of gas are distributed in a storage tank.

At first the stars and our sun were taken as being the molecules of this cosmic gas. But, following the work of the U.S. astronomer, Edwin Hubble, the galaxies—those islands of matter containing thousands of millions of stars—have become the molecules of cosmology.

However, things are not quite so simple. Galileo taught that the same laws of physics are applicable in the heavens as on earth. If we attempt to apply the laws of universal gravitation to a gas of infinite extent, like that in which the galaxies are molecules, a simple calculation shows that this gas could not be in a state of equilibrium. Either the force of attraction will prevail or the cosmic repulsion will predominate. A gas formed of galaxies must of necessity either expand or contract.

In 1926 observations made by Hubble showed that the universe is receding. The further into the depths of space we look the faster are the galaxies we can see receding from us. All these observations have confirmed Hubble's law that the speed of recession of galaxies is proportional to their distance from us.

Galaxies at a distance of a thousand million light-years have a recession speed of 30,000 kilometres per second, that is a tenth of the speed of light. Those that are twice as far away—two thousand million light-years—are receding from us twice as fast, and so on. The universe is not a static, invariable formation. It unfolds before us a picture that changes with time.

Living in an evolving universe we cannot but speculate as to what took place in the past and what is to happen in the future. How long will this recession, this expansion of the universe continue? If it is to continue indefinitely the galaxies will end up at such vast distances one from the other that the light emitted from one galaxy will no longer be able to reach even those galaxies that at one time were closest. Is our own galaxy, the Milky Way, destined then to float like a solitary island in the void?

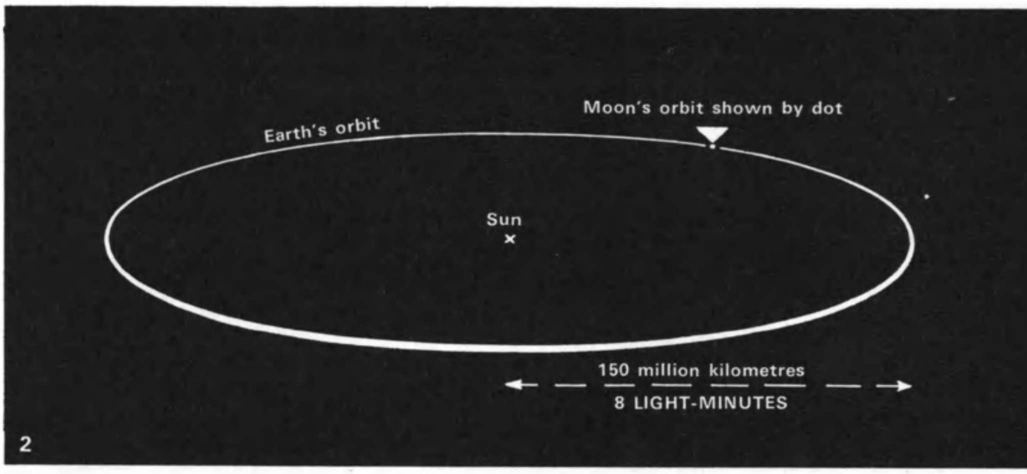
SUPPOSE that we, as it were, run the film backwards towards the past. We should then see the galaxies getting closer to one another, and it can be deduced that about ten thousand million years ago all the matter of the universe was very highly condensed. Expansion must have taken place from an extremely dense state and have begun in a manner similar to an explosion.

Many astronomers, relying on the Friedman calculations, have adopted this hypothesis of an original state in which matter was very dense and have attempted to deduce from it, by calculation, the various conditions observable in the universe as it now is. Others have had some reservations about this, pointing out that a chain of deduction going so far back is at the mercy of the slightest circumstance that might have been overlooked.

In the midst of this sea of speculation, a first point of reference became

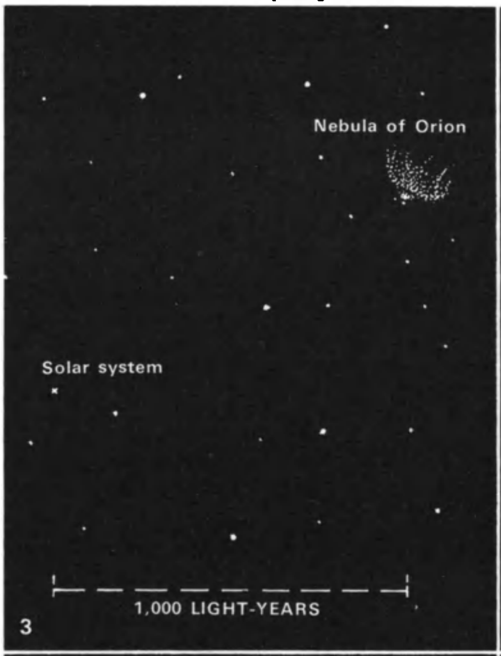
GYORGY MARX *is professor of theoretical physics at the University of Budapest and chief editor of the Hungarian scientific publication "Fizikai Szemle" (Physics Review). For his studies on the quantum theory of particles he was awarded the Hungarian Kossuth Prize in 1955. This article is condensed from a series of six talks recorded by the author for the International University of the Air.*

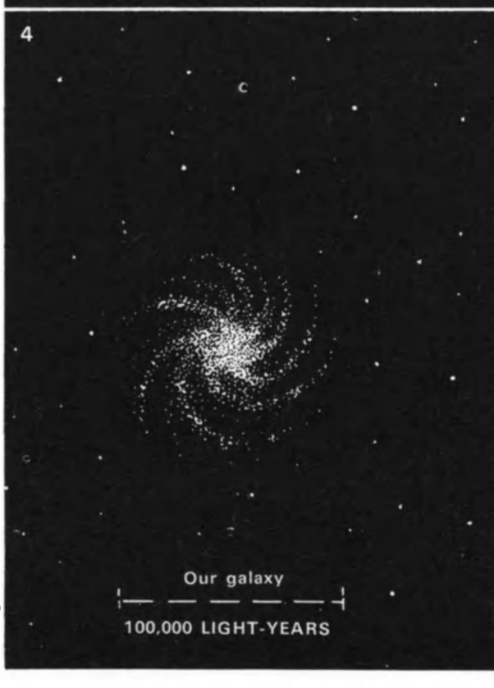
Photo © National Geographic Society - Palomar University, California

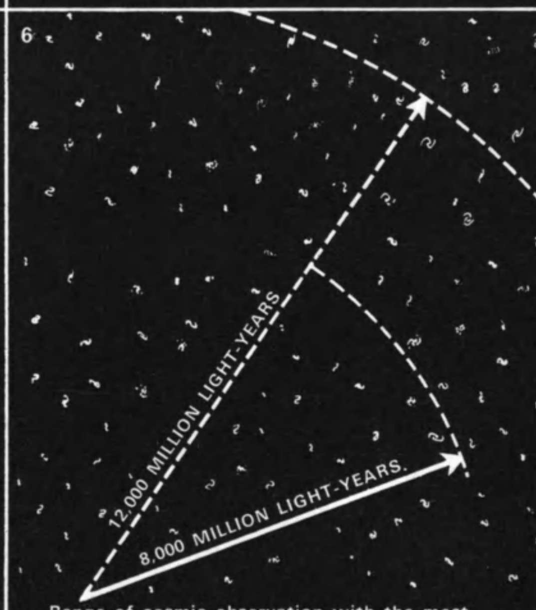


MESSAGES 8,000 MILLION YEARS OLD

Six years ago, a lively new branch of astronomy was born with the publication in the March 1963 issue of the English journal Nature of four papers by Australian and American scientists reporting the discovery of mysterious celestial objects, now known as quasars or QSOs (quasi-stellar objects). Since that date our knowledge of quasars has grown steadily. Above left, Quasar 3-C-9 (arrowed) a tiny luminous dot in space visible through a powerful telescope. Its light, reaching earth after 8,000 million years (at a speed of 300,000 km. a second), is helping scientists to reconstruct cosmic events as old as the birth of our own galaxy. Comparative distances shown in drawings above and below help us to visualize the awe-inspiring dimensions of the universe.







