

CONFERENCES AND SYMPOSIA

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Scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences (1 October 1997)

A scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences was held on 1 October 1997 at the P L Kapitza Institute for Physical Problems, RAS. The following reports were presented at the session:

(1) **Trapeznikov V A** (Physico-Technical Institute of the Ural Department of the Russian Academy of Sciences, Udmurtian State University, Izhevsk) "Electron spectroscopy of small radiation doses";

(2) **Khalfin L A** "Quantum theory of unstable elementary particles and relativity theory".

A brief report on the first talk is presented below.

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Electron spectroscopy of small radiation doses

V A Trapeznikov

The number of methods of investigation of a surface as a common part of two adjacent spatial regions amounts to several dozen, the method of electron spectroscopy (ES) being among them. ES is one of the most informative direct methods of studying the electron structure and chemical bonds, and for the analysis of superthin surface layers in the limits from the maximum thickness determined by the free path of electrons up to the monoatomic layer and individual atoms adsorbed on the surface. The ES method is especially efficient when used together with X-ray absorption and emission methods. Because the electron spectrum cross section is several orders of magnitude greater for the X-rays, the ES method shows an obvious advantage in the investigation and analysis of small radiation doses .

Small radiation doses are possible either for a small amount of substance to be examined and a comparatively high specific emitted intensity or for a short radiation recording time and a high specific emission density, or for a specific emission density tending to zero and an unlimited emission recording time with the maximum possible area of an analysed surface determined by the device aperture. As the dose is decreased, the transmission and sensitivity of the spectrometer should be heightened. An increase of the cyclotron orbit radius and the use of microchannel multianode plates for spectrum recording are necessary conditions for electron magnetic spectrometers because devices of this type possess a focal plane [1].

All other conditions being equal, the valence band spectra are the least intensive in the X-ray electron spectroscopy method because their density of states is small compared to that of internal levels. Our results of studying the electron structure of palladium alloys [2] using the combined electron and X-ray spectroscopy methods are presented in Fig. 1. The problem consisted in determining the degree of collectivisation of valence electrons of components in alloy formation. The materials used to obtain samples (Pd, Cu, Ag, Au, Rh) were exceedingly close in parameters: of identical crystal lattice (Fcc) symmetry and similar in properties due to the neighborhood of the components in group and period. The methods using X-ray electron spectra for determining the electron structure — the distribution of electron states in a band by density and the symmetries of the wave functions — consist in reduction to one energy scale of the X-ray spectra of the components in which the selection rule is fulfilled and combination of these spectra in the alloy valence band obtained from the electron spectrum. In the electron spectrum of the valence band, the cross sections of all the symmetries are equiprobable because all the final-state symmetries overlap at a distance of several tens and hundreds of electron-volts (all the transitions obey the dipole selection rules). In the valence band of the Pd – Rh alloy (Fig. 1a) the states of Pd and Rh coincide, which allows us to speak of collectivisation of the valence electrons of the components when they enter the alloy according to the Mott theory. The valence band of the Pd – Ag alloy (Fig. 1b) shows the energy position of the components' spectra which they had before they entered the alloy, but with a shift of 2.6 eV, which may be explained in the framework of the coherent potential theory. Figures 1c,d illustrates the Pd – Cu and Pd – Au spectra which represent a mixed case.

The study of electron line intensities of nickel-based molten samples with soaking at a given temperature (Fig. 2) showed cyclic variations in the intensity of the components with periods of 10 – 20 min with exponential fluctuation damping, which is indicative of a time-dependent redistribution of component concentration on the melt surface for each temperature [3]. A study of the fine structure of the individual peaks of these fluctuations of the components and especially of the valence bands in the liquid state (Ni and Cu, Ref. [4]) reflecting the variation of the atomic and electron structure of melt surface layers (Fig. 3) suggests that the spectrum recording time should be as short as possible because the above-mentioned exponential run is indicative of rapid stabilization of the process.

