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In Memory of A. A. Fridman

ALEKSANDR ALEKSANDROVICH FRIDMAN
(On the seventy-fifth anniversary of his birth)

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A. A. FRIDMAN was born on June 17, 1888. His father was a musician and composer; his mother, Lyudmila Ignat'evna Voyachek, herself the daughter of a Czech musician, gave piano lessons. According to Fridman, he did not inherit any musical talent from his parents.

A. A. Fridman attended the Second St. Petersburg Gymnasium. His mathematics teacher, Nikolaï Ivanovich Bilibin, a well-known educator who translated Bertrand's book on algebra into Russian, was impressed by his young student's outstanding ability. While at the school, Fridman with his friend Ya. D. Tamarkin conducted an investigation involving Bernoulli's numbers. The paper was published in 1905 in *Math. Ann.*, Vol. 62.

After graduating from St. Petersburg University in 1909, Fridman was invited by Professors V. A. Steklov and D. K. Bobylev to remain at the university to pursue advanced studies with a view to entering the department of pure and applied mathematics. In 1913 the physicist and meteorologist B. B. Golitsyn invited the young scientist to work in the Pavlov Aerological Observatory.

From 1913 to 1916, Golitsyn was the director of the Main Physical Observatory—an institute which concerned itself with meteorological observations and the compilation thereof and with atmospheric investigation, and which was later renamed the Main Geophysical Observatory.

In 1914, Fridman was sent to Leipzig to study methods of synoptic and dynamic meteorology under Bjerknes.

W. Bjerknes, with other Norwegian scientists, had founded the Norwegian school of dynamic meteorology. He laid down the foundations of the frontal method of weather analysis, in which the development of fronts is considered a significant factor in weather changes.



A frontal surface (or front) is a surface of discontinuity as regards temperature or some other meteorological element. The most important fronts are those dividing arctic, tropical, and equatorial air masses.

An eclipse of the sun was expected in August 1914. Fridman took part in preparations for the observation of the eclipse, going up in a dirigible for that purpose.

In the fall of 1914 he joined a volunteer air corps which operated at the front in the vicinity of Osovets.

Between December 1914 and March 1915 he made a number of flights over Peremyshl in order to test bombing procedures which he had worked out. An eye witness of these tests reported that that was the only time he had seen a target hit from the air. Until November Fridman served in the air corps as an observer, studying atmospheric vortices. For these activities, he was awarded the honorary rank of observer-pilot.

In 1916–1917 Fridman headed the air-navigation service on all fronts, gave a series of lectures in Kiev and, jointly with A. F. Gavrilov, directed the computation of ballistic tables. During this early period of his activity, he already exhibited the organizational ability, personal courage and ardent interest in his work which were so characteristic of him in later life.

In 1918 Fridman was in charge of the aviation measurements department in Moscow, and was then appointed professor of mechanics at Perm' University. In 1920 he returned to Petrograd. Professors V. I. Smirnov, Ya. D. Tamarkin, and Ya. S. Bezikovich also came to Petrograd at that time. They gave courses in various branches of mathematics, and Fridman in hydrodynamics. At the same time, a number of physicists—Yu. A. Krutkov, V. K. Frederiks, V. R. Bursian and P. I. Lukirskii—began to give courses in quantum mechanics, the theory of relativity, and other branches of theoretical physics. Fridman developed close contact with them and invited them to deliver lectures in the Mathematical Society, an initiative which aroused great interest and attracted a large audience. Fridman himself began to study the principle of relativity and gave a course in tensor analysis. Joint seminars for physicists and mathematicians were organized.

Fridman assimilated the theory of relativity very quickly, and in 1922 he wrote "The World as Space and Time," a book whose aim was to acquaint a wide circle of readers with the actual ideas underlying the theory of relativity, expressing these ideas as simply as possible but without descending to cheap popularization. Fridman's article on the curvature of space was published in the same year (*Z. Physik*, Vol. 10, 1922). This paper is now highly thought of, and the theory it expounds is regarded as an important step forward in the study of cosmic space (see V. A. Fock, "Theory of Space, Time and Gravitation," 1961, and also the next article in this issue).

While working in close contact with physicists, Fridman in turn influenced them; thus, G. A. Grinberg carried out an investigation of the equations of relativistic hydrodynamics at his suggestion.

Fridman recruited a number of young men, including N. E. Kochin, V. A. Fock, and B. I. Izvekoy, who was somewhat older than the rest, for work in the department of theoretical meteorology; later, in 1925,

I. A. Kibel' worked under him. At the same time, Fridman was not afraid to enlist a much older man, Lev Vasil'evich Keller, who was then middle-aged and who had previously been concerned with insurance statistics and had no scientific reputation. In Fridman's department, Keller carried out important investigations of the statistical theory of turbulence.

Fridman and Keller introduced the concept of coupling moments, i.e., mathematical expectation values for the products of pulsations of hydrodynamic elements at different points and at different instants. This did much to elucidate the physical structure of turbulence and, neglecting third-order terms, made it possible to effect closure of the set of equations for turbulent motion.