Range of cosmic observation with the most powerful photographic telescopes (continuous line) and with radiotelescopes (dotted line)

Drawings © from "A l'Affût des Etoiles" (Tracking the Stars) by Pierre Bourge and Jean Lacroix, Editions Dunod, Paris.

available with the discovery in 1965-1966 of radio waves coming from the depths of space.

In the range of metric waves and above, we can distinguish radio emissions from galaxies and various extra-terrestrial bodies. In the millimetric wave range, emissions originate from our atmosphere and the ionosphere. But in the intermediate, centimetric range there was silence.

In probing this silent range more closely weak thermal radiation was discovered. This incoherent radiation does not originate from known heavenly bodies nor from a particular sector of the sky. It is a background noise that fills the entire universe in a homogeneous manner and is identical in all directions. It corresponds to a temperature of 3 degrees absolute, that is to say 270 degrees below zero centigrade (1).

This background radiation is apparent as a weak radio noise, but when it is considered that it is present uniformly throughout the universe its importance becomes evident. It contains a thousand million times as many photons as there are atoms in the universe and the energy density of the radiation is a hundred thousand times greater than that of the light coming from all the stars.

If we make the deduction that in the past the universe occupied a smaller and smaller volume of space, the further we go back in time, we find greater and greater intensities of radiation and higher and higher radiation temperatures. Since the temperature today is three degrees absolute, then five thousand million years ago it must have been six degrees absolute, and thirty degrees absolute 7,000 million years ago.

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(1) Absolute zero is approximately minus 273 degrees C.

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There is only one possible explanation for such a large number of photons in space. They were produced in the heart of matter that is highly condensed and extremely hot, just as it must have been 10,000 million years ago when the universe began to expand.

From this starting point, with the radiation spreading over a greater and greater volume, the temperature diminishes. At three degrees absolute, radiation today bears witness that the starting point for the expansion of the universe was a special state of matter with the temperature doubtless exceeding a billion degrees and with radiation predominating over atomic matter (1).

ACCORDING to Jacob Zeldovitch's calculations, during the first second of expansion the temperature dropped to ten thousand million degrees, and, at the end of the first minute, to some millions of degrees. At this point matter began to dominate with the formation of the first atomic nuclei. During the first ten million years the temperature dropped to four thousand degrees and, in the heart of the ionised plasma, neutral atoms, that is to say atoms having their full complement of peripheral electrons, were able to form.

After that, vast clouds of gas were able to develop, each of them forming the basis of a galaxy. Gradually the universe took on the aspect that we know today and we move from the realms of misty speculation to those of scientific research based on observation.

Naturally, the residual radiation at three degrees absolute gives only a confused picture of the birth of atoms and galaxies without providing any details. The information that can be drawn from the present state of atomic matter gives a no less distorted picture.

Heavy elements are being formed continuously in the universe of today. It is, then, almost impossible to deduce from our present knowledge the original proportion of the elements and, hence, the density and temperature conditions prevailing at the beginning. This is why astronomers would find it of inestimable value if direct undistorted evidence, providing specific information about the initial phase of the universe, were to be discovered.

In fact we should need beacons visible at enormous distances, a billion times brighter than the stars and a hundred times brighter than the galaxies, to find our way far enough into the depths of space and time to be able to discover there the structure of our universe.

Now it is precisely such beacons that astronomers believe were discovered during the early years of this decade. These stars have been named quasars, a word formed from the contraction of the phrase "quasi-stellar". In fact they are galaxies of a particular kind which were at first mistaken for stars.

Quasar 3-C-9, which has been identified both optically and by radiotelescope, has a light spectrum whose rays are displaced 215 per cent towards the longer wave lengths. If, as is generally accepted, this "redshift", as it is called, is due to the velocity of recession, and if this velocity is proportional to distance (in other words, if our universe is expanding), this redshift corresponds to a recession velocity of 240,000 kilometres per second and to a distance of eight thousand million light-years.

The astonishing thing is that these stars emit enough light or radiation energy to be discernible at such distances. Their output of energy can be estimated at more than a billion times the light of the sun.

Beyond this distance the objects are too pale for it to be possible to measure their redshift and our optical telescopes can probe no further. But eight thousand million light-years indicates that the light from Quasar 3-C-9 has been travelling for that length of time. To look at this quasar is, therefore, to look eight thousand million years into the past, that is to say, to cover about 80 per cent of the history of our universe.

EVEN though at present eight thousand million light-years appears to be the extreme limit for optical observation, radio-astronomy can take us further. In fact, radio sources of the same type as quasars and weaker than 3-C-9 have been detected by radiotelescopes. If we assume that all these radio sources have the same absolute intensity, their apparent intensity allows us to estimate the range of our radiotelescopes as being nine thousand million light-years. This range is largely exceeded by the new giant radiotelescope sited in a natural bowl at Arecibo, Puerto Rico (See "Galaxies Caught in a Steel Mesh," "Unesco Courier", Jan. 1966).

It is expected that the new radiotelescope will be able to record emissions from radio galaxies and quasars situated at distances of ten to twelve thousand million light-years. This means that it will be possible, so to speak, to listen to a direct broadcast of the beginnings of the universe.

This possibility, which just a few years ago would have been considered fantastic, has become a reality thanks to the extraordinary intensity of the quasars' output both of light and radiation. Their radio emission is the result of one or several explosions which, at the same time, heated the central nucleus in such a manner that it could shine like a million suns for a million years or longer. Radio emission from the radio galaxies is due to an explosion of a similar kind, but perhaps less intense.

These beacons in space can be used as triangulation points from which to map the entire stellar field in space and in time. This is not just a hope for the far off future. The map-making venture has already begun and the results obtained are of enormous interest.

WHAT can we assume about the behaviour of quasars throughout time? During the hundred thousand years that followed the first flash, radiation must have been of constant intensity. From then on the strength of the radiation began to decrease exponentially. A million years after this spark-off the power of radiation was already only a thousandth of what it had been at the start, and after ten million years it had again diminished a thousand times. At this point the quasar fades to the extent that it is no longer discernible. No quasars have been detected whose age has been assessed at more than a few million years.