Two trends exploiting small doses of recorded electrons are now being developed in electron spectroscopy. The first trend indicates that in examining the electron structure and

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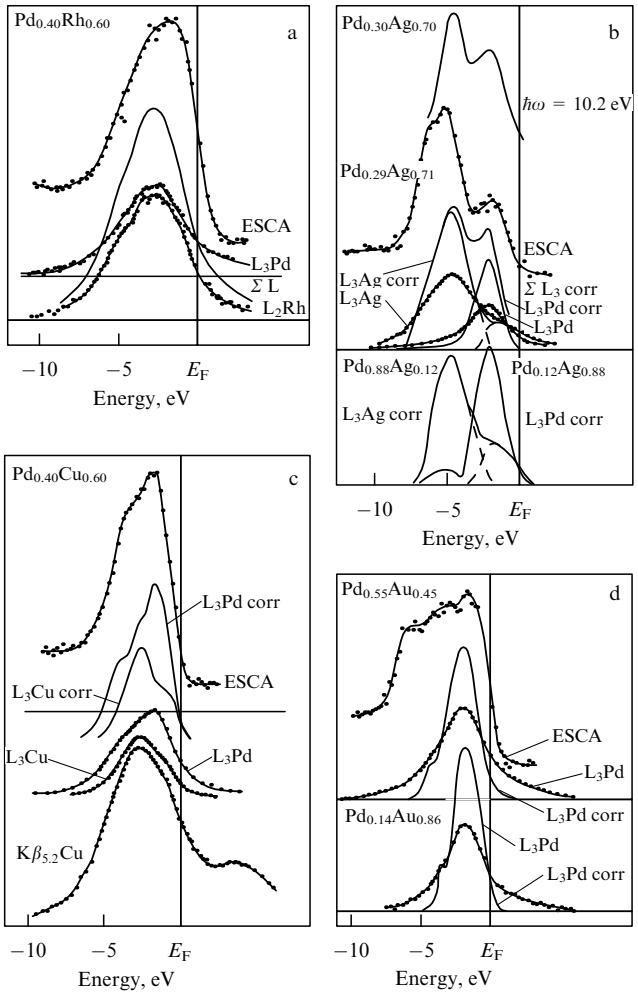

Figure 1. ESCA and X-ray emission spectra: $Rh_{60}Pd_{40}$ (a); $Ag_{71}Pd_{29}$ and the UV electron spectrum of the valence band of the $Pd_{30}Ag_{70}$ (b) and $Cu_{60}Pd_{40}$ (c) alloys; the ESCA-valence band of $Au_{45}Pd_{55}$ and the X-ray emission spectra of PdL_3 for two Au – Pd alloys (d).

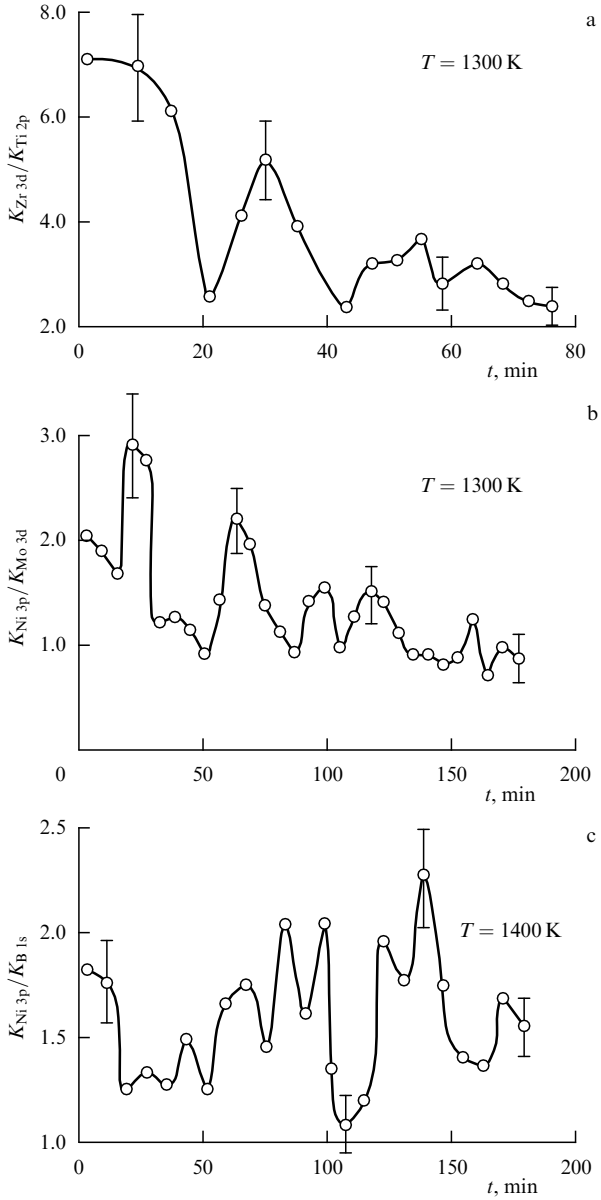

Figure 2. Time dependence of the spectral line contrast ratio K_i/K_j for $Zr_{60}Ni_{20}Ti_{20}$ (a), $Ni_{72}Mo_{14}B_{14}$ (b), and $Ni_{83}B_{17}$ (c) melts.