Fridman was one of those executives who praise their subordinates in the presence of others. If one of his collaborators made an interesting finding, Fridman was lavish with compliments. Thus, he was absolutely delighted when N. E. Kochin discovered a case of adiabatic motion in which vortex formation occurs. Praising Kochin highly, he added, "And here was I, trying to scratch my right ear with my left hand" (in trying to solve the question whether vortex formation can take place without an influx of energy).

In general, Fridman was highly self-critical, and he often deplored aloud his various shortcomings, both real and imaginary. His relations with his collaborators were such that they were able to make criticisms and suggestions, and he would take them into account.

On one occasion, the women in his department told Fridman that they were indignant because in his book, "The World as Space and Time," in illustrating arithmetical notation, he denoted the human being's property of being a woman by 0, and the property of being a man by 1. He promised to reverse the terms in the second edition. It should be noted that Fridman trained the women in his department as scientists, and did not merely use them as slaveys.

Fridman took care of his collaborators. Thus, when a new category of apprentice-scientists was instituted, Fridman wrote reports on the work of each one of his people as soon as they undertook some project, as that would entitle them to supplementary food rations. And he could write reports very quickly.

Fridman did not, however, adhere to the rule that a collaborator should not be scolded in the presence of witnesses. On the contrary, being of an expansive temperament, he would often deliberately raise his voice to reprove someone who was absent (usually in such matters as lateness, negligence, etc.), so that those present might hear and take due note. He counted on them to report his remarks to the culprit.

Fridman had an immense capacity for work, and his enthusiasm was infectious. He organized a seminar on dynamic meteorology which was attended also by members of other departments of the Main Geophysical Observatory; everyone drew maps of isobars,

sketched weather fronts on them, followed the movement of cyclones, etc.

Fridman found the regular working hours too short, and his students often foregathered in his apartment to discuss various questions. They all took part in computing the ballistic tables which Fridman had taken up again with a view to refining them. Everyone, too, was involved in the publication of the works of A. M. Lyapunov, first in the preparation for print of the many manuscripts discovered after his death, and then in correcting the proofs.

2

The year 1922 saw the publication of Fridman's book, "Experiment in the Hydromechanics of Compressible Liquids," which lay down the groundwork for theoretical meteorology.

Fridman made the point that in studying atmospheric movements air must be regarded as a compressible baroclinic liquid, i.e., a liquid in which pressure depends not only on density but on the temperature as well. A factor to be taken into account is that the atmosphere receives heat from the sun and loses it through radiation into outer space. Fridman's aim was to pose the basic general problems of the hydrodynamics of compressible liquids.

He began by investigating the kinematics of vortex motion. As we all know, Helmholtz's theorem holds for barotropic liquids (i.e., liquids in which pressure is a function of density only). According to this theorem, (1) during the motion of the liquid, a liquid vortex tube remains a vortex tube, composed of the same liquid particles; and (2) the stress of the vortex tube does not change with time. Under these conditions, Thomson's theorem also applies, to the effect that the derivative of the velocity of circulation with respect to time is equal to the circulatory acceleration.

Fridman evolved his own theorems, in which he combined those of Helmholtz and Thomson. He demonstrated, in particular, that Helmholtz's second theorem will hold when the necessary conditions for the first are not present.

The second part of Fridman's book deals with the dynamics of compressible liquids.

It should be noted that Fridman divided the elements of motion into kinematic and dynamic, the former comprising velocities and their derivatives and the latter pressure, density and temperature and also their derivatives with respect to coordinates and time. He separated a group of dynamic equations, i.e., equations of motion and an equation of continuity, in an endeavor to discover the conditions for the possibility of dynamic motion of compressible liquids, in other words, to discover the correlations representing necessary and sufficient conditions under which motion with a given field of velocities is possible, so

that pressure and density may be found as functions of the coordinates and of time.

In the case of an ideal compressible liquid the conditions making dynamic motion possible correspond simply to Helmholtz's equations for vortex motion derived by excluding pressure from Euler's equations.

Assuming a specific velocity distribution, it proved possible in many cases to find the final expression for the velocities and also to determine the pressure and density. Fridman illustrated his theory by a number of examples.

In a separate article (*Meteorologicheskii Vestnik*, Vol. 31, 1921), he applied this method to the case of a cyclone with a moving axis, a particularly interesting case from the standpoint of meteorological science. Models of this type were then being studied by the English scientists Rayleigh, Shaw, and Green under serious limitations, such as assuming that density remained constant.

Fridman studied motion in which density is a function of pressure and temperature, taking into account the force of gravity and the centrifugal force of the earth's rotation. He assumed that on each horizontal plane there is a vortex center whose position is a function of time and that, consequently, the axis of the cyclone changes its position and the cyclone moves along the surface of the earth, here regarded as a horizontal plane. The angular velocity of rotation of the liquid around the center is deemed to be constant for all altitudes, and the vertical velocity equal to zero.

N. E. Kochin was invited to generalize this cyclone model, assuming that the angular velocity varied with both altitude and time; this resulted in a better approximation of the actual motion in cyclones and anticyclones than did the earlier models.

