liquid confined to a hydrophilic stripe in a hydrophobic surrounding. They studied the changes in shape of liquid stripes that were several micrometers wide in a periodic pattern as a function of their volume. With increasing volume, the fluid stripes of constant cross section undergo a transition to a state with a single bulge rather than into a row of individual droplets as would be expected from the classical Rayleigh plateau instability (*10*) of a free-standing cylinder decaying into a periodic array of droplets. The shape instability of the liquid cylinder confined to a hydrophilic surface area and the formation of a single bulge are explained by a theoretical model that contains no adjustable parameters and only depends on the two contact angles of the fluid on the hydrophilic and hydrophobic substrate areas. Swelling of the cylinders confined to a hydrophilic stripe implies that with increasing volume the contact angle at the boundary between the hydrophilic and hydrophobic surface areas does not satisfy Young's equation and hence the liquid channel becomes unstable.

No patterning of the substrate with hydrophilic or hydrophobic structures is needed by Gallardo *et al.* (*4*) to control the movement of organic or aqueous liquids or particles suspended in a fluid. Rather than patterning the surface energy of the solid support, Gallardo *et al.* control the surface pressure and consequently the movement of liquids and particles by creating and consuming surfactant molecules with redox active groups at electrode surfaces in their microfluidic system. Surface active molecules generated at one and consumed at the other electrode create a spatial gradient in surface pressure to guide droplets of organic liquids through the fluidic network. The velocity of the flow (in the millimeters per second range) is directly proportional to the voltages applied to the electrodes (hundreds of millivolts range). Gallardo *et al.* demonstrate these effects by pumping liquid crystal droplets that are not soluble in the aqueous electrolyte into different channels of a multielectrode array and by controlled dewetting of an electrode pattern that a priori has no spatial inhomogeneities in surface energy. When these principles are used for surfactant-induced patterned spreading of a liquid, this would allow one to control precisely the stability and position of a contact line and open the possibility of controlled mixing of fluids and chemical reactions in microscopic dimensions.

Current methods to control the flow of solutions or dissolved particles through a predefined channel network rely on electrokinetic phenomena requiring high voltages, mechanical actuators and syringes, or capillary wetting (*11*). In the work of Gau *et al.* (*3*), the curvature of the expanding liquid structure drives the flow of the fluid. When single bulges along liquid channels merge, the solutions mix and react through these interconnects. The electrochemical method developed by Gallardo *et al.* (*4*) does not even require a permanent channel system nor a hydrophilic-hydrophobic surface pattern to move suspended particles. Instead, a microelectrode array provides the means to direct flow in a continuous liquid film. Mixing by volume or electrochemical control rather than stirring or mechanical pumping provides novel cost-reducing design principles for microfluidic devices, in particular for disposable "laboratories on a chip," which are needed for a fast and inexpensive chemical analysis of complex fluids. And why should it not be possible to extend these nonmechanical fluid control principles to direct the flow of reactants into microreactors, to sort and separate proteins and cells, or to build temporary or permanent microstructures by spatially controlled reactions or deposition of particles?

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PERSPECTIVES: SUPERCONDUCTIVITY

Effective Mass and Color Change

M. V. Klein and G. Blumberg

There are sum rules in physics, consequences of fundamental laws and principles. The sum rules are exact expressions that relate sums of measured quantities to known parameters. These rules help scientists to study physical states of matter by analyzing how different measured constituents of the sum respond to external perturbations. On page 49 of this issue, Basov *et al.* (*1*) report new optical data on high–transition temperature superconductors that show how these nonconventional superconductors obey a sum rule in a novel way.