Their distance and their distribution in space can be calculated by their apparent intensity. It then becomes noticeable that their density in space is more or less homogeneous within the limits of one to two million light-years. Beyond this distance the number of quasars appears to increase in all directions. Their density doubles over a spherical layer with a radius of some thousands of millions of light-years. Beyond that it diminishes again strongly and, at the radio horizon, nine thousand million light-years away, the density is only a fiftieth of that observed in the close range.

In reality, this arrangement in space expresses evolution in time, the quasars being observed at distances that correspond to the date of their existence. If quasars seem to us to be more numerous at a distance of some thousands of millions of light-years, this is because in that distant period of time their eruptions were more frequent.

If we look further still, we see scarcely any quasars, despite the fact that our radiotelescopes are now powerful enough to detect radio sources even further away. This is because we are reaching back into an era preceding the first quasars.

If we can liken quasars to the nuclei of galaxies burning themselves

CONTINUED ON PAGE 41

(1) In this text "Billion" is used in the English sense to mean a million million.

THE WEAVING OF AN ENGINEERING MASTERPIECE —A SPIDER'S ORB WEB

A step-by-step analysis by a structural engineer of the extraordinary way a spider builds its web

by Bert E. Dugdale

EARLY one morning in August of 1942, at Fayson Lakes, New Jersey, an opportunity came to me that I had watched for, but missed, for many years. A spider had just completed placing the structural supporting lines for a web. Realizing that this was my opportunity to study the step-by-step construction of a spider web, I hurriedly assembled my drawing board and paper, my pencils, and a six-foot rule, so that I could record as carefully as possible the steps to completion. My chair was placed so that I was about an arm's length from the weaver as I watched it.

As the spider added new elements to the web, I added corresponding new lines to my sketch, along with noting the order in which the lines were being made. The spider kept me busy indeed, and I had little time to ponder the engineering significance of what it was doing. After both of us were through with our work, we each went about our own affairs. The sketch eventually ended up in my filing cabinet at home.

Twenty-three years later, in the course of shifting papers, I found it again, and it fascinated me. I began plotting the stages of the spider's work on different sheets of paper, and only then, as step-by-step I traced what it had been doing, did I begin to realize the full significance of the pattern it had followed—a pattern corresponding to a detailed blueprint that left little to chance.

Drawing below left shows where

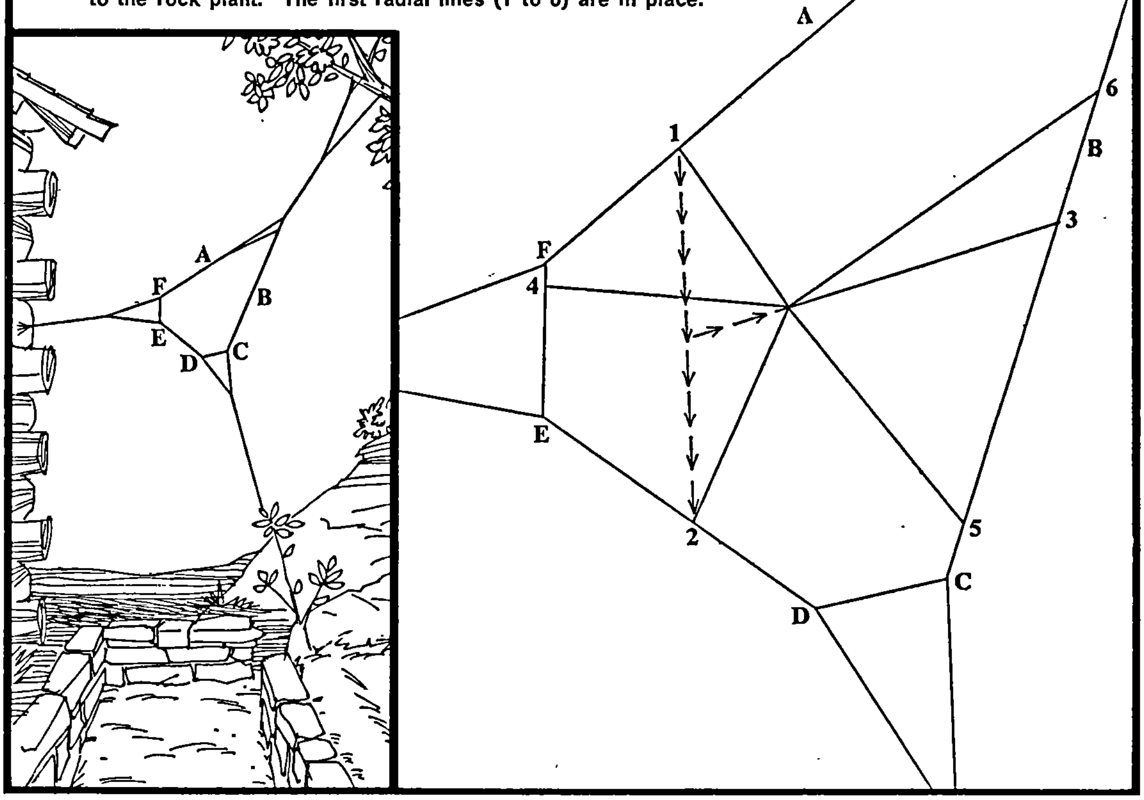
CONTINUED ON NEXT PAGE

BERT E. DUGDALE *is a retired American structural engineer. His interest in spiders began as a child. Later, in his professional life he was struck by the similarities between the problems faced by a spider building a web and those that confront construction engineers. This led him to undertake the painstaking observation of the actual weaving of a web. His article originally appeared in "Natural History", the journal of the American Museum of Natural History, New York, in March 1969.*

FOUR STAGES IN THE WEAVING OF A WEB

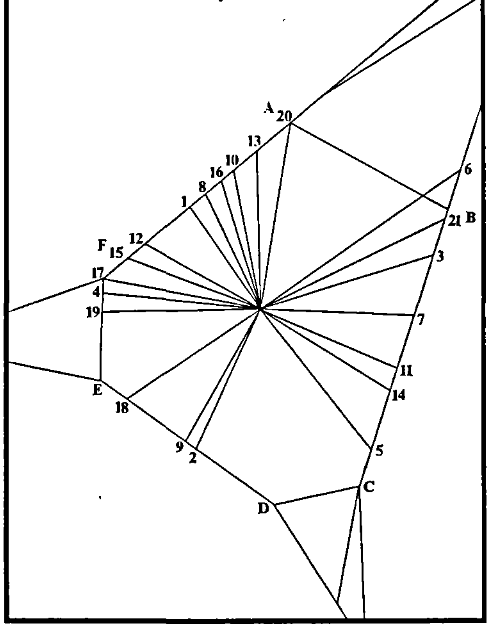
Nature's most expert spinners and weavers, spiders spread their silken nets where they are most likely to ensnare flying insects and other prey. On these pages, an engineer describes the methodical four-stage workplan followed by a spider as it wove a web in his garden, noting each operation step by step. Sketch on right shows the garden site where spider anchored its web to a log cabin, a hazel bush and a rock plant.