analyzing superthin surface layers of condensed systems within the free path of electrons in fast processes proceeding within fractions (up to 10^{-5} s) of a second, the electrons should be recorded within the shortest possible time. The second trend consists in determining the energy distribution of electrons along the portion of the intensity curve which asymptotically approaches zero, and in this case the smallest possible spectrum intensity should be registered with an admissible confidence interval. If this electron spectroscopy method might be called pulsed in the former case, the term is inapplicable in the latter because of the long recording time, but the doses of registered radiation are of the same order of magnitude (vanishingly small) in both cases and this unambiguously suggests that the doses should be small, which imposes certain restrictions on the devices employed. In both cases an electron spectrometer should have high transmission, resolution and sensitivity for simultaneous electron recording over a broad spectral range. Double-focusing ($\pi\sqrt{2}$) electron magnetic spectrometers suit this purpose perfectly well because their focal plane is sufficient for simultaneous recording of a substantial spectral region of several tens of electron-volts (see the description of the spectrometers of the Physico-Technical Institute of the Ural Department of the Russian Academy of Sciences [5]). It will not be out of place to cite I P Pavlov's words concerning the development of science: "It is often said, and not for nothing, that science advances in pushes depending on the progress made in the methods. As the methods step forward, we also seem to make another step wherefrom a wider horizon opens to disclose objects that have been previously unseen".

Pulsed electron spectroscopy was initiated by experimental work on electron emission from cerium, praseodymium, neodymium, and samarium under pressure [6]. Under a pulsed pressure of up to 10 kbar and a pressure increase rate of 2.5 kbar s^{-1} in the region of 7 – 10 kbar, i.e., in the limits of one (last) second, an electron emission (12000 pulse s^{-1}) from cerium was revealed that exceeded the emission from praseodymium (500 pulse s^{-1}), neodymium (450 pulse s^{-1}), and samarium (80 pulse s^{-1}) by two orders of magnitude. The high intensity of fractoemission for cerium is associated with the release (in the energy breakdown) of a corresponding

