Transfer Phenomena and Indeterminacy

J. G. DAUNT AND K. MENDELSSOHN
Clarendon Laboratory, Oxford, England
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A FEW years ago we advanced the hypothesis of a basic analogy between superconductivity and the λ-phenomenon in liquid helium.[1] Its salient feature is the fact that superconductive electrons and superfluid helium atoms remain energetically at absolute zero, even when the substance as a whole is raised to a finite temperature. Thus, in both cases frictionless transport is provided by an assembly of particles with zero entropy (z particles). Experimental evidence for this conclusion is furnished by our observation of zero Thomson heat in a superconductor[2] and of a mechano-caloric effect in liquid helium II.[3] The latter experiments, which had to be discontinued in 1939, have since been confirmed with greater accuracy by Kapitza.[4] The analogy is further strengthened by our discovery of a critical rate of transfer in helium[5] which is the counterpart of the "current threshold" in superconductors.

It has been suggested by one of us[6] that the momentum of frictionless transfer is derived from zero-point energy and that the rate of transfer of mass or charge (R) gives an indication of the number of z particles (n). This view seems to be supported by an important paper of F. London.[7] Taking up our analogy, he has shown that, numerically,

$$R \lesssim nh/2\pi \qquad (1)$$

in superconductors as well as in liquid helium. While in our opinion the experimental data hardly justify an evaluation of n to a greater accuracy than an order of magnitude, there seems to be little doubt that R/n is of the order of h. London's relation can also be written as

$$\int mv\cdot dx \sim h, \qquad (2)$$

where m and v are the mass and the velocity of the z particle and where the integration is carried out over the cross section of the specimen along which transfer takes place. Taking v as the average velocity throughout the cross section, we get

$$v \sim h/md, \qquad (3)$$

where d is the thickness of the specimen carrying the transfer. Thus, v is identical with the zero-point velocity conferred by the uncertainty principle on a particle confined to a space of linear dimension d. By assuming frictionless transport to be zero-point motion, London's formula (Eq. (1)) is then seen to follow as a necessary corollary.

The peculiar result that the velocity of the z particles is inversely proportional to the *linear* dimensions of the specimen is well borne out by Silsbee's rule in superconductors and by the observation of Allen and Misener[8] that frictionless flow of helium is proportional to the *diameter* of the capillary. These effects have usually been regarded as surface currents but Eq. (3) indicates a much deeper physical significance. Frictionless transport clearly implies that, if collisions take place, not only the sum of momenta is conserved but also that each individual momentum is conserved, regardless of the identity of the particles carrying it. Individual momenta will therefore be conserved until a collision with the boundary of the specimen takes place. Thus, the observed dependence of v on $1/d$ is a direct consequence of the uncertainty principle and arises from the impossibility of locating a z particle in the specimen with greater accuracy than d.

This fundamental inability to locate z particles within the macroscopic dimensions of the specimen causes frictionless transport to appear in all determinations as a surface flow. (In multiply connected bodies the situation is more complex, though not fundamentally different.) However, what significance has to be ascribed to the "depth of penetration" of this surface flow is by no means clear, and recent observations by Casimir[9] seem to show that its physical reality has been interpreted too literally up to now.

[1] J. G. Daunt and K. Mendelssohn, Nature **150**, 604 (1942).
[2] J. G. Daunt and K. Mendelssohn, Nature **141**, 116 (1938); Proc. Roy. Soc. A, in print.
[3] J. G. Daunt and K. Mendelssohn, Nature **143**, 719 (1939).
[4] P. L. Kapitza, Phys. Rev. **60**, 354 (1941).
[5] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. **A170**, 423 (1939).
[6] K. Mendelssohn, Proc. Phys. Soc. **57**, 371 (1945).
[7] F. London, Rev. Mod. Phys. **17**, 310 (1945).
[8] Allen and Misener, Proc. Roy. Soc. **A172**, 467 (1939).
[9] H. B. G. Casimir, Physica **7**, 887 (1940).

A Proposed High Energy Particle Accelerator—The Cavitron

RICHARD F. POST
Naval Research Laboratory, Washington, D. C.
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AS tools for the investigation of nuclear phenomena, particle accelerators are unequaled. The cyclotron, the betatron, and most recently, the synchrotron[1,2] are the best known examples. In the quest for higher and yet higher particle energy outputs, accelerators have, perforce, been made larger and larger, until their very size precludes construction by any but the largest laboratories. It is the purpose of this letter to explore the potentialities of an accelerator of much different physical design from any of the above, compact in construction, and in principle capable of producing much higher peak energies than are at present available.

Little has been published on the advantages of an accelerator which would incorporate no iron in the magnetic circuit. Terletzky[3] points out that, if radiation effects could be eliminated, an iron-less betatron should be capable of producing very high energies. Whereas the phenomenon of radiative dissipation is a serious limitation upon the ultimate attainable output from a betatron,[4,5] it has been shown[1,6] that the mechanism of "resonance" acceleration (as employed in the synchrotron) is far less subject to this effect. In addition, this means of particle acceleration is not limited by relativistic effects.

The accelerator herein proposed is to be iron-less. It is to employ "resonance" acceleration, achieved by slow increase of the guiding magnetic field. High intensity