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A Direct Comparison of the Exponents of Superconductivity and Superelasticity Near the Percolation Threshold

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Abstract. — The divergences of the dielectric and elastic constants of gels filled with aluminum particles near the percolation threshold are investigated on the same samples. We found that the ratio of the two exponents s of the dielectric divergence and of s' of the elasticity divergence is $s'/s = 0.80 \pm 0.05$, showing definitely that $s' < s$.

The problem of superelasticity in percolation has some similarity with that of superconductivity. In the first case, one introduces at random inclusions with infinite stiffness in an elastic medium. In the second case, the inclusions are made of a superconductor, and they are embedded in a normal metal. When the inclusion concentration p increases, one expects divergence of the elastic constants in the first case and of the electrical conductivity in the second, when p approaches the critical concentration p_c . It is thus possible to define two exponents: s' for the divergence of the elastic constants and s for the conductivity.

There are several determinations of the exponent s , theoretically [1] and experimentally [2]. In 2D, one has $s = t = 1.33$ (t is the conductivity exponent in the case of a mixture of an insulator in a conductor) and in 3D, $s = 0.73 \pm 0.01$. The exponent s' was also determined by computer simulation. In 2D, it is found that s' is very near s . From his simulation, Bergman [3] concluded that $s = s'$. However, other determinations [4,5] of s' showed that $s' < s$. The most precise determination of s' was recently given by Arbabi and Sahimi [5]: $s' = 1.24 \pm 0.03$ in 2D and $s' = 0.65 \pm 0.03$ in 3D. The experimental value of s' (in 3D) was also investigated by the present authors [6]. It was found that $s' = 0.67 \pm 0.05$, in good agreement with the theoretical value. However, the difference between the two exponents remains small and it should be interesting to have a direct comparison of the two exponents. In this paper, we present a direct confirmation of the inequality between the two exponents by measuring the divergence of the dielectric constant and of Young modulus for the same samples. The exponent of the dielectric constant divergence of a mixture of an insulator and a metal is identical to that of the electrical conductivity in the case of superconductor - normal metal compounds.

In reference [6] the samples were made of a very soft material (polyacrylic gels) with inclusions of alumina and of zirconia. These last two materials are very stiff in comparison to the gel but

are electrical insulators. So it was only possible to measure Young's modulus. For the present purpose, it is necessary to replace alumina or zirconia with a good conductor. But, putting in the polyacrylic solution powders of conductive materials (nickel, copper, iron, black carbon) prevents the gel from being formed. We chose another gel from Rhone-Poulenc (RTV 1508), which is a silicon-based gel. By mixing equal quantities of RTV 1508A and 1508B, one gets a gel with a Young's modulus around 10^5 cgs. As a hard material, an aluminum powder (mean grain size $\sim 20 \mu$) was selected. The gel is a good insulator (unlike polyacrylic gels) and the dielectric constant of the mixture can be determined as a function of the aluminum content.

The most important problem is to get homogeneous samples. To prepare them, the two components of the gel are mixed together and the desired amount of aluminum is added. During the gelation process (24 hours), the sample is slowly rotated (1 RPM). Once the sample is ready (height 3 cm, diameter 2 cm), Young's modulus E and the dielectric constant ϵ are measured. Then, the sample is cut into three slices and E and ϵ of these new smaller samples are measured. When the difference between the highest and the lowest values is larger than 30% of the mean value, the sample is discarded as too inhomogeneous. The reported values are the means of the measurements on two samples.

Young's modulus was measured by means of a home-built apparatus [6] and the dielectric constant by means of the impedance-meter 4800 A of Hewlett-Packard, in the range of 10 kHz, where it was checked that ϵ is independent of the frequency.

In Figure 1, we show the variations of E as a function of ϵ . At low values of p , the relation between E and ϵ is linear but for larger values of p ($> 35\%$) there is a deviation of the straight line with a curvature downward.

$$E \approx |p - p_c|^{-s'} \quad (1)$$

and

$$E \approx |p - p_c|^{-s} \quad (2)$$

From (1) and (2), one gets

$$E \approx \epsilon^{s'/s} \quad (3)$$

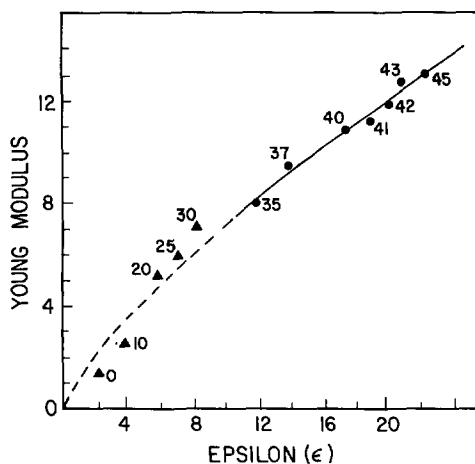


Fig. 1. — Young's modulus *versus* the dielectric constant. The continuous line is the result of the fit with equation (3).

From equation (3), one can see that if $s' = s$, the curve $E(\varepsilon)$ must be a straight line asymptotically and if $s' < s$, this curve will have a curvature downward as effectively observed in Figure 1.

We tried to fit the experimental curve $E(\varepsilon)$ with the help of equation (3). We found a good fit (see the continuous curve in Fig. 1) with the ratio s'/s equal to 0.80 ± 0.05 . This value is slightly lower than that obtained from the theoretical values of s and s' . Taking $s' = 0.65 \pm 0.03$ and $s = 0.73 \pm 0.01$, one has $s'/s = 0.88 \pm 0.05$. However, the two values are within the limits of the error bars. This difference can be easily explained if one recalls that the samples we prepared (even that with the largest p) are not in the immediate vicinity of p_c . From the behavior of $\varepsilon(p)$ and $E(p)$, it is possible to estimate $p_c \cong 48\%$. It is difficult to prepare samples closer to p_c because of the relatively high viscosity of the gels. Indeed, with scaling corrections added to equations (1, 2), our conclusions might change.

In conclusion, we can say that this direct comparison of s' and s gives further confirmation of the different values (with $s' < s$) of the exponents of superconductivity and superelasticity.

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