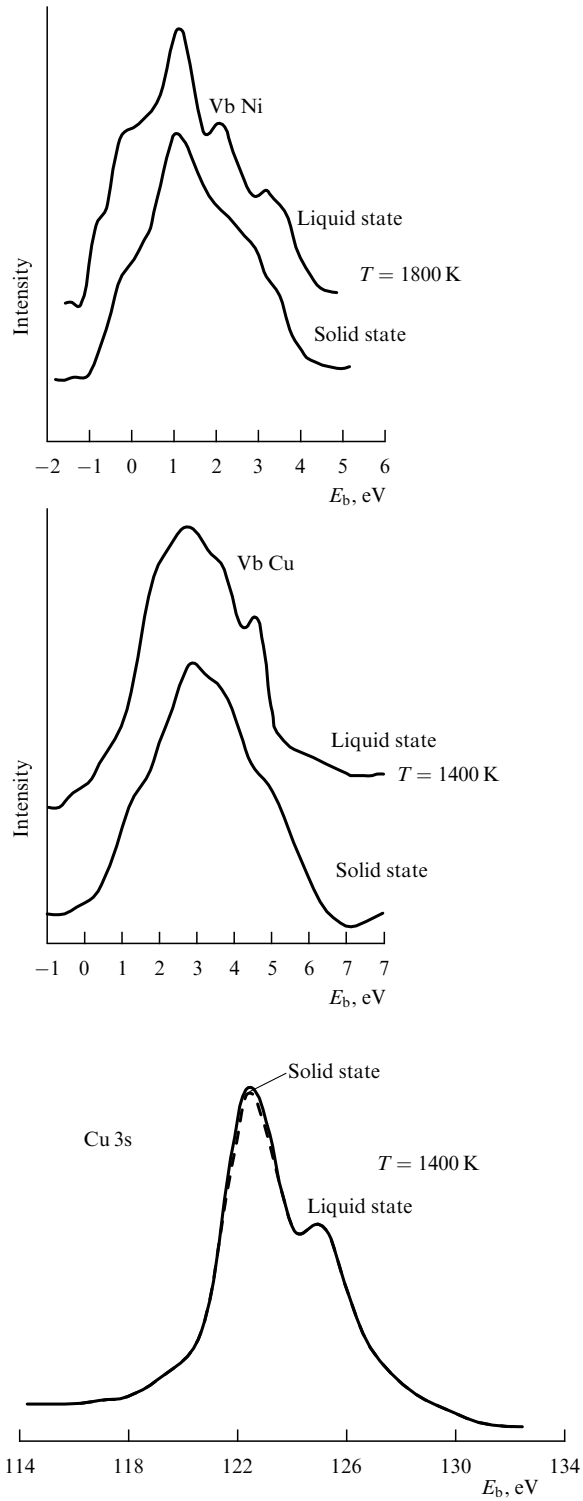

Figure 3. X-ray electron spectra of nickel and copper valence bands in the solid and liquid states, and the ESCA-spectrum of liquid Cu 3s.

strong interatomic bond which appears with a high density of states at the Fermi level due to hybridization under pressure of 4f-electrons with a valence of 5d 6sp. For other rare-earth elements, hybridization of the highly dense 4f 5d 6sp-states is less probable because of the large energy and space difference in the positions of their lines. The electron emission from praseodymium, neodymium and samarium and, of course, partially from cerium is caused by baraelectron emission [7] based on the tunnel effect. Strengthening the interatomic bonds at a pulsed pressure at minimum in the surface layer (dynamical covering) from which electrons are emitted can be used for self-reinforcement of machine elements operating in a cyclic regime (parts of compressor blades and engine turbines in flying vehicles, rings and cylinders in internal combustion engines, barrels of automatic guns and milling cutters (the series is given in an increasing order of cycle time) at the expense of working pressure in the cases when the time of idle run in the cycle without pressure is shorter than the time of material relaxation from the state with a strong interatomic bond.

It is suggested that the increase of the interatomic bonding force due to hybridization under pressure of 4f- and valence electrons with the formation of a strong covalence bond in cerium should be explained proceeding from the results of X-ray electron spectroscopy of the shake-up effect [5].

The high intensity of cerium fractoemission associated with the pressure-induced formation of a high density of states at the Fermi level (which is several orders of magnitude higher than that without pressure) can also be explained by the Abrikosov – Sul resonance [8] used to account for the Kondo effect [9]. This effect was predicted for compounds of cerium and uranium by V V Moshchalkov and N B Brandt [10]. It admits the appearance in a metal of highly conducting states up to superconductivity. Neptunium is reported [11] to produce the same effect. We associate the increase of the number of electrons responsible for interatomic bonding forces with the high density of states at the Fermi level. The classical Kondo (low-temperature) effect has a fairly narrow (thousandths of a Volt) energy interval with a high density of states at the Fermi level, but this interval may significantly broaden at the high pressure that may occur at much higher temperatures. As the temperature rises, anharmonism appears which automatically leads to broadening of the interval with a high density of states at the Fermi level.

The estimate of the interatomic bonding forces characterized by the Debye temperature Θ in thin surface layers ($10^{-3} - 10^{-1}$ μm) and over a short time ($10^{-4} - 10^{-1}$ s) becomes decisively important. A method of determining Θ from the electron spectra excited from one atomic level by two X-rays with different energies obtained either from two anodes or using two narrow spectral regions of synchrotron radiation was proposed in Ref. [12].

The use of electron pulse spectroscopy seems to be most appropriate since it allows a high intensity to be obtained within a short time of milli- and microseconds, and the depth of the investigated layer is determined by the mean free path of the electrons. For metals this value is within the limits of 10^{-3} μm (20 – 40 A), for semiconductors and dielectrics it rises to $10^{-2} - 10^{-1}$ or even 1 μm. The spectrum recording time can be shortened by enlarging the electron orbit radius in the spectrometer, heightening the electron-exciting source power and by recording the entire electron spectrum simultaneously with the use of microchannel multi-anode plates, which gives a gain of several orders of magnitude compared to normal spectra [13].

The task is to choose such covering materials and working pressures with which strong interatomic bonds are formed (Θ) without initiating the destruction of the covering. Of course, a high fractoemission intensity could also be due to the formation of a high density of states on the Fermi surface N (E_0) and its realization. The latter may also accompany strong bonding forces or may be independent under the Kondo effect.

