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1. Room temperature superconductivity

The discovery of superconductivity [1] at a critical temperature reaching $T_c = 203$ K in the pressure range of 100 to 250 GPa (in diamond anvils) in the H_3S system stimulated a flood of experimental studies of high-temperature superconductivity of hydrides at megabar pressures (see reviews [2, 3]). A theoretical analysis immediately confirmed that these record T_c values are due to traditional electron–phonon interaction, and a good description of the experimental situation is due to the Eliashberg–McMillan theory in the limit of a sufficiently strong electron–phonon interaction [4, 5]. Moreover, detailed calculations for a whole number of transition metal hydrides under pressure [4] resulted in the occurrence of a rather large number of such systems with record T_c values. In some cases, these predictions found a magnificent confirmation, in particular, record temperature values $T_c = 250-260$ K were reached experimentally in the LaH_{10} system [6, 7]. These studies were of great importance, mainly because they clearly demonstrated the absence of substantial restrictions on T_c in the framework of the electron–phonon mechanism of Cooper paring, where it was conventionally accepted that T_c cannot exceed 30–40 K. After the appearance of papers [6, 7], it became clear that the discovery of room temperature superconductivity, which had been only the dream of a few theoreticians over many years [8, 9], was not too far off. And now this barrier has been crossed, for in recent paper [10] superconductivity with $T_c = 287.7 \pm 1.2$ K (i.e., nearly $+15\,^\circ$C) has been obtained in the C – H – S system at a pressure of 267 ± 10 GPa. The authors took advantage of the fact that hydrogen sulfide H_2S mixes well with methane CH_4. Such a mixture (with an additional injection of H_2) underwent high-pressure photochemical synthesis (using laser radiation) and was examined at pressures from 100 to 300 GPa. Fairly convincing data were obtained on a sufficiently narrow superconducting transition (from resistive measurements) with T_c from 175 to 287 K upon pressure variation from 175 to 267 GPa that were confirmed by measurements of diamagnetic response (Meissner effect) at pressures from 175 to 200 GPa and by direct (resistive) measurements of the upper critical magnetic field (T_c lowering to 9 T under the action of the external magnetic field) near T_c. These measurements showed that the system under study was a conventional second-order superconductor and the H_{c2} values at $T = 0$ could reach 62 or 87 T (depending on the applied extrapolation to $T = 0$). Unfortunately, the authors have not yet exactly determined the structure of the investigated superconducting phase C – H – S because of the difficulties in X-ray measurements in light-atom systems (smallness of the X-ray scattering cross section). It is believed that this problem will be solved in the nearest future in a combination of direct experiments and modern methods of theoretical simulation of high-pressure stable structures [4]. It is practically certain that the limit $T_c = +15\,^\circ$ can be overcome in future experiments with hydrides under high pressure and, perhaps, also in the case of experimentally obtaining metallic hydrogen.

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2. Gravitational redshift

The effect of gravitational redshift (GRS), i.e., a decrease in the frequency of radiation coming from a massive object, is one of the classical tests of General Relativity (GR). GRS was measured on Earth in the Pound–Rebka experiment and was observed for the Sun and stars — white dwarfs. GRS corrections are also taken into account in navigation systems. GRS measurements for the Sun are hampered by convective plasma motions (granulation) responsible for Doppler shifts. However, the technique of spectral observations has recently undergone new development, which allowed J I Gonzalez Hernandez (Canary Islands Institute of Astrophysics and University of La Laguna, Spain) and colleagues to perform new, more exact measurements of the GRS effect on the Sun [11]. Sunlight reflected from the Moon was observed in which the contribution of the entire solar disc was summed up. A high-stability spectrograph on the 3.6-meter telescope of La Silla Observatory in Chili was used. It was calibrated by the method of the laser frequency comb. The central frequency and an equivalent width of 326 iron absorption lines were measured. The observations were interpreted using a 3D model of the photosphere, allowing the line profiles to be predicted. The observation of 15 strong lines gives a GRS of 639 ± 14 m s^{-1} with a minimum of model assumptions. And a global fitting of 97 lines by the 3D model gives 638 ± 6 m s^{-1}. The obtained values are highly consistent with the calculated value of 633.1 m s^{-1}, thus confirming the GR prediction once again.

