Possibility of producing a bulky supersensitive thermal detector at a temperature close to absolute zero

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The possibility is discussed of using a large-mass system, cooled to infralow temperatures (≤ 1 K) and insulated, as an ultrasensitive detector of energy-releasing interactions with fields and particles. The detectors register the change of the system temperature. The necessary condition for the realization of high sensitivity (10^{-22} W/g at $T = 0.01$ K) is a decrease of the inflow of parasitic heat due to mechanical vibrations, to electromagnetic induction, and to the cosmic and natural-radioactivity background. The principal results of an investigation at 1 K are reported. It is observed that the main obstacle to the development of the detector may be the reversible effect of thermal relaxation in the detector material after the cooling.

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Modern methods of obtaining low temperatures permit effective cooling of rather large masses to temperatures on the order of several thousandths of one degree. If the working body can then be sufficiently well insulated both from the cooling system and from the action of mechanical and electromagnetic oscillations, then such a device can serve, in a large number of problems, as a most sensitive thermal detector, capable in principle of responding to weak actions of all kinds of penetrating neutral fields and particles, whether presently known or still unknown.

The principal problem in the development of a detector of this type is to provide sufficient insulation against irrelevant heat sources that usually cause a rapid temperature drift of the insulated body and bring the system out of the ultrasensitive state. So far, the smallest attainable heat fluxes, say, in installations with nuclear cooling, for which the degree of insulation is of decisive importance, still greatly exceed the calculated values and are never less than of the order of 10^{-11} W/g.[1] On the other hand, the minimum heat-released by terrestrial systems, due to cosmic rays alone, is of the order of 10^{-14} W/g. A detailed study of the causes of so large a discrepancy between the indicated limits is of interest from various points of view. We have made a preliminary study of this problem at a temperature 1 K and have established that the heating of an insulated body is due most frequently mainly to reversible residual thermal processes that occur in the sample itself after it is cooled to the working temperature of the cryostat. Thus, for rapidly crystallized copper, with impurity concentration not more than 0.02% and cooled to 1 K, the heat release was 5×10^{-10} W/g and decreased with a relaxation time of approximately 100 h. An effect with magnitude and relaxation time of the same order was observed by us in rolled copper of the same purity. It can be assumed that these processes are connected with grain-boundary relaxation. Using the best available sample of copper of the same purity, but with initial heat release 4×10^{-13} W/g, we reached a steady temperature drift 2.5×10^{-6} K/h in an insulated sample with mass 18 kg over dozens of hours, corresponding to a constant heat influx 8×10^{-15}

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W/g. This is lower by a factor of approximately 1.5 than the calculated value (with account taken of the gamma background from the radioactive contamination), and needs to be determined with greater accuracy. Setting this question aside, we can conclude that the attained mechanical and electromagnetic interference level is apparently not higher than 10^{-15} W/g. This undoubtedly uncovers new possibilities of reaching the microdegree temperature region. The installation used by us consisted of a helium cryostat of 130 liter capacity, pumped off by a group of noiseless pumps located 15 m away. The cryostat was rigidly mounted on a two member concrete foundation with mass 7 tons, suspended on air-operated shock absorbers. The experimental chamber with double vacuum insulation, coated on the outside by a superconductor layer, was suspended in the cryostat in the form of a free pendulum on a thin steel tube, the suspension being additionally shock-insulated with the aid of soft rubber. The working bodies were suspended inside the chamber on caprone filaments. The thermal contact of the working body with the helium bath was with the aid of a mechanical thermal switch. The temperature was measured with an Allen-Bradley thermal resistor.

From the point of view of the degree of insulation against the electro-magnetic fields and mechanical vibrations, the results are far from the ultimately attainable. However, further experiments on the study of the insulation must be carried out in a low-background underground laboratory, with a cosmic background weaker by 5–7 orders of magnitude than on the earth's surface. Under these conditions, the main noise is due already to the radioactive contamination of the employed materials. It should be noted that the existing methods of monitoring radioactive contamination are not suitable for an exact determination of long-lived impurities if their concentration is less than 10^{10} atoms per gram of analyzed substance.[2] Most suitable for this purpose is the thermal detector itself, which makes it possible to determine the absolute content of any member of the radioactive family in the investigated sample. Thus, at a concentration of 10^{10} impurities of uranium-family nuclei at equilibrium with U^{238} in a sample having a mass 1 kg, the number of decays in 24 hours is still 4.3 and can be distinctly registered with a detector, provided that the latter operates at a temperature 10^{-2} K. It is therefore desirable to develop for the instrument in question a material whose radioactive contamination is smaller by an additional one or two orders of magnitude.

There are practically unlimited possibilities of increasing the sensitivity of the thermal detector once its insulation is improved, whether by lowering the working temperature of the instrument or by increasing the resolution of the measuring system, but principally by choosing a material with a smaller specific heat for the working body. If, for example, we use single-crystal germanium at a temperature 10 mK and the SQUID measurement technique, then the registration of heat release on the order of 10^{-22} W/g is apparently attainable. An instrument with this sensitivity will serve as a new tool for the study of fundamental properties and the population of space. It can be used directly to determine the limits of applicability of a fundamental premise of physics—that of the existence of an isolated system and of the law of energy conservation in slow processes.

[1] O.V. Lounasmas, Experimental Principles and Methods below 1 K, Academic 1974.

[2] A. Pomanskiĭ, Doctoral Dissertation, Nuclear Research Institute, USSR Acad. Sci., 1977.