The shorter the cycle time, the more probable the use of the scheme discussed for self-reinforcement machine operation. For the indicated machine elements, the cycle time increases from the beginning towards the end of the list (for blades it is 10^{-4} s and smaller, for rings and cylinders 10^{-2} and for barrels and milling cutters it is of the order of 10^{-1} s). On the other hand, it is desirable to have as long a relaxation time as possible. The best is infinity. The latter case includes materials with high resistance stable in time. Among the materials exhibiting the above-mentioned properties obtained using the pulsed effect is polyphosphonitride which is formed upon excitation of phosphorus and nitrogen atomic electrons onto high vibrational levels under the action of a pulsed electron beam [14].

In paper [12] the two electron lines for the estimation of Θ variation are not taken at random, but correspond in kinetic energies of excited electrons to the energies of two fluctuations of the fine structure of X-ray absorption spectra of the level from which the electron spectra are obtained. We automatically borrowed here the method of estimation of interatomic bonding forces in terms of Θ from the dependence of the ratio of intensities of the amplitudes of fluctuations of the fine structure of X-ray absorption on the temperature T and alloying C [15]. In the X-ray absorption method, Θ affects the amplitude of the perturbing potential A of the atomic layer surrounding the absorbing atom as $\exp(-1/\Theta)$. When X-ray electron spectroscopy is used instead of the X-ray absorption method, the gain in the spectrum recording time amounts to several orders of magnitude and becomes fractions of a second instead of tens of minutes and hours, which allows a short-time estimation of the pressure-induced variations of interatomic bonding forces by Θ variation.

To the two pairs of fluctuations of the absorption coefficient of the K-edge (for Fe D and A, and Ni E and C) chosen for iron and nickel correspond two pairs of the electron spectral lines of $Fe_{1s}A$ (Gd $L\beta_9$) and $Fe_{1s}D$ (Gd $L\beta_7$) for Fe and $Ni_{1s}C$ (Er $L\beta_9$) and $Ni_{1s}E$ (Ho $L\gamma_5$) for Ni (Fig. 4). As can be seen from the choice of X-ray emission lines, the problem is not solved in the best way for the excitation of two electron lines corresponding to two fluctuations of the iron and nickel absorption coefficients because the emission lines do not exactly coincide in energy with the fluctuation maxima and are weak in intensity. A source of synchrotron radiation is not always accessible. An increase of the electron line intensity becomes a necessary condition for this method to be applied. One of the possibilities is to increase the transmission of the spectrometer and the sensitivity of its recording path.

Udmurtian State University and Physico-Technical Institute of the Ural Department of the Russian Academy of Sciences designed and fabricated a 100-cm electron magnetic spectrometer with double-focusing $\pi \cdot \sqrt{2}$ (Fig. 5) [16]. The increase to 100 cm (a record value) of the cyclotron orbit radius R in itself makes it possible to raise the sensitivity L which is proportional to R^2. The large chamber in the installation (Fig. 6) makes room for the rather cumbersome devices (a recording path consisting of several multi-anode microchannel plates, electron-optical transducers and other units), which also provides an improvement of spectrometer sensitivity [17].

A new trend in the development of electron spectroscopy is the use of tunable lasers for the investigation of vibrational and rotational electron spectra, the main idea of which was formulated by K Siegbahn in his appeal to K and A Wallenbergs for assistance in foundation of his new ESCA – LASER laboratory in Upsal University, which was published as a special issue [18]. He motivated this new trend and emphasized that laser sources of exciting radiation had an advantage over traditional X-ray and ultraviolet sources: a short pulse time (the pico- and femtosecond ranges), locality and a high emissive power, which opens new horizons in the investigation of fast processes, including small objects and surface regions. An acquaintance with the ESCA – LASER laboratory in the summer of 1997 showed that this new trend was being successfully developed.

The idea of an increase of interatomic bonding forces by the application of working pressure onto the surface of machine elements operating in a cyclic, i.e., self-reinforce-

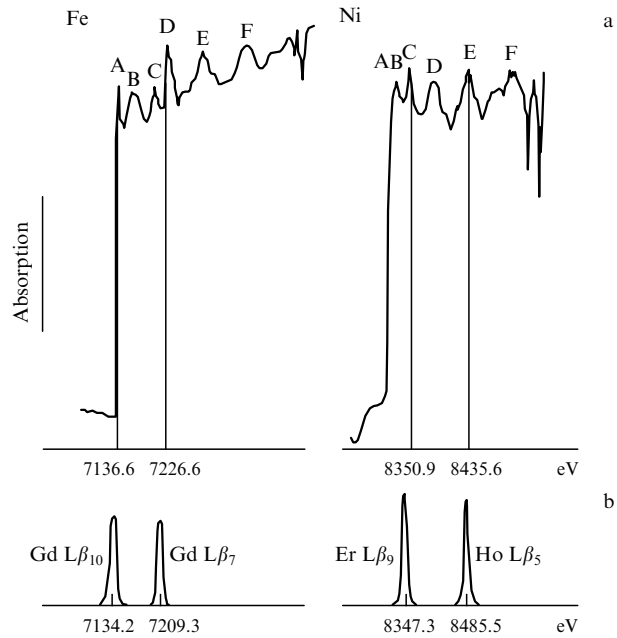

Figure 4. X-ray iron and nickel absorption K-spectra (a); schematic X-ray erbium, gadolinium and holmium emission L-spectra (b).

