the extent that Icarus can be represented by a perfectly conducting sphere of density 3.5 gm/cm^3 (photometric observations have shown it to be nearly spherical), $f|Q|$ is less than 6×10^{27} esu, f being a screening factor. The corresponding limit obtained from Mercury is about 10^{28} esu.

These limits may be compared with values of $-Q$ of around 10^{27} to 10^{28} esu suggested by V. A. Bailey. These values correspond to an excess of one electron for each 10^{20} or 10^{21} nucleons. It is of interest to compare Bailey's charges with some geophysical quantities[7]: the mean charge in a lightning stroke is around 5×10^{10} esu and the Earth's negative surface charge is around 10^{15} esu.

Write Q as $\beta G^{1/2}M$ where G is the Newtonian gravitational constant and M is the mass of the charged body. The charge will modify the space–time metric; hence[4], with the Reissner–Nordström metric, the perihelion precession rate is multiplied by $(1 - \beta^2/6)$. In Bailey's work, $-\beta$ is around 10^{-3} to 10^{-2}, so the gravitational effects of Q are negligible. For a black hole, the maximum possible value of $|\beta|$ is one. For a proton β is approximately 10^{18}; for an electron β is approximately -10^{21}.

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Superconductors again

I would like to comment on the letter of W. A. Little (April, page 11), in which he has stated that "the absolute value of T_c is less important technologically than its value relative to what can be achieved economically." He has further suggested that "it would be far more worthwhile from the technological point of view to devote proportionally less effort to this dying approach of raising T_c and a much bigger effort to the goal of improving the efficiency of cryogenic refrigerators."

Absolute value of T_c is quite important if superconductivity is to be used as an inexpensive technique in big operations. Helium gas cannot be compared with hydrogen or neon in availability or cost of production; therefore high efficiency of a refrigeration system would not play a major role in cutting down the cost. Only liquid helium can be used for the superconductors having T_c below 20 K, but the discovery of the $Nb_3(Al\text{–}Ge)$ superconductor[1] ($T_c = 21$ K) has already brought T_c into the temperature range of liquid hydrogen (boiling point = 20.3 K). And G. W. Webb and his colleagues[2] have recently discovered a binary superconductor, Nb_3Ga, with a T_c of 20.3 K. An emphasis on efforts to raise T_c would give us a better superconductor in the temperature range of liquid hydrogen or even liquid neon (boiling point = 27.1 K). Of course there are problems in handling liquid hydrogen, but these can be solved. Therefore a 13% increase in T_c should not be considered a modest return in 17 years. At the same time it is not possible to develop technically better superconductors if the dying approach of raising T_c is not kept alive.

Apart from the technological question, this same effort has given us a lot of understanding about the basic mechanism of superconductivity. It is not possible to study the influence of various physical structural parameters over T_c without the synthesis of new superconducting materials. By no means is superconductivity a mature field and it is too early to give up all hope.

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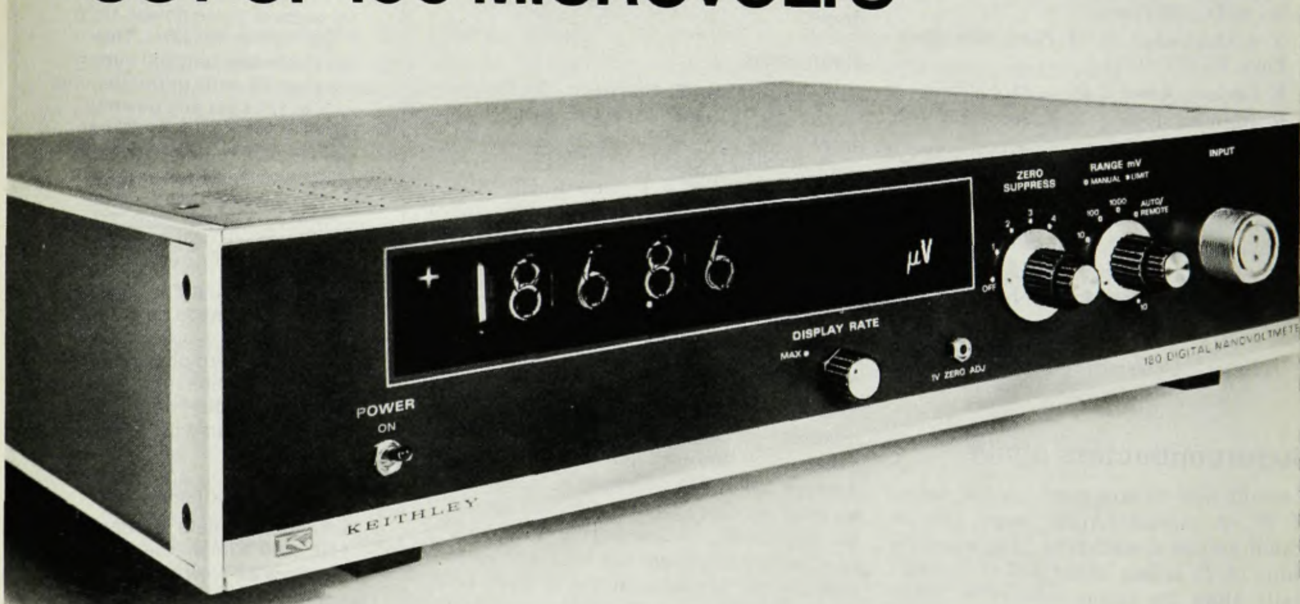
The author comments: Khan is quite incorrect in stating that "only liquid helium can be used for the super-conductors having T_c below 20 K." This is an error which is often made and should be corrected. Closed-cycle refrigeration using helium *gas* are widely used to provide refrigeration in the 6–20-K region. Furthermore, hydrogen can and has been used as a cryogen down to about 14 K. It is not limited to 20 K as suggested by Khan. The 20-K figure, of course, is related to the normal boiling point of hydrogen at one atmosphere pressure. There is no pressing reason for a refrigerator system to be operated



