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Vladimir Vasil'evich Zheleznyakov (on his 90th birthday)

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January 28, 2021 was the 90th birthday of the outstanding physicist and astrophysicist, Academician Vladimir Vasil'evich Zheleznyakov, advisor in the Russian Academy of Sciences (RAS) at the Federal Research Center, the Institute of Applied Physics of RAS.

V V Zheleznyakov was born in the town of Gorky. Having graduated from the Radiophysical Department of Gorky State University (1954) and from the postgraduate course, where he studied under the guidance of the Nobel laureate, academician V L Ginzburg, he worked as a research fellow and head of department at the Gorky (now Nizhny Novgorod) Radiophysical Institute (1957–1977). His candidate thesis (1959) and then doctoral thesis (1964), based on the monograph, ''Radio Emission from the Sun and Planets'' (Moscow: Nauka, 1964), became pioneering studies in solar radio astronomy. At the Institute of Applied Physics (IAP) of RAS, he created the Department of Astrophysics and Cosmic Plasma Physics in 1977 and was its head till 2011. The development of his ideas in a number of fields in plasma astrophysics, electrodynamics, and radiation propagation in different media has been under way for many years.

V V Zheleznyakov's fundamental work has been highly appreciated by astrophysicists, radio astronomers, and specialists in cosmic plasma physics in Russia and abroad. Several avenues of research proposed by him remain topical for solving contemporary problems of electromagnetic wave generation and their interaction with plasma of various astrophysical objects, first and foremost in magnetospheres of stars of later spectral classes, magnetic white dwarfs, and neutron stars. Of no less importance is V V Zheleznyakov's contribution to other areas of physics, especially to high-power electronics, the theory of quantum and classical superradiance, liquid-crystal optics, and nonlinear phenomena in a magnetized vacuum.

V V Zheleznyakov has clarified the decisive role that the cyclotron mechanism of radiation plays in the formation of various characteristics of observable spectra of solar radio emission and magnetic Ap-stars, optical radiation from magnetic white dwarfs, and X-ray emission from pulsars. It was to a great extent his initiative to investigate the depression of electron cyclotron radiation at the gyrofrequency in dense plasma and nonequilibrium plasma instability under conditions of the anomalous Doppler effect; he analyzed for the first time possible regions of synchrotron instability in cosmic plasma and pointed out the considerable influence the relativistic velocity dependence of the electron mass has on the growth rate of cyclotron instability in low-relativistic plasma. This last phenomenon, in particular, turned out to be crucial in some problems of vacuum electronics and found application in the creation of cyclotron-resonance masers at the Scientific Research Radiophysical Institute and the Institute of Applied Physics of the USSR Academy of Sciences. The collective wave effects associated with the velocity dependence of electron gyrofrequency discovered by V V Zheleznyakov are hitherto being widely used to solve research and applied problems in electronics and cosmic plasma physics. For his work on cyclotron radiation in astrophysics, V V Zheleznyakov won the A A Belopolsky Award of the USSR Academy of Sciences in 1984.

Vladimir Vasil'evich Zheleznyakov

In the theory of slowly varying components of solar microwave emission, V V Zheleznyakov revealed the leading role of the thermal cyclotron mechanism. It has turned out that the joint effect of thermal bremsstrahlung and cyclotron mechanisms in nonuniform magnetic fields of solar active regions gives an explanation of the observed properties of radio emission. The contemporary data processing of radio observations of the Sun providing insight into the magnetic field and plasma temperature distribution in active regions of the corona and upper chromosphere is based on the results of the theory V V Zheleznyakov formulated.

He proposed and substantiated the plasma mechanism of radiation for the interpretation of data on Raman scattering (coalescence) of plasma waves in the solar corona resulting in their transformation into electromagnetic radiation at the doubled plasma frequency and proved the efficiency of such mechanisms in plasma wave conversion into electromagnetic waves under cosmic conditions. The indicated result underlay all the subsequent studies of the radio emission of sub-

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relativistic electron beams in the solar corona (types III and V solar radio bursts). Moreover, this astrophysical examination of Raman scattering of plasma waves became one of the pioneering studies in a series of further studies on nonlinear decay interactions in plasma.

V V Zheleznyakov has solved a number of key problems of electromagnetic wave propagation in cosmic plasma. He developed a theory of linear wave interaction (transformation) in smoothly inhomogeneous weakly anisotropic media, including plasma in a magnetized vacuum in the neighborhood of neutron stars. In particular, he gave a quantitative description of the effects of linear transformation of magnetoactive plasma modes during propagation through transverse magnetic field regions, which was repeatedly verified by observations of microwave solar emission. He managed to solve the problem of 'limiting polarization' of radiation escaping from magnetoactive plasma and to find new types of linear coupling of waves, for example, in the inhomogeneous plasma of planet magnetospheres and in neutral current layers of the solar corona. As a consequence, the observed features of noise-storm polarization led V V Zheleznyakov to the conclusion that current sheets must exist in the active regions of the solar corona.

Observations and the construction of models of formation of solar radio emission that are now being carried out in our country and abroad have to a large extent been stimulated by the work of V V Zheleznyakov and his team. Speaking of the leading role of his theoretical work in solar radio astronomy, suffice it to note, for instance, the discovery of cyclotron lines in the solar radio emission spectrum, predicted in these studies. A natural consequence of this line of research was the analysis of the mechanism of cyclotron radiation in the coronas of magnetic Ap stars. He has shown that microwave emission from them can be detected by modern facilities, even in the case of rarefied coronal plasma, whose X-ray radiation is insufficient for observation.