Figure 5. Appearance of the 100-cm electron magnetic spectrometer with double-focusing $\pi \cdot \sqrt{2}$ (rear view).

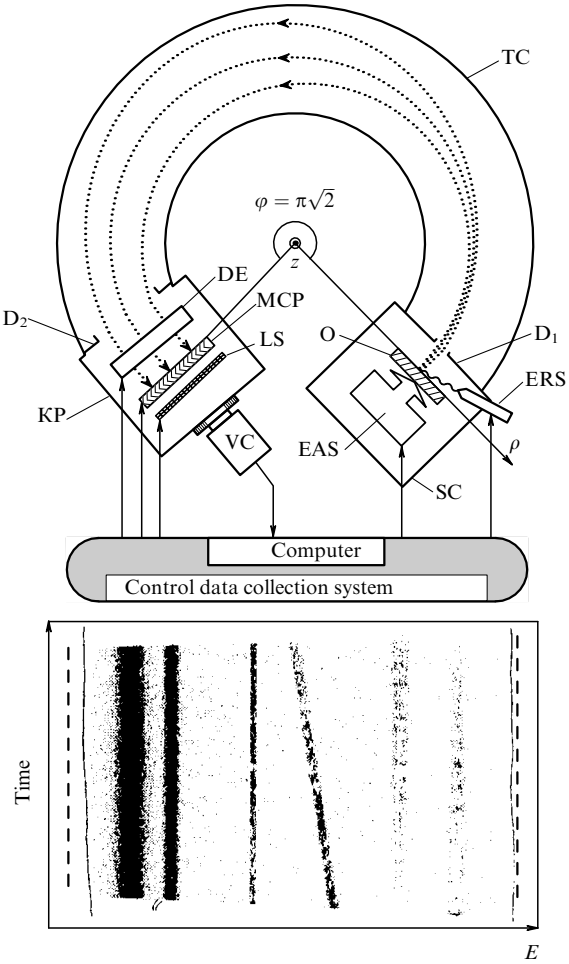

Figure 6. Schematic drawing of the 100-cm electron magnetic spectrometer in the parallel recording regime (dashed lines); TC indicates the toroidal chamber, SC the sample chamber, O the object under investigation, ERS the exciting radiation source, EAS the external action source, D_1 and D_2 the input and output apertures, DE the deviating electrodes, MCP microchannel plate assembly, LS a luminescent screen, and VC a video camera.

ment regime under conditions when the relaxation time of an excited electron system exceeds the part of the cycle time without pressure, seemed tempting for preventing the formation and development of fatigue cracks. This can be used, for example, to increase the resilience of aircraft engine blades experiencing considerable alternating loads with high frequency. This becomes possible when the covering material fills the surface fatigue cracks in a region where the crack size corresponds to the capillary size for a given pair of base-covering materials. The properties may change significantly in the portion of a crack which schematically looks like an intersection of two lines going from its vertex and two parallel lines of a capillary superposed coaxially on the crack in the material of the filler. The effective electron mass in capillaries of a metal-ammonia solution was reported [19] to increase 2.3×10^4 times compared to the electron rest mass. It can be interpreted as an increase of the density of states on the Fermi surface with a corresponding strengthening of the interatomic bonding forces on a capillary-like region of the crack, which should prevent its development.

The method of X-ray electron spectroscopy with its low resolved layer depth in the limits of the mean free path of electrons allows the examination of the capillary-like region of a crack provided that it is not filled above the investigated region, and the angle of incidence of the electron-exciting X-ray emission is smaller than the crack opening angle. We have shown experimentally [20] that in the course of deposition of a covering layer the pores and cracks are not always filled completely [21] and only after this the covering material is lodged on the interporous surface. It has been demonstrated [20] that in the deposition of copper onto aluminum oxide with a porous surface electron spectra of the copper appear from the interporous surface when the substrate pores are 5% filled with copper atoms. An analysis of a small amount of substance inside a capillary-like region of a crack and especially an investigation of its electron structure call for an appreciable increase in the electron spectrometer sensitivity.