1 **The three main structural lines are in place, providing a triangular-shaped framework for a web roughly 15 cm. (6 in.) across. Lines measure respectively 77 cm. (30 in.) to the anchorage point on the log cabin, 100 cm. (39 in.) to the hazel bush and 77 cm. to the rock plant. The first radial lines (1 to 6) are in place.**

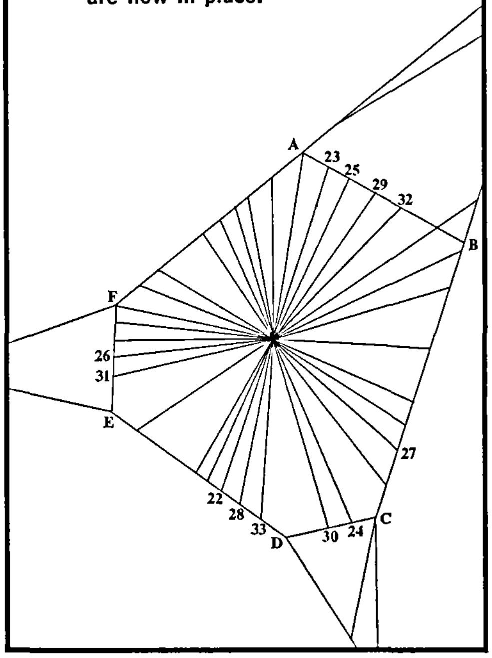


SECOND STAGE

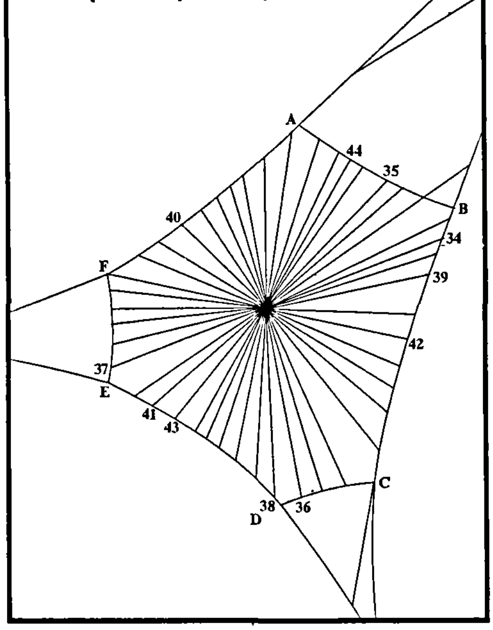
2 Fifteen new radial supports (7 to 21) have been added. Line from A to B completes frame.



3 Twelve more radial supports (22 to 33) are now in place.



4 With the addition of ten final radials (34 to 44) the system of radial lines (44 in all) is complete.



An innate sense of geometrical precision

the spider had worked, alongside my family's log cabin, one of several inhabited by nature-loving vacationers in summer. About two metres (6 ft.) from the corner of the cabin was a rocky knoll, with a small bush sprouting out of a crevice in the rock. A branch of a larger plant, a hazel bush, reached over the knoll toward the cabin. Between the cabin and the knoll grew a small patch of wild irises, daisies, asters, and other wild woodland flowers in their season.

It is probable that the protection provided by the overhanging eaves of the cabin, the presence of the protruding corner logs, the pathway between the cabin and the wild flower bed, and the stone steps leading up to the rocky knoll all combined to produce an ideal location for an orb-weaving spider to set up housekeeping.

Many times, over a span of several years, I had seen orb webs suspended almost vertically in this exact location, and I had watched numerous spiders of several species carrying on various stages of web construction there—indeed, I had often walked into these webs while fetching firewood.

It is also probable that on that morning the favourable air currents around the cabin, and the prospect that insects attracted by the flowers would fly head-on into the hanging web, were bonus inducements that caused one *Micrathena gracilis*, an orb-weaving spider, to start spinning its silken lines.

Of a species reported to be widely distributed in North America, it was grayish in colour, about 6 mm. (1/4 in.) in length, and its abdomen was armed with distinctive spines as well as the more conventional pairs of appendages called spinnerets. It is through these organs that spiders excrete threads of silky material.

The entire process took about two and one-half hours and consisted of four stages, which can be described as follows:

First Stage: Placing structural supporting lines to provide a triangular-shaped framework for the web, which would itself be roughly 15 cm. (6 in.) in diameter (drawing I shows the scene when first observed, and the establishment of the web centre).

Second Stage: Completing a system of radial lines to connect the web centre with the surrounding framework (drawings 2 to 4).

Third Stage: Building a temporary scaffolding spiral, extending from the web centre to the outer frame (drawing 5).

Fourth Stage: Installing the final viscid spiral webbing and removal of the scaffolding (drawing 6).

STAGE ONE: When I first observed the web, it already had the three main supporting lines, with crosslines C-D and E-F in place (drawing 1), thus completing the polygonal, outer web framing, BCDEFA (except for a crossline between A and B, which was not placed until later).

The spider had also reinforced each main structural line by traversing it from time to time, adding a new strand on each passage. These strands fanned out at the anchorage points to provide multiple attachments (a common human practice when anchoring the cables of a large suspension bridge).

The spider now proceeded to establish the web centre (drawing 1). First, it attached a free-running line at point 1 on AF; then, moving through point F down to ED, it attached the other end at point 2. A quick movement of the spider's spinnerets fastened the line sufficiently well.

Now it moved up this line and, approximately midway between 1 and 2, attached one end of another line. Again spinning out a line as it went, the spider carried it down to 2 and then along DC to line CB, where the other end was attached at point 3.

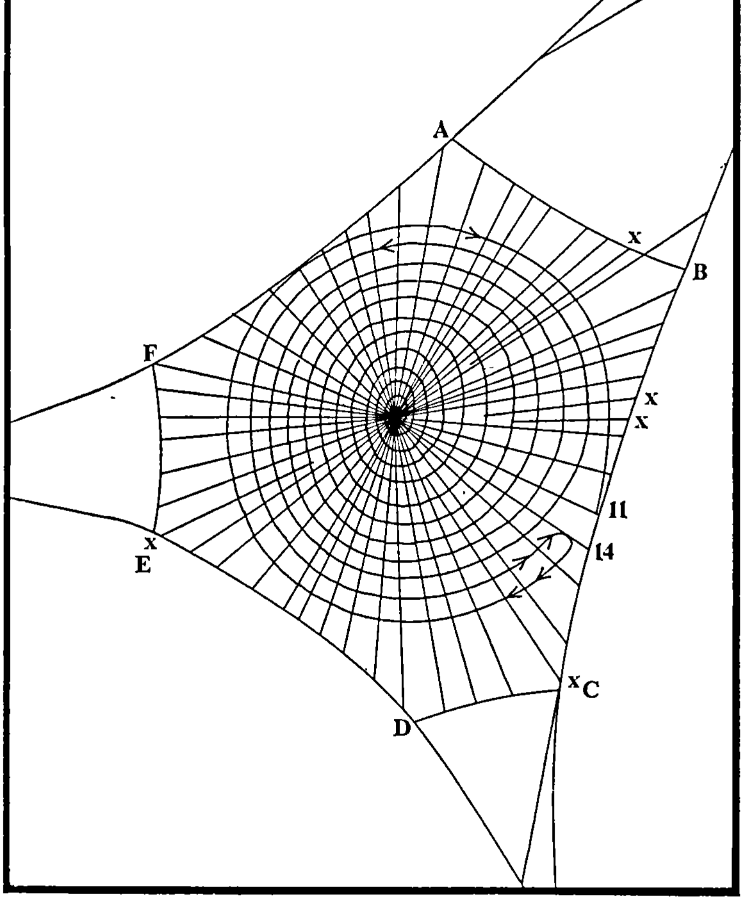
This time the line was pulled taut before it was attached. It was this pull that brought radial lines 1, 2 and 3 to the positions shown on drawing 1. The conjunction of these first three radials determined the web centre, which was then stabilized by the placing of radials 4, 5 and 6.