The Model 180 Digital Nanovoltmeter . . . latest in the Keithley tradition of sensitive instrumentation at this pressure. Low-pressure systems can and have been built. Further work in this region on hydrogen refrigeration and on closed-cycle helium refrigeration undoubtedly would yield improvements of greater relative magnitude from the technological point of view than can be expected from the preparation of still more conventional superconductors. This is precisely the point I make in my letter.

I have no quarrel with the author in regard to the fundamental scientific significance of preparing new superconductors, but the justification for this should not be based on the technological advantages that might accrue from the work but rather on its scientific merit alone. From the economic point of view, at this point, a better return on your money will come from refrigerator research.

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Charged-tachyon replies

In his recent letter (May, page 11) Howard Robbins raises the question of whether or not a charged tachyon could have a trajectory that is consistent with relativity. He points out that the motion must be accelerated because of Cerenkov radiation and that rectilinear, accelerated motion is not an invariant concept and thus the trajectory of a charged tachyon could not be predicted with knowledge of its position and velocity at one time. This question has also been raised in some detail by H. K. Wimmel[1] who concludes that no satisfactory answer exists at present.

It should be pointed out, however, that this problem is not unique to tachyons but arises in any problem that includes radiation reaction as a significant ingredient. In these cases the differential equation of motion includes the time derivative of the acceleration and hence the initial value of the acceleration must also be given (this is the "new dynamical quantity" suggested by Robbins).

It can be shown[2] that a properly Lorentz-invariant classical theory of Cerenkov-emitting, charged tachyons may be given in terms of an extended, Lorentz deformable particle. Such a particle follows a law of motion given by

$$\frac{d^2U}{ds^2} - \left(\frac{\kappa e^2}{m a_0^{2}}\right) U = 0$$

where U is the tachyon's space-like 4-velocity, ds is the increment of invariant length of the world line, m is its mass, a_0 its "size" and κ a constant of order unity depending on the details of the charge distribution. Such a law of motion is clearly covariant, and the special class of frames in which the particle motion is rectilinear is picked out by the initial conditions, not by the law of motion.

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With reference to Robbins's letter, in a just-finished work (H. Bacry, Ph. Combe and P. Sorba "Connected Subgroups of the Poincaré Group" Preprint 72/p. 449, Marseille, 1972) we suggest a group theoretical definition of the motion of a charged particle in a homogeneous field. Our definition has the advantage of being valid for all kinds of particles, namely tardyons, luxons and tachyons. It is a natural assumption based on the following property: all worldlines of charged massive particles (tardyons) in a homogeneous field are orbits in space-time of some one-dimensional subgroup of the Poincaré group.

As an example, in the case of a homogeneous electric field pointing in the z direction, a possible motion for a tachyon is the following one: at time zero, the tachyon is at point 0; its speed is finite in *both* positive and negative directions! At a given time $t > 0$, it has two distinct positions A and B, symmetric with respect to 0 and a *finite* speed. As time is increasing, the speed becomes smaller and tends to c, the velocity of light, when time becomes infinite. For negative times, the tachyon does not exist at all!

Various other peculiar motions can be found with the aid of this method.

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Einstein in 1905

Without in any way belittling the impressive accomplishments of nuclear physicists in 1932 I wish to note that, while it may have been "the most exciting time yet in the history of physics," it may not have been the most productive—by far! For years I have been describing to physics classes the remarkable discoveries published by one man in a single year: Albert Einstein in 1905. In that year he founded two revolutionary fields, quantum theory (from the photoelectric effect) and special relativity, and made a

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