Without waiting for the 100-cm spectrometer, with which one could estimate the variation of interatomic bonding forces within a short time and choose the most appropriate material, a study was carried out on the hardening of blades of the third stage of a high-pressure compressor of a PC-90A aircraft engine by an ion-implanted deposition of a thin (about 0.1 μm) layer of cerium compound onto the surface. Fatigue tests of series-produced (without a coating) and experimental blades on the maker stands demonstrated an increase in the resilience of the experimental blades compared to the serial ones by more than an order of magnitude with an identical load of 22 kg mm^{-2} and an oscillation frequency of 6.7 kHz, and a covering with polyphosphonitride P_xN_y exhibited the same gain in resilience with heightened loads of 24 and 26 kg mm^{-2}.

The operation of the 100-cm spectrometer opens the possibility of realizing the second of the above-mentioned trends in electron spectroscopy with the purpose of evaluating the rest mass of an electron antineutrino through the determination of the energy loss by the electrons in the high-energy region of the spectrum in the β-decay of tritium ($H^3 \rightarrow He^3 + \beta^- + \bar{\nu}_e$) [22]. Since Paulis' prediction of the existence of electron neutrino ν_e in 1930, the upper bound for the value of the rest mass of this particle had decreased with an improvement of experimental possibilities from 1 MeV to 4.35 eV accepted in 1994 according to the data of the Institute for Nuclear Research of the Russian Academy of Sciences in Troitsk [24]. In addition to this result the fine structure of the β-spectrum distribution curve in the high-energy range having a width of 4 eV in the region 10 eV from the maximum energy was revealed in an experiment on an electrostatic spectrometer in Troitsk, and the time dependence of the intensity of this region of this unique spectrum was traced for two years (1994–1996) [25] (Figs 7 and 8). The results have not yet been interpreted. The 100-cm magnetic differential electron spectrometer will make it possible to discover a richer fine structure than that obtained on the electrostatic integral device [26] in the region of $\sim$ 10 eV and will perhaps show a neutrino upper mass bound of 6.5 eV. The anticipated result rests on the comparison of the potentialities of two analogous spectrometers with identical magnetic focusing by an inhomogeneous field $\pi \cdot \sqrt{2}$ and different radii R: the 75-cm Japanese spectrometer [27] with an upper bound of 13 eV and the 100-cm Russian spectrometer, which, with other conditions being equal and allowing for the Curie graph linearity for the quadratic dependence of sensitivity L on the radius ($L \sim R^2$), will permit the indicated energy bound (6.5 eV). A new result from the Institute for Nuclear

Research of the Russian Academy of Sciences of 1994 – 1996 gave an antineutrino rest mass bound of 3.9 eV. With a resolution of the order of 10^{-4} inherent in the 100-cm device, the bound may be shifted down to 2 – 1 eV.

In recent reviews on neutrinos [28, 29], the method of estimating the electron neutrino rest mass from the β-decay of tritium is believed to be of prime importance.

Far-reaching gnosiological conclusions are drawn from the estimation of the electron antineutrino rest mass. In his book "From the Big Bang to Black Holes" [30] S Hawking writes: "However, if neutrinos are not massless, but have a small mass of their own, as suggested by an unconfirmed Russian experiment performed in 1981 (Ref. [31], with a boundary of 14 eV — V.T), we might be able to detect them indirectly: they could be a form of 'dark matter,' like that mentioned earlier, with sufficient gravitational attraction to stop the expansion of the universe and cause it to collapse again".

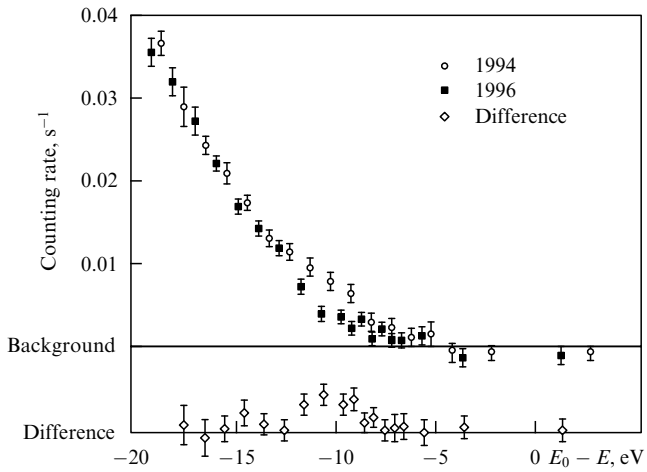

Figure 7. Superposition of the short-wave regions of the β-spectra in tritium decay obtained in 1994 and 1996 at the Institute for Nuclear Research of the Russian Academy of Sciences.