The web frame, with the initial radials 1 through 6, was not in a completely vertical plane; it was inclined about 15 degrees off vertical, with the upper part leaning away from me.

I was not sure on which side the

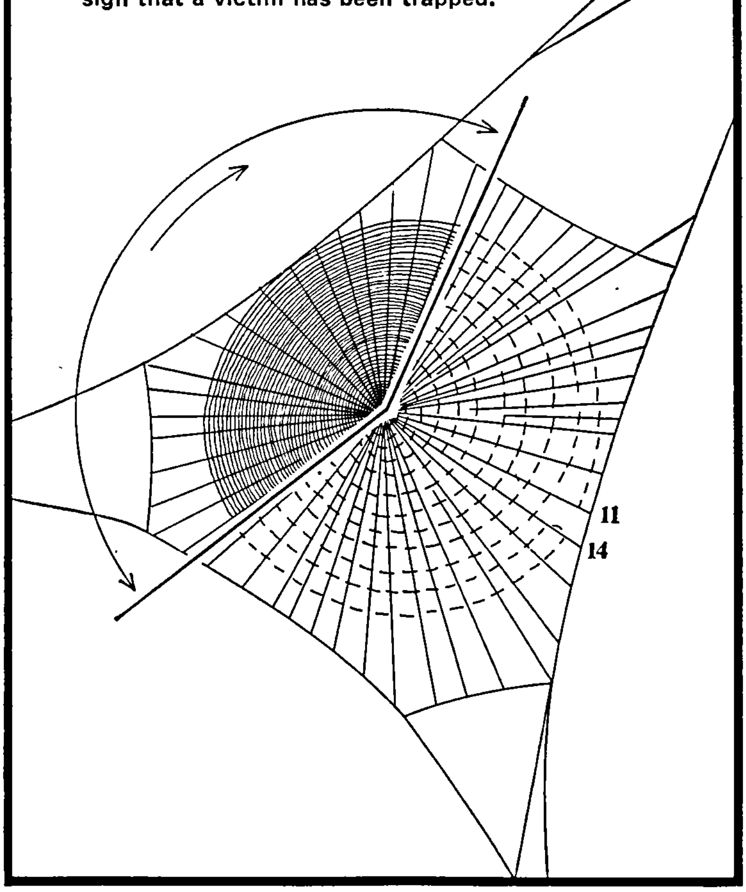
THIRD STAGE

5 **Spider has constructed a spiral scaffolding, laid anticlockwise from the centre, which will be removed in stage 4. Lines marked "X" are partial radials added to facilitate scaffold construction. When the spider reached the outer end of radial 14, it reversed direction and made a full circuit to complete the scaffold spiral at radial 11.**



FOURTH STAGE

6 **Scaffold completed, the weaver now installs the sticky spiral web that will serve to catch prey. The web, this time laid clockwise starting from the outside, has an average diameter of 17 cm. (six and a half inches). Spider then cuts a hole at centre of web, giving itself access to either side. It then waits for vibrations, the tell-tale sign that a victim has been trapped.**



spider would operate, but inasmuch as viewing was most convenient with my back to the sun, all my observations and sketches of the web were made with the spider working from the other side. This was fortunate. As the weaving proceeded, my position afforded close-ups of the weaver's use of abdomen, legs, mandibles, and spinnerets.

Having now established a web centre the spider proceeded to the second stage of construction.

STAGE TWO (drawings 2 to 4): A complete system of radial lines joining the centre point to the several enclosing framework lines was now put into place.

The method of installing the additional radials was like that for the initial radials, except that each new radial was first attached to the centre and then carried to a selected location on the enclosing frame. The spider was adept at holding a hind leg high and keeping the freerunning line from becoming entangled with existing lines. The fact that the spider was working on the underside of the off-vertical web many have helped, as gravity would tend to draw its body and the free line away from the web plane.

If the reader will run his eyes over the radials in their numerical sequence, starting with the three initial lines, he must be impressed by the fact that never was a new radial placed adjacent to one just laid, but always at a distance from it, so as to continually equalize the tensions on the system and thereby maintain the location of the web centre. Otherwise, because of the elasticity of the fibres, the centre would have constantly shifted to new points, and the polygonal form of the framework would have assumed ever changing shapes and distortions.

Drawings 1 to 3 show the structural frame as straight lines. This was not actually the case. As each new radial was attached to a frame line, the tension placed upon that line caused it to deflect to a more curved line. For convenience in field sketching, I kept the straight-line form for the frame, until all the radials were placed.

When radials 20 and 21 were placed, there was as yet no cross member from A to B. The spider, after placing 21, went back down it without hesitancy, up 20 to A, then returned the same way with a running line that became crossline AB and was attached to radial 6 at their intersection point. The full polygonal frame, ABCDEF, was now complete, and other radials could be attached to AB.

It is of interest to note that during this selective method of locating the radials, in only one instance was a new one anchored too near an existing radial, and that was 22, adjacent to radial 2. In a few cases there was too much space between radials. In each case the spider later filled the gaps with partial radials.

That an apparently deliberate method was used by the spider to maintain the approximate web shape established by the first six radials is suggested when the next eight radials are studied (drawing 2).

Lines 8, 10, and 13 are well dispersed between points A and F, and radials 7, 11, and 14 are similarly spaced between points B and C. Further evidence of deliberate planning at this

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A SPIDER THAT SIGNS ITS NAME

The Argiope, a tiny spider (right) found widely in Europe, is easy to spot because of its bright yellow abdomen crossed with black stripes. It has also the unique characteristic of signing its name to its web with a zig-zag band of silk fixed between two radial lines.

Photo © Jacques Six

NEW SKINS FOR OLD

This greatly enlarged photo of a spider's leg in the process of moulting (below) recalls the delicate brush strokes of a classical Chinese ink drawing. Old claws being shed with the skin (top of photo) are being replaced by new ones. Spiders shed their outer skin several times while growing.

Photo © Louis Jacques Laporte

Ready for occupancy

stage is seen in the placing of numbers 15 through 21.

Again, in drawing 3, one sees that tensions on the centre of the web remain balanced by the spider through its choice of radial locations for lines 22 through 33. With so many radials now in place, further care in spacing would not have been necessary, yet the weaver continued its careful selection of locations as radials 34 through 44 (drawing 4) were added.

STAGE THREE: With all full-length radials in place, the weaver proceeded with the next item of construction, the scaffolding, which would be removed after serving its purpose. It consisted of a spiral starting from the centre and continuing to the outer perimeter of the web (drawing 5).