3. Quantum heat engine

Microscopic quantum systems considered to be heat engines can show quantum superposition of their different, including opposite, thermodynamic cycles, which is impossible in the classical case. Quantum heat engines based on various systems have already been developed in experiments. K Ono (Institute of Physical and Chemical Research RIKEN, Japan) and colleagues have designed for the first time a quantum heat engine based on the spin state of an impurity electron in a tunnel field transistor [12]. A high-frequency variation of the gate potential induced transitions between two energy levels and ensured their definite population. A modulating signal was applied to the gate, which changed the distance between the levels. The Otto cycle direction depended on the instant of transition between the levels, when the distance between them was minimum or maximum. If the period of the modulating signal exceeded the system coherence time, the system could work either in the heat engine regime with a direct cycle or in the freezer regime. However, if the period was less than the coherence time, the system could be in a superposition of these states.

4. Levitating microdrop optical resonator

A spherical optical resonator might have a very high Q-factor owing to the existence of many different detours and the summation of the light-wave phase on the sphere. To this end, a high quality of the spherical surface is needed. In solid microspheres lying on a plane, even the presence of a supporting point leads to deformation, worsening their optical properties. J Kher-Alden (Israel Institute of Technology — Technion) and co-authors used silicone-oil liquid drops 10 μm in radius as resonators. The drops were held in the air by optical tweezers [13]. In this case, the drops show a high degree of sphericity and surface quality. A curved optical fiber passed by the drops. The optical modes in the fiber and in the drops were coupled through an evanescent field without a notable impact on the droplet shape. The optical finesse of this resonator exceeded 11.6×10^6 (the Q-factor was 1.2×10^9), that is, the light could make more than 10 mln turns inside the drop. In the first levitating spherical resonators that A Ashkin created in the 1970s, this value was only ~ 300. The authors also measured experimentally the degeneracies and densities of states of the optical modes. The described resonator can find application in precision physical measurements and in optical sensors.

5. Quantum fluctuations near Landauer's limit

As was shown in R Landauer's work, logic operations are accompanied by entropy production and heat dissipation. For example, erasure of one bit of information transfers to the environment the amount of heat $q \geqslant k_B T \ln(2)$ (Landauer's limit), where k_B is the Boltzmann constant and T is temperature. J Goold (Trinity College, Dublin, Ireland) and colleagues investigated theoretically [14] the increase in dissipation near the Landauer's limit owing to quantum fluctuations upon an irreversible information erasure. The presence of quantum coherence of a system results in a dissipation increase above the Landauer's limit and makes the distribution of energy losses non-Gaussian, as distinct from the case of thermal fluctuations. Another specific feature of quantum effects is energy dissipation in finite portions — quantum emission. The authors then applied the obtained general principles to a model two-level system. They found that, owing to quantum fluctuations, energy dissipation can exceed the Landauer's limit 30 fold, whereas classical dissipation effects only yield a 4-fold increase. The effect of enhanced dissipation may turn out to be important for microscopic logic cells operating near the Landauer's limit, because it can lead to their damage.

6. Nonlinear magnetoelectric effect

In many crystals, the magnetoelectric effect (the occurrence of electric polarization under the impact of an external magnetic field) is proportional to the first or second degree of magnetic field strength. L Weymann (Vienna University of Technology, Austria) and co-authors revealed in [15] that in holmium doped langasites $Ho_xLa_{3-x}Ga_5SiO_{14}$ with $x = 0.043 \pm 0.005$, it can be a fourth-order or a sixth-order effect. Single crystals were examined at a temperature of 2 K in a magnetic field of 6–14 T. The polarization was measured using silver electrodes on crystal faces. The measurements showed that polarization undergoes four periods of oscillations under magnetic field rotation at an angle of 2π in the crystal *ac* plane and six periods under rotation in the *ab* plane. This testifies to the dependence on the magnetic field components in the fourth and sixth degrees, respectively, the dependence of the polarization amplitude on the magnetic field strength remaining linear. The sixth degree of dependence has never been observed in crystals. The authors worked out a theoretical model that reproduces rather well the discovered properties, allowing for the mutual influence of the local and global symmetries. The discovered effect opens new pathways for control over the electric properties of substances with the help of a magnetic field. Participants in the study were researchers from MSU, Prokhorov General Physics Institute, MIPT, and the National Research University MIET. For magnetoelectric materials, see Refs [16, 17].