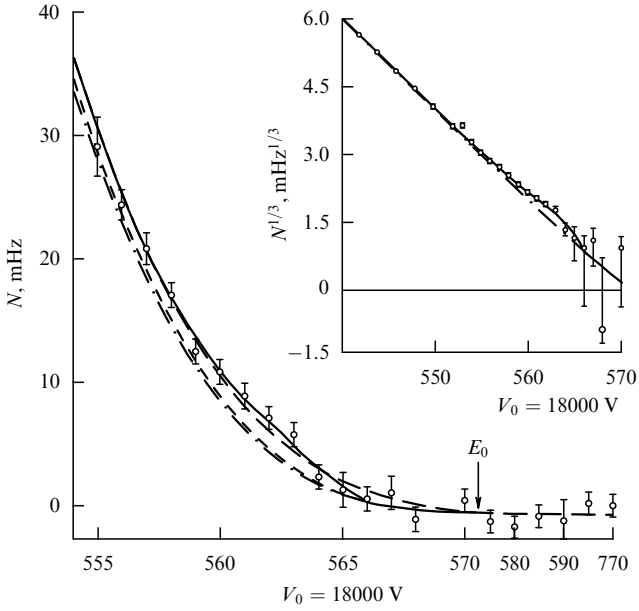

Figure 8. Curie graph of the short-wave regions of the β-spectra in tritium decay and the same experimental spectrum.

Alongside the microscopical methods of estimation of the neutrino rest mass one may use the data of cosmological studies evaluating the Universe's mean density. The estimation of the neutrino rest mass is of great importance not only for elementary particle physics in the formulation of the unified theory of all four types of interaction: gravitational, electromagnetic, weak, and strong, but also for the explanation of the appearance of the Universe and for the prediction of its further evolution. The Universe was either created by God and will infinitely expand according to Friedman, or the neutrino has no rest mass and the mean density will be below 10^{-29} g cm^{-3} (it is presently estimated not accounting for the neutrino mass as 10^{-30} g cm^{-3}), that is, the Universe must be open, or there has never been any beginning†.

A recent study of Universe openness [32], where various versions of its density evaluation allowing for light neutrinos (i.e., just the electron neutrino considered in the present paper) are discussed, has shown that the Universe is most likely to be open. The authors formulate the conclusion rather carefully: "We have looked here at the main aspects of cosmology in which the density of the Universe plays a role as either a prediction or a parameter. We hope we have convinced the reader that no strongly convincing case can be made for a critical-density Universe, and that on the balance of the evidence, an open Universe should be preferred. We are not arguing that we have proved the Universe to be open — there is simply not sufficient evidence to make this claim — but we do argue that there are considerable grounds for doubting the assertion that we live in a critical-density Universe." From this we may conclude that the neutrino rest mass must be zero.

The opposite point of view based on a nonzero neutrino mass and, accordingly, on the presence of a critical (10^{-29} g cm^{-3}) or a higher density of the Universe predicts that the expansion of the Universe will stop one day and it will begin contracting to a point to form a large black hole. Such a state will be unstable and a new Universe will thus appear by way of a bang similar to that which took place approximately 10 billion years ago when our Universe was born. The latter gnosiological conclusion from the estimate of the neutrino rest mass makes no room for other ideas of the birth and death of the Universe: it has always existed and evolved in a cyclic regime with a cycle time exceeding 20 billion years, and it will always exist according to the same cyclic law.

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† The results of neutrino rest mass estimates may cast doubt on the eternal question of the existence or non-existence of God. In his foreword to Hawking's book [30] C Sagan says, "This is also a book about God ... or perhaps about the absence of God". We note that the Russian translation of this phrase is not quite adequate because the Russian for 'perhaps' implies that in the original there may stand either 'could be' or 'may be' which have quite different meanings — in the former case one concludes from the book with certainty that there is no God, while in the latter case there is no certainty in respect of the existence or non-existence of God. An acquaintance with the original puts an end to any doubt because the word 'perhaps' implies both possibilities, i.e., the question of the existence or non-existence of God remains open and the answer can come from an unambiguous estimate of the neutrino rest mass.

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