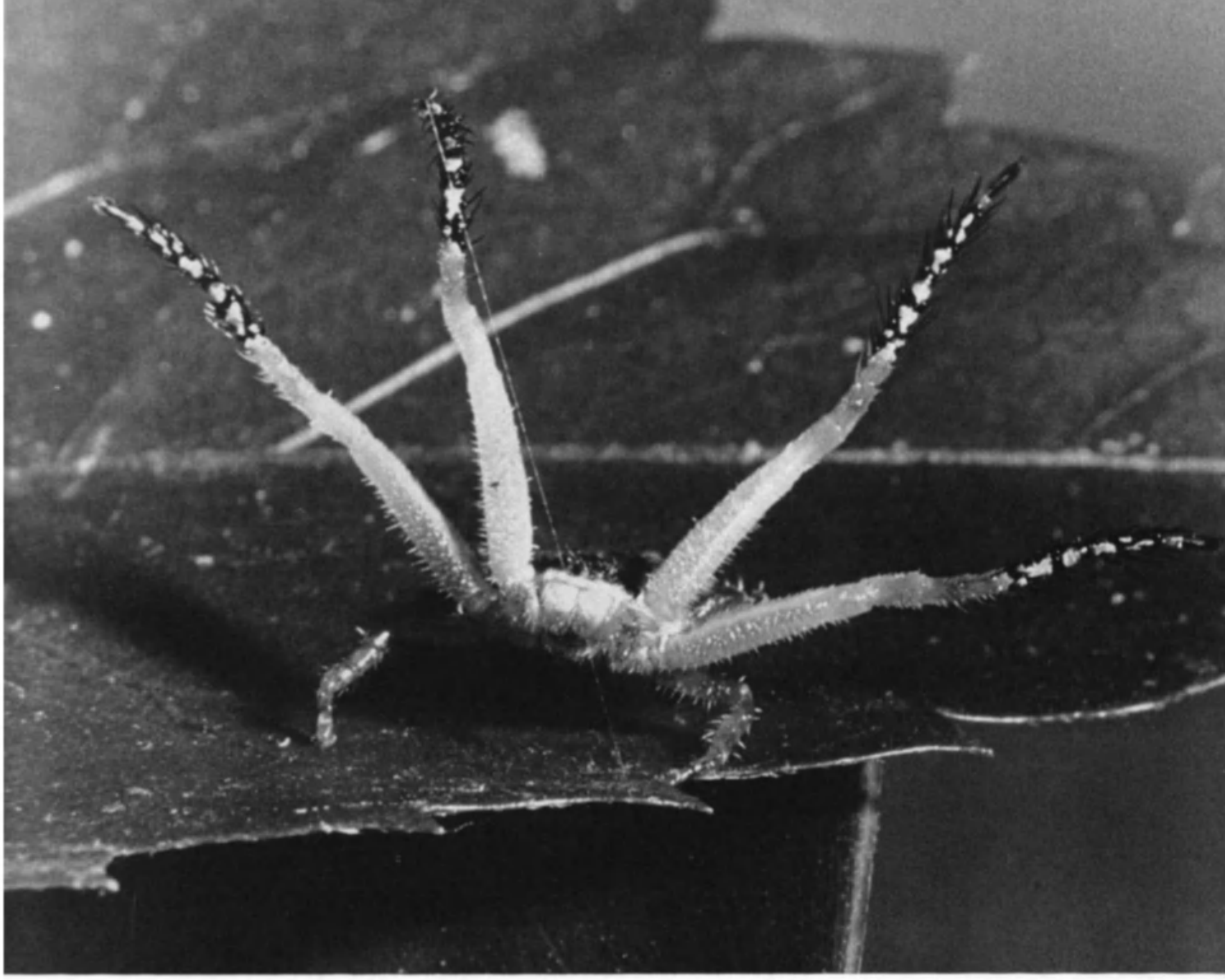
The first seven circuits of the spiral were spaced very closely, about .8 mm. to 2.4 mm. (1/32" to 3/32") apart. The next four or five were spaced 6.3 mm. to 8 mm. (1/4" to 5/16") apart, and 9.5 mm. (3/8") apart. To maintain an even spacing the spider kept a foot on the preceding circuit as it hurried around the web.

Several interesting examples of what appeared to be decision making occurred during this stage. At a few places where radials were too far apart and the spider would have to stretch to reach the next one, it discontinued the spiral and installed a

COUTURIÈRE FROM SINGAPORE

Using one of its claws as a needle, this Singapore Spider (right) stitches together leaves for its nest. A "chameleon" of the spider world, it can change colour according to its surroundings. Inconspicuous on a leaf, it patiently waits for its unsuspecting prey.

Photo © F.G.H. Allen



after removal of scaffolding

partial radial long enough to reach the outer frame, and held in place by existing scaffolding. The partial radials are marked X on drawing 5.

Again, when the spider had run the scaffold line to the outer end of radial 14 on what could have been the last lap, it immediately reversed direction, and made a full circuit, terminating the scaffold line where radial 11 joined the outer frame.

It is at this point that the spider began the final stage of construction —spinning the viscid, or sticky, webbing, while simultaneously removing the scaffolding. The purpose of the stickiness, of course, is to trap prey for the spider. The viscid filaments are so effective that insects, once enmeshed, seldom escape. The spider, which itself may be bothered by the adhesive, exhibits much dexterity in running about the web without getting into trouble.

When constructing the web, it can exude either dry or viscid fibre. The dry is used for all purposes except catching victims. In the first three stages of construction, every filament was of the dry, non-sticky type. I know this because I repeatedly tested the lines for adhesiveness.

However, the filaments may vary in makeup. The spinnerets of the spider can be controlled to produce either round, dry lines, each comprising a bundle of several strands held together as a unit, or a flatter, ribbonlike line. Sometimes the dry line may have a succession of sticky beads. But this is a special case. Observers have found that there is a viscid layer on such a filament when it is emitted, but the layer then forms a succession of beads.

STAGE FOUR: We have seen that the spider terminated the scaffold spiral at radial 11, after having reversed direction at radial 14 the previous time around. Whether planned or not, this reversal served a useful purpose, for without a second's hesitancy the weaver proceeded to spin the viscid spiral, this time starting from the outside, instead of from the centre (drawing 6).

During this final phase of construction, the spider had better footing than previously; it could step on the dry scaffolding lines as well as the radials. This does not mean that the viscid spiral conforms exactly to the contour of the scaffolding. Several circuits of the viscid line were made for each circuit of the scaffold.

As the viscid fibres were indistinguishable from the scaffold fibres by sight, it was difficult, while making drawing 6, to discern the scaffold lines in areas where they were crossed or overlapped by viscid lines. Only later, in the final moments of the spinning, did it become clear that the scaffold lines were gone.

When the spinning was completed a ball of white material was visible at the centre of the web. This material the spider consumed. Theodore Savory, in his *The Biology of Spiders*, informs us that as the viscid fibre approaches the next turn of scaffolding, that turn is rolled up by the spider; thus accounting for the accumulated ball at the finish.

Different species of spiders have characteristic patterns for their web centres. *Micrathena gracilis*, after consuming its discarded scaffolding, actually cut out the centre area of the web to provide an opening through which it could come out on either side of the web. The diameter of this opening was such that the spider's eight legs spanned the gap without difficulty.