The optical conductivity $\sigma_1(\omega)$ describes the absorptive response of an electronic system to a weak electromagnetic field of frequency ω. The integral of $\sigma_1(\omega)$ over a finite range of ω defines the spectral weight over that range. When applied to a system of N_e electrons per unit volume in a solid, it obeys a fundamental sum rule for the total spectral weight:

$$S = \int_0^{\infty} \sigma_1(\omega) d\omega = \pi e^2 N_e / 2m \qquad (1)$$

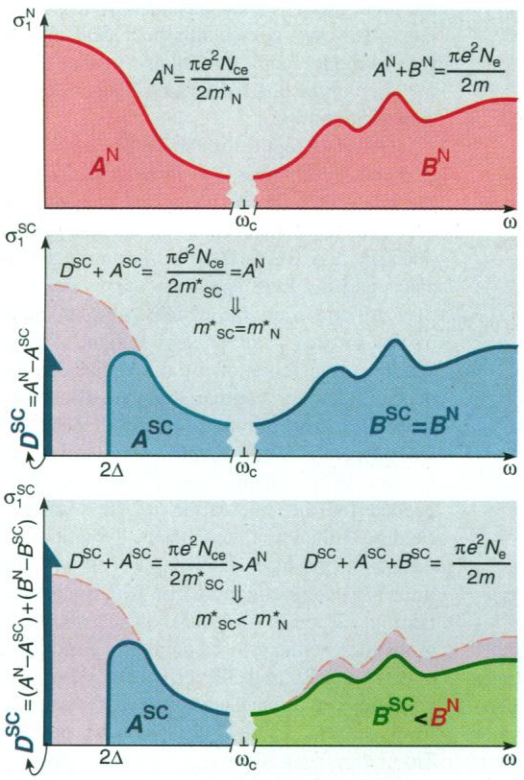
where e and m are the electron charge and the bare electron mass, respectively. Metals have one or more bands of quantum-mechanical states partially filled with electrons, the conduction bands, and many other bands that are either completely filled or completely empty. At low frequencies ω, $\sigma_1(\omega)$ will have contributions only from transitions within the conduction band ("intraband"), whereas at higher ω, "interband" transitions involving the other bands will also contribute to the conductivity. The interband transitions are expected for frequencies in the energy range from a fraction of an electron volt (eV) to many eV.

The two types of transition additively contribute to $\sigma_1(\omega)$, and thus, according to the sum rule, the constant S may be written as the sum $A + B$ of intraband (A) and interband (B) contributions. It is instructive to write A in the form of

$$A = \int_0^{\omega_c} \sigma_1(\omega) d\omega = \pi e^2 N_{ce} / 2m^* \qquad (2)$$

where N_{ce} is now the density of electrons in the conduction band and m^* is an effective electron mass in the band—the bare electron mass renormalized because of electron-ion and electron-electron interactions. The effective mass describes electron motion and is related to dispersion in the conduction band. Here, we have assumed that the conduction band is sufficiently separated from other electronic bands so that a frequency ω_c can be chosen to separate these contributions. If ω_c and m^* are not changing as a function of temperature or applied perturbation, Eq. 2 is referred to as a partial sum rule, however, the sum A does not reflect any funda-

M. V. Klein is at the NSF Science and Technology Center for Superconductivity and the Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801–3080, USA; e-mail: m-klein5@uiuc.edu. G. Blumberg is at Bell Laboratories, Lucent Technologies, Murray Hill, NJ 07974, USA; e-mail: girsh@bell-labs.com



Summing up. Relations between the fundamental and partial sum rules **(top)**. For conventional superconductors, the effective mass is preserved through the superconducting transition that leads to the Ferrell-Glover-Tinkham sum rule **(middle)**. The latter is violated for c axis conductivity in the cuprate superconductors, where, as a result of delocalization of carriers at temperatures below T_c, the strength of the zero frequency δ function gains only about half of its spectral weight from intraband transitions A and the remainder from interband transitions B **(bottom)**.

mental physics relations and may change if interactions in the physical system change the N_{ce}/m^* ratio. The relations between A and B are summarized schematically in the top panel of the figure.

For metals below the superconducting transition temperature T_c, electrons form a condensate that is able to carry lossless supercurrent. Spectroscopic measurements of the conventional superconductors at low frequencies showed the existence of an energy gap 2Δ in the optical conductivity in the superconducting state, $\sigma_1^{SC}(\omega)$ (*2*). The gap is a frequency range where the electromagnetic field cannot excite quasi-particles out of the superconducting condensate and $\sigma_1^{SC}(\omega)$ is reduced compared with its normal state value $\sigma_1^N(\omega)$, as shown schematically in the middle panel of the figure. Ferrell, Glover, and Tinkham (*2*, *3*) were able to show that the "missing area" $A^N - A^{SC} = \int_{0+}^{\omega_c > 2\Delta} [\sigma_1^N(\omega) - \sigma_1^{SC}(\omega)]d\omega$ appears as a δ function for σ_1^{SC} at $\omega = 0$. The δ function contributes a finite amount of spectral weight D^{SC} to the integral S. It represents the absorption of energy from an applied dc electric field to supply kinetic energy to the lossless supercurrent.