7. Anomalous magnetar Swift J1818.0-1607

Magnetars are young single neutron stars with very strong magnetic fields and a slow rotation. Their X-ray emission is fed by the magnetic field dissipation. One more class of neutron star with strong magnetic fields exists that, on the contrary, radiate mainly owing to the rotation energy. These neutron stars with rotational feeding and magnetars were assumed to belong to one population of objects, but intermediate-type neutron stars have never been observed. Observations of the X-ray source Swift J1818.0-1607 using Swift BAT and the NICER ISS telescope showed that it could be the required intermediate type [18]. Swift BAT registered the hard portion of the X-ray burst spectrum typical of magnetars, and NICER observed the following (the next ~ 100 days) spectrum evolution in the soft region. Swift J1818.0-1607 is the fastest known rotating magnetar, with period of 1.36 s. The character of deceleration and strong glitches and antiglitches (changes in the rotation frequency) are indicative of a relatively young neutron star age. The radiation can be partially fed by rotation, and the magnetic field and luminosity have intermediate values of 2.7×10^{14} G and 7.9×10^{35} erg s^{-1}, respectively. The observed radio emission from Swift J1818.0-1607 designates it also as an intermediate type neutron star, because it is only a few magnetars that generate radio emission. For pulsar magnetospheres, see [19–22]. It is highly likely that magnetars are sources of fast radio bursts [23].

References

1. Drozdov A P, Eremets M I, Troyan I A, Ksenofontov V, Shylin S I *Nature* **525** 73 (2015)
2. Eremets M I, Drozdov A P *Phys. Usp.* **59** 1154 (2016); *Usp. Fiz. Nauk* **186** 1257 (2016)
3. Pickard C J, Errea I, Eremets M I *Annu. Rev. Condens. Matter Phys.* **11** 57 (2020)
4. Liu H, Naumov I I, Hoffman R, Ashcroft N W, Hemley R J *Proc. Natl. Acad Sci. USA* **114** 6990 (2017)
5. Gor'kov L P , Kresin V Z *Rev. Mod. Phys.* **90** 011001 (2018)
6. Drozdov A P et al. *Nature* **569** 528 (2019)
7. Somayazulu M et al. *Phys. Rev. Lett.* **122** 027001 (2019)
8. Ginzburg V L *Phys. Usp.* **47** 1155 (2004); *Usp. Fiz. Nauk* **174** 1240 (2004)
9. Maksimov E G *Phys. Usp.* **51** 167 (2008); *Usp. Fiz. Nauk* **178** 175 (2008)
10. Snider E et al. *Nature* **586** 373 (2020)
11. González Hernández J I et al. *Astron. Astrophys.* **643** A146 (2020)
12. Ono K et al. *Phys. Rev. Lett.* **125** 166802 (2020)
13. Kher-Alden J et al. *Phys. Rev. X* **10** 031049 (2020)
14. Miller H J D et al. *Phys. Rev. Lett.* **125** 160602 (2020)
15. Weymann L et al. *npj Quantum Mater.* **5** 61 (2020)
16. Pyatakov A P, Zvezdin A K *Phys. Usp.* **55** 557 (2012); *Usp. Fiz. Nauk* **182** 593 (2012)
17. Bukharaev A A et al. *Phys. Usp.* **61** 1175 (2018); *Usp. Fiz. Nauk* **188** 1288 (2018)
18. Hu C-P et al. *Astrophys. J.* **902** 1 (2020); arXiv:2009.00231
19. Beskin V S, Gurevich A V, Istomin Ya N *Sov. Phys. Usp.* **29** 946 (1986); *Usp. Fiz. Nauk* **150** 257 (1986)
20. Beskin V S, Istomin Ya N, Philippov A A *Phys. Usp.* **56** 164 (2013); *Usp. Fiz. Nauk* **183** 179 (2013)
21. Beskin V S *Phys. Usp.* **61** 353 (2018); *Usp. Fiz. Nauk* **188** 377 (2018)
22. Potekhin A Yu *Phys. Usp.* **53** 1235 (2010); *Usp. Fiz. Nauk* **180** 1279 (2010)
23. Popov S B, Postnov K A, Pshirkov M S *Phys. Usp.* **61** 965 (2018); *Usp. Fiz. Nauk* **188** 1063 (2018)