After two and a half hours of steady work, all was completed; the house was ready for occupancy. The spider then took up its position over the centre opening (about one-half inch; 1.27 cm. in diameter) with legs spread out upon the radials. It was now ready to detect any vibrations that would indicate that a victim was trapped, and would also give its location.

The term "engineering masterpiece" in the title of this article is more applicable than one might suppose. The use of three main structural supporting lines is an engineering technique based on the geometrical proposition that it takes three points to

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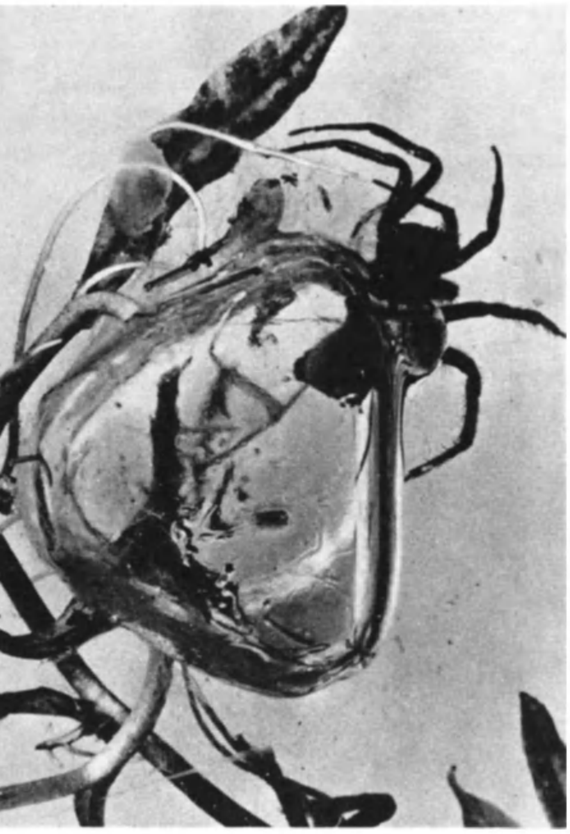

SPIDER'S DOMAIN IN A DIVING BELL

Numerous spiders are found on the surfaces of ponds and quiet streams, but the only one that lives all its life under water is the European water spider (Argyoneta aquatica). This ingenious spider builds a rough framework for its bell-shaped underwater home by attaching a few threads to the stems of water plants. Then, rising upwards, it collects air on its abdomen and rear legs by projecting them through the surface of the water (above right). Carrying this air bubble to its building site, it places it where the silken cables will hold it prisoner. The spider repeats the operation until it has collected about one cubic centimetre of air (above left), and then completes the nest by weaving a silken covering around the bubble. To this home it brings water bugs and other prey (photo left) and here too it lays its eggs and raises a family. Baby water spiders (photo right) are completely transparent before they moult for the first time.

determine, or stabilize, a plane. Also, the triangle is the basic form used in construction to secure stability and equilibrium.

The division of the web-weaving process into four separate steps closely reflects similar procedures in the construction of a building:

- Laying the foundation.
- Placing the structural framework.
- Building the scaffolding for enclosing the structure.
- Preparing the place for occupancy, and removing the scaffolding.

After construction, the spider will continue to have engineering problems, but now under the heading of "Repairs and Maintenance".

It was hard not to think in human terms as well as strictly engineering terms when contemplating the events at this place. These questions occurred to me:

- Why was it that so many webs had been constructed at this same location, the various spiders taking advantage of the same existing cabin logs, tree branches, protruding rocks, etc., to build above the little wild garden? Are spiders able to stand off far enough and in some way survey all the attributes of a possible web site?
- Having selected a site, can the spider then determine which of several logs, branches, etc., would be most suitable for anchorages?
- Can a spider, having established a line from the end of a certain log to a branch, say six feet distant, then use some decision-making process that eliminates several alternate possibilities in favour of centering the web directly above the pathway, where insect traffic will be heaviest?

These and many other questions are unanswered, as far as I have been able to discover. I myself have no answers but it is my belief, based on many years of observation, that scores of spiders, of various species, have built webs at this site in a manner that suggests that the answer to these questions could be "yes".

At least, I can say that the same structural problems had been faced by innumerable builders, and all of them had been solved in the same competent manner. ■

SPINNING LESSONS FOR THE SCIENTIST

The web building spider can be a unique laboratory animal that may help scientists to investigate many aspects of physiological, behavioral and psychological research, say three scientists who have made extensive studies of spiders at work on their webs. Their conclusions are published in a short and easy-to-read little book, "A Spider's Web, Problems of Regulatory Biology" (1).

Their study reveals many interesting and little-known facets of the spider's habits and working methods. Spiders produce with amazing speed large amounts of silk which they daily spin into a web of specific design. The authors discuss the anatomy, physiology and histology of the silk glands, as well as the composition of the silk itself.

The web is of utmost importance in the life of the spider, and its design has presumably evolved through some selective process. The authors point out that the spider nervous system is programmed to achieve construction of a web through the spreading of silk. The specific nature of the web enables it to be characterized, and thus computational methods for describing it in mathematical or geometrical terms can be drawn up.

The authors suggest that the detailed geometric patterns of webs are important for proper mating by providing a clear and unambiguous signal for an approaching male. They also note that spiders are able to catch and process flies on strange webs as efficiently as on their own.

The scientists studied the many differences that occur in web patterns resulting from natural processes such as aging, growth and weight changes in spiders, as well as others induced by "manipulating" spiders through the use of drugs and by other means, and they describe the effects of drugs on web weaving behaviour.

Since spiders build webs frequently, it is possible to have a spider in "normal" condition construct a web, then make some alteration to the spider and compare the resulting web with the normal or standard from the same animal.

(1) By P.N. Witt, C.F. Reed and D.B. Peakall. Springer-Verlag, Berlin; Heidelberg, New York, 1968, 107 pp.

QUASARS AND THE BIRTH OF THE UNIVERSE

(Continued from page 34)

out and aging rapidly, the date that they flared up must be related to the birth of the galaxies. The quasars must be contemporary with the birth of the galaxies or have followed at a limited interval of time. They therefore situate in time the birth of the galaxies which in turn denotes a critical state of the matter of the universe, already considerably cooled down after the initial explosion. Thermal turbulence must already have reduced sufficiently to allow gravitational forces to accumulate the vast mass of the proto-galaxies, that is, the galaxies in the process of condensation.

From these observations it seems to follow that the period in which quasars flared up reached its culmination eight to nine thousand million years ago. It is unlikely that more than nine thousand million years ago there were many quasars.

We are living in a comparatively calm period of the development of the universe, at a time when matter has long been gathered together in galaxies or stars. But with our radiotelescopes we can survey the past and reach back to an earlier stage in the life of the universe to an epoch in which thermal flux and not the accumulation of matter was the dominant factor. We are on the point of having access to the very dawn of the world at a time when, perhaps, there were no stars and all that existed was amorphous matter.

The initial results of this investigation are still far from precise. The given facts of time and distance will have to be checked and verified. This will be the task of larger telescopes that are today planned or under construction. The results they supply will enable astronomers and astrophysicists to re-constitute the history of our universe.