In conventional superconductors that are described well by theories of the Bardeen-Cooper-Schrieffer (BCS) type, the superconducting interactions change mainly those electronic excitations having energies about or below 2Δ. The value of B (interband contribution to the integral S) is unaffected by the superconducting transition. Hence, $D^{SC} + A^{SC} = A^N$, or $D^{SC} = A^N - A^{SC}$, where A^N is the interband contribution in the nonsuperconducting state. The latter equation is often referred as the Ferrell-Glover-Tinkham sum rule (*2*, *3*). Because for conventional superconductors, the total intraband contribution, including the D^{SC}, remains unchanged, we can say that the effective mass is the same below and above T_c ($m^*_{SC} = m^*_N$).

The cuprate superconductors have many highly anomalous properties that distinguish them from the conventional metals and the BCS-type superconductors. Basov and collaborators present new optical conductivity data taken for three different families of the cuprates (*1*). The cuprates are materials that contain stacks of CuO_2 sheets separated by "charge reservoir" layers. The strong electron-electron interactions within CuO_2 planes and the weak interaction between the planes lead to very anisotropic electrical conductivity. These materials are metallic when currents flow within the CuO_2 planes. When the current flows in the direction perpendicular to the planes (that is, parallel to the c axis), the conductivity $\sigma_1(\omega)$ at low frequencies in the nonsuperconducting state is so small that the electrons in the partially filled bands can be considered as almost localized. As a consequence, the intraband contribution A^N is very small, several orders of magnitude smaller than the value of the sum A^N_{ab} for the integrated conduction measured parallel to the planes. Because of the near localization of electrons along the c axis, their effective mass m^*_N is unusually heavy. The transitions within the partially filled bands make only a tiny contribution to the sum S; most of the spectral weight in the fundamental sum rule (Eq. 1) comes from interband transitions.

In the cuprates at temperatures below T_c true three-dimensional superconductivity occurs with lossless supercurrents flowing in all directions. The condensate contributes a finite amount D^{SC} to the sum rules (Eqs. 1 and 2) for c axis optical conductivity. Basov and collaborators found that, in contrast to conventional superconductors, for cuprates the total intraband contribution in the superconducting state is larger than above T_c, $D^{SC} + A^{SC} > A^N$, or that the Ferrell-Glover-Tinkham sum rule is violated. This is equivalent to the statement that $m^*_{SC} < m^*_N$. The mass reduction implies that the kinetic energy decreases when the system enters the superconducting state. This loss in the kinetic energy is in marked contrast to the BCS theory, which is based on the notion that a loss of potential energy drives the superconducting transition. Various models have been proposed to describe how superconductivity can be driven in novel ways by reduction of the kinetic energy (*4*–*8*).

The measurements (*1*) give $D^{SC} \approx 2(A^N - A^{SC})$, twice as much a relative change in A as for conventional superconductors. From the fundamental sum rule (Eq. 1), it follows that $A^N - A^{SC} \approx B^N - B^{SC} \approx (D^{SC}/2)$. This shows that the spectral weight in the condensate comes roughly equally from finite frequency intraband weight loss and from interband weight loss. Recalling that the interband weight is anomalously high in the non-superconducting state due to near localization of electrons, we conclude that superconductivity partially alleviates the effect of localization, thereby reducing the interband weight.

Superconductivity in the cuprates shows two effects: (i) The measurements show that the effective mass in the conduction band as determined from the partial sum rule (Eq. 2) has decreased ($m^*_{SC} < m^*_N$). (ii) A decrease has occurred in the spectral weight of the optical conductivity at relatively high energies, perhaps as high as the visible range, 2 to 3 eV. The superconducting sample is less absorbing of electromagnetic radiation at these energies. It must therefore reflect light differently. Perhaps its "color" has changed (*4*).

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