The series of V V Zheleznyakov's papers on the theory of radio pulsars, devoted to investigating physical conditions and processes in neutron star magnetospheres, was important. He analyzed in detail the synchrotron mechanism of optical and X-ray emission from the Crab pulsar to show that the radiation source in short-period pulsars must be located near the light cylinder.

V V Zheleznyakov has lately been focusing on investigating white dwarfs and neutron stars with super-strong magnetic fields. So, V V Zheleznyakov and his colleagues have proposed and tested an effective method for detecting hot plasma coronas of isolated white dwarfs with megagauss magnetic fields. A substantial advance in the theory of radio pulsars was the detailed development of the mechanism of double plasma resonance in nonrelativistic plasma as applied to the explanation of the fine structure of quasi-harmonic lines in the dynamic spectrum of high-frequency intermediate pulses of the Crab pulsar. V V Zheleznyakov and his team constructed an inhomogeneous plasma current sheet with superthermal electrons as a model of a radiation source to find specific features of propagation of radio waves generated by this source in the neutron star magnetosphere and to show that the predicted spectral dynamic characteristics of radiation completely reproduce the observational data of modern radio telescopes in the gigahertz frequency range with submicrosecond resolution. Half a century ago, they explained observations of a zebra pattern of the dynamic spectra of solar radio emission, and later Jupiter radio emission using such a mechanism of double plasma resonance under which the upper-hybrid frequency coincides with one of the harmonics of the electron gyrofrequency.

In great demand for interpreting modern satellite data is the series of V V Zheleznyakov's studies where he proposed and justified a model of an X-ray emission source on a neutron star (an X-ray pulsar). This model explains the formation of continuum and cyclotron radiation lines in dense isothermal plasma of the polar spot on the star's surface. It turns out that the observed lines in absorption are due to efficient cyclotron scattering and appear against a continuum attenuated as a result of Thomson scattering by free electrons. Of great demand to date is Zheleznyakov's previous research devoted to the specific features of X-ray emission propagation and the efficiency of its cyclotron absorption in strong magnetic fields, where the wave polarization is determined by the magnetized vacuum. Later on, V V Zheleznyakov and his colleagues developed the theory of radiation transfer at the cyclotron harmonics in plasma atmospheres of neutron stars and white dwarfs with a strong magnetic field.

V V Zheleznyakov's published monographs on the physics of cosmic plasma and astrophysics — *Radio Emission of the Sun and Planets* (Pergamon Press, 1970), *Electromagnetic Waves in Cosmic Plasma* (Nauka, 1977), *Radiation in Astrophysical Plasmas* (Kluwer, 1996), and *Radiation in Astrophysical Plasma* (Yanus-K, 1997) — make up an extensive panorama of the physical processes related to cosmic radiation. These books, as well as several of his review papers, are an example of pedagogical skill, simplicity, consistency of physical arguments, and thoroughness of presentation. Several generations of physicists interested in radiation generation, transfer, and dynamics in magnetoactive plasma have gratefully read these books.

Among the deep theoretical studies by V V Zheleznyakov and his colleagues, of distinction is a series of investigations on the nonlinear electrodynamics of a magnetized vacuum and inverted two-level systems. In particular, they pointed out the possible existence of shock waves and solitons in the magnetized vacuum around neutron stars. They also predicted the existence of a dissipative instability of polariton modes in inverted media, discovered a close connection between this type of instability and the effect of Dicke superradiance, and proposed a new physical interpretation of this effect. Based on this research, they found and examined a classical analogue of this phenomenon of collective spontaneous radiation — cyclotron superradiance of an ensemble of moving electrons. These results stimulated a theoretical analysis and led to the experimental discovery of superradiant regimes in vacuum electronics and semiconductor physics.

For more than 50 years, V V Zheleznyakov delivered lecture courses in astrophysics and radio astronomy both at the State University of Nizhny Novgorod and at several foreign universities, including the University of Maryland (USA, 1989), Nagoya University (Japan, 1990), Utrecht University (Netherlands, 1991), the Institute for Space Research (Brazil, 1995), and the Goddard Space Flight Center (USA, 1999). The research work of three generations of V V Zheleznyakov's pupils who had been engaged in the problems of the interaction of electromagnetic radiation with astrophysical and geophysical plasma at his scientific school won deserved recognition. About 20 of his pupils (members of this school) became candidates and doctors of physico-

mathematical sciences and four were elected corresponding members of the Russian Academy of Sciences. V V Zheleznyakov was elected a member of the editorial board of the journal *Solar Physics* (1977–1992). For almost half a century, he was a member of the editorial board of the journal *Izvestiya Vuzov. Radiofizika* ("Radiophysics and Quantum Electronics" in English edition), and its editor-in-chief (1998–2016); he ensured a high standing of published papers and one of the leading positions of the journal among Russian science periodicals.

The results of V V Zheleznyakov's scientific organizational activity were substantial. Since 1990, he has been continuously elected a member of the Bureau of the Division of Physical Sciences of RAS. He was member of the Council of the Russian Foundation for Basic Research in the period of its formation (1992–1999) and took part in the work of the Commission for State Prizes under the RF President (1992–2004). V V Zheleznyakov is member of the Bureau of the Astronomical Council and the Sun–Earth Council, and a member of expert commissions of RAS for the A A Belopolsky and I S Shklovsky Awards and the Ya B Zeldovich Medal. He was a founding member of the European Astronomical Society and several other international organizations. For nearly 60 years, he has been a member of the International Astronomical Union and its Committee on Radio Astronomy.

Vladimir Vasil'evich's colleagues, students, and friends heartily wish him all the best on this milestone and hope for his good health, prosperity, successful work, and happiness for many years to come.

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