Although atmospheric movements are not adiabatic, inasmuch as heat exchange is often significant, Fridman nevertheless singles out adiabatic movements because of their relative simplicity. Among these latter, he further distinguishes anisentropic movements for which the entropy is not constant throughout the entire region of motion, but its total, or partial, derivative vanishes; thus, every particle carries with it constant entropy which, however, changes as it passes from one particle to another and, at a given point in space, may change with time.

Fridman also distinguishes the case of a compressible liquid in which the total derivative of density with respect to time vanishes and consequently the velocity divergence is zero; he called this phenomenon incompressible motion.

Fridman was keenly interested in whether there can be adiabatic movements in which pressure does not depend on density and in which formation and disintegration of vortices can consequently take place. This question was answered in the affirmative by N. E. Kochin, who constructed a model of a circulatory move-

ment around a vertical axis with an angular velocity dependent on the altitude—the movement itself being caused solely by the force of gravity. The movement turned out to be incompressible, the liquid a baroclinic one, and the vortices lacking permanence. It was thus demonstrated that vortices can be formed without an influx of energy.

In a posthumously published article, Fridman stated the approximate conditions for the possibility of dynamic motion. Together with B. I. Izvekov, he investigated the conditions of dynamic possibility in Lagrangian coordinates.

Fridman's students studied a number of other models of motion which were of interest to meteorology; Fridman's results were generalized to cases of movement of viscous compressible liquids (B. I. Izvekov) and compressible liquids with a specific heat influx (I. A. Kibel').

Subsequently, dynamic meteorology was greatly developed in the Soviet Union. I shall mention below some of the work of representatives of the older generation, making no reference to the investigations now being carried out in the Main Geophysical Observatory.

A. A. Dorodnitsyn, B. I. Izvekov, and M. E. Shvets gave final shape to the mathematical theory of general atmospheric circulation, I. A. Kibel' evolved a theoretical method of weather forecasting, E. N. Blinova developed the hydrodynamic theory of pressure waves and centers of atmospheric activity and laid down principles of long-range weather forecasting. E. S. Kuznetsov advanced the theory of radiant heat exchange, and he also derived equations for the transfer of radiant energy.

3

Fridman's investigations covered a very wide range. From the beginning of his scientific career he was interested in the basic questions of theoretical geophysics, such as the causes of temperature inversions, the theory of atmospheric vortices and wind gusts, the theory of discontinuities in the atmosphere, and the theory of atmospheric turbulence. He was also ready to tackle any question that had an immediate practical application. Thus, early in his career, he drew up instructions for flying kites carrying meteorographs.

Fridman was a lively and gregarious person, and at his best in scientific discussions. He took an active part in entertaining such eminent visitors as the German physicist P. Ehrenfest, the Dutch authority on hydromechanics I. Burgers and the Italian scientist T. Levi-Civita, with all of whom he corresponded.

Fridman became a member of the mathematical society of the city of Palermo and brought his closest collaborators into it. After his death, these collaborators automatically dropped out of the society and no longer received its journal.

Fridman made several trips abroad: to Germany and Norway in 1922, and to Delft, Holland, to attend

the First International Congress of Applied Mechanics in 1924. At this congress Fridman reported on his joint investigations with Keller and on Kochin's research, and also mentioned the work of his other collaborators and of several Soviet scientists concerned with mechanics. Fridman's conversations with other scientists often led to their working together. It is thus that he came to write an article on the order of magnitudes of meteorological elements jointly with T. Hesselberg, and various other papers with Tamarin, Izvekov, Keller, et al.

In February 1925 Fridman was made Director of the Main Geophysical Laboratory. There can be no doubt that, being a man of boundless energy, he would have greatly furthered its development had it not been for his premature death.

A. A. Fridman passed away on September 15, 1925, at the age of 37, a victim of typhoid. "In him we have lost the strongest hope of theoretical meteorology," said Prof. Ficker, head of the Prussian Meteorological Institute.

Shortly before his death, in July 1925, Fridman went up in a balloon, reaching the record altitude, for that time, of 7,400 meters, and staying aloft for 10 hours and 20 minutes. His pilot was P. F. Fedosenko, who was killed a few years later in a stratospheric balloon ascent.

Fridman was entranced with the element of air, and felt that to know it and to observe its phenomena he had to plunge into it himself.

When the balloonists had come down near the village of Okoroki in the Novgorod district, they reported to the peasants who had gathered to greet them on the meaning of their ascent. After his return to Leningrad, Fridman corresponded with Komsomol youths from that village who were members of the Radio and Aviation Society.

Fridman was also keenly interested in questions of outer space, and thought that the dream of communicating with other worlds might become a reality in the near future.

As we have seen, in the field of theoretical meteorology Fridman was concerned with the most general and fundamental questions. The same may be said of his investigations in the field of the theory of relativity. His "Expanding Universe" was but the beginning of studies he was not fated to continue. N. M. Gyunter has very rightly said that "Fridman had the lofty soul of a student of the eternal problems of creation and the noble nature of a priest of pure knowledge."

A. A. Fridman has left his impress on those fields of knowledge which he explored, and his name is certain to live on in science.

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