The first radiotelescope was built scarcely a quarter of a century ago and the first optical telescope three centuries ago. Man has existed on earth for a million years and life for a thousand million years. The sun, the earth and the planets are six to seven thousand million years old and the galaxy of which we are part goes back eight to nine thousand million years. The expansion of the universe, which can still be observed today, may have begun ten to twelve thousand million years ago. But the further back we go into the past the more uncertain become the events that marked the prehistory of the universe.

It is not so long since scientists began their enquiry into the past of man and of the earth. To avoid straying in the labyrinths of speculation or losing their way in the mists of space and time, they now have as guides the quasars, those beacons whose light and radio signals travel towards us across thousands of millions of years. ■

UNESCO NEWSROOM

ILO awarded Nobel Peace Prize

The Nobel Peace Prize for 1969 has been awarded to the International Labour Organization, which this year celebrates its 50th anniversary (see the "Unesco Courier", July 1969). In making the award the Nobel committee commended the ILO as an organization which has worked to create stable social relations and thus contributed to safeguarding world peace, and noted the ILO's important work in the field of technical assistance to developing countries. The ILO is the third U.N. body to receive the award. The U.N. Children's Fund (1965) and the Office of the U.N. High Commissioner for Refugees (1955) were previously honoured.

Unesco Indian translations honoured

Special editions are being prepared of two outstanding Indian novels recently published in English for the Unesco Literature Translations Programme, by Allen and Unwin in U.K. and Indiana University Press in U.S.A. **Pather Panchali** by Bibhutibhushan Banerji will be the first of over 130 volumes published in English in the Unesco Collection to appear in a special book club edition (Folio Society of Great Britain). **The Gift of a Cow** (Godaan) by Premchand will be the first book in the collection to be published in Braille (National Library for the Blind, London).

'Prospects in Education'

Unesco recently published the first issue of "Prospects in Education", a new quarterly which aims to bring to educators, educational institutions and teachers articles and information from worldwide sources and to give teachers—especially in primary schools—an insight into educational problems and their solutions in other countries. Annual subscription: $3.50 or 21/-stg. Subscribers will receive the first six issues (1969-70) free of charge, and their subscription will cover Nos 7-11 (1971). Order from Unesco national distributors (P. 43).

Developing Asia's book industry

A centre for the promotion of book publishing in Asia has been set up in Tokyo (Japan) by the Japanese Publishers' Association with aid from the Japanese National Commission for Unesco. It will carry out research on publishing technology, provide training courses for the industry and report new trends in Asian publishing. Unesco is contributing $36,000 to provide courses for trainees from 18 countries.

Hazards of food poisoning

The danger of food poisoning is everywhere increasing, not only from food-borne diseases but also through chemical contaminants that find their way into food through mishandling, reports the World Health Organization. Mass production and distribution of food and the growth of international trade and travel all contribute to the danger.

Dial-a-lesson Classrooms

Teachers in Ottawa, Canada, will be able to dial-a-lesson under an experimental project in four schools. Each of the schools' 110 classrooms will be connected to a video library, and teachers will be able to choose recorded programmes by telephone to be played back over a coaxial cable network and received on classroom TV.

BOOKSHELF

■ **Desert Traveller**
(The Life of Jean Louis Burckhardt)
By Katherine Sim
Victor Gollancz Ltd., London, 1969 (60/-).

■ **Scribes and Scholars**
(A Guide to the Transmission of Greek and Latin Literature)
By L.D. Reynolds and N.G. Wilson
Oxford University Press, London, 1968 (15/-).

■ **Writing in French from Senegal to Cameroon**
Selected by A.C. Brench
Three Crowns Library
Oxford University Press, London, 1967 (10/6).

■ **Language Today**
(A Survey of Current Linguistic Thought)
By Mario Pei and William F. Marquardt, Katherine Le Mée, Don F. Nilsen
Funk and Wagnalls, New York, 1967 ($5.95).

■ **Europe**
By Jasper H. Stembridge and David Parnwell
The New World Wide Geographies, Second Series, Oxford University Press, 1968 (12/6).

■ **Human Rights and Fundamental Freedoms in Your Community**
By Stanley I. Stuber
Associated Press, New York, 1968 (Cloth: $3.95; paperback: 95 c.).

■ **The Complete Poems of Michelangelo**
Translated by Joseph Tusiani
(Unesco's Translations Series)
Peter Owen Ltd., London, 1969 (38/-).

Ocean exploration decade

A long-term and expanded programme of oceanic research, which would comprehend the proposed International Decade of Ocean Exploration, was recently adopted by the Intergovernmental Oceanographic Commission meeting at Unesco headquarters in Paris. It comprises some 50 projects covering the whole spectrum of oceanography from the study of the earth's crust under the ocean basins and research on the ocean as the "boiler" for the world's weather system to ways of doubling or even quadrupling the present annual salt-water fish catch of nearly 60 million tons.

IVAN KOTLYAREVSKY

Poet Laureate of the Ukraine (1769-1838)

This year's bi-centenary of the birth of Ivan Kotlyarevsky, "Poet Laureate of the Ukraine," was marked by celebrations throughout the Soviet Union, including special ceremonies in the Bolshoi Theatre, Moscow, in September.

Ivan Kotlyarevsky was the leading figure in the literary revival of the Ukrainian cultural renaissance that took place early in the 19th century. He wrote the first Ukrainian musical drama, "Natalka of Poltava" and his translations—of La Fontaine's Fables into Ukrainian and of Greek and Latin literature into Russian—are still widely read. But the work which brought him the greatest fame and established him as the founder of Ukrainian literature is his poem, "The Aeneid Transposed."

This vigorous, sparklingly witty poem is in no sense a parody of Vergil's masterpiece. Borrowing only the story outline, Kotlyarevsky produced a brilliant and original work whose purpose was to challenge Tsarist despotism at a time when the very survival of the Ukrainian language and culture was at stake. In its verses, the gods on Olympus, the Trojan, Carthaginian and Latin peoples speak, act, dress, eat and quarrel like Ukrainians at the close of the 18th century. The author's style, his humour and philosophical irony have led many to compare him with Rabelais, Swift, Ariosto and Anatole France.

Kotlyarevsky shook off the shackles of 18th century classicism, raised a vernacular language to the rank of a literary one and introduced Ukrainian literature into Russia's cultural life. His "Aeneid" is so rich in Ukrainian folk wisdom and turns of speech that few have attempted to translate it, although it well deserves to be read in every country.

Flashes...

■ *Seventy per cent of Soviet doctors are women, whose numbers reached 438,000 last year compared with 96,000 in 1940.*

■ *Traffic congestion in Great Britain, which has nearly 60 vehicles for every mile of road, is increasing more rapidly than in any other major country, according to the British Road Federation.*

■ *By 1975 the world's nuclear power stations are likely to number 300 with a total generating capacity of 150,000 megawatts as against 20,000 today.*

■ *One out of every seven persons in the world is a citizen of India. India's population (over 520 million last year) grows annually by 13 million.*

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WEB OF PEARLS

Since Antiquity, man has marvelled at the geometrical precision with which a spider spins its web. On page 35, a structural engineer of today describes with professional admiration the detailed, step-by-step construction of an engineering masterpiece—the web he observed a spider spinning in his garden.