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Short Communication

Experimental simulation of polymers in a disordered medium

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Résumé . — Nous modélisons des polymères par une chaîne de disques connectés sur le plateau d'une table soufflante. Les fluctuations temporelles et spatiales du flux d'air à travers le plateau poreux conduisent à des mouvements désordonnés de la chaîne, la table se conduisant alors comme un pseudo réservoir thermique. On crée un désordre gelé de l'environnement du polymère en plaçant des objets lourds sur la table. Nous trouvons que les variations du rayon de giration moyen de la chaîne, r, en fonction de sa longueur N sont bien traduites par une loi en puissance $r \sim N^{\nu}$ où $\nu = 0,68 \pm 0,03$, pour trois différentes densités d'objets lourds. La valeur effective de ν est inférieure à la valeur exacte 3/4 prévue par le modèle de marche autoévitante.

Abstract . — We model polymers by a chain of connected disks placed on the horizontal porous bronze working plate of an air table. Spatial and temporal fluctuations of the air stream at the bronze plate act as a heat source for the polymer causing it to move and curl in a random fashion. The quenched randomness of the polymer's environment is modelled by placing heavy objects on the bronze plate. We find that the average radius of gyration of the chain, r, scales with the chain length N as $r \propto N^{\nu}$, where $\nu = 0.68 \pm 0.03$, for three different densities of heavy objects. This effective exponent is below the exact value 3/4 for two-dimensional free SAWs.

The dynamics of polymers interacting with a disordered environment has for a long time been a field that has attracted much attention, not only for its intrinsic interest but also for its technological importance [1,2]. A large theoretical and computational effort has gone into modelling the polymers as self-avoiding random walks [3]. However, in spite of the apparent simplicity of this model, very few analytic results have been found, and numerical studies have not yielded results with a high precision due to the fact that these computations are very costly.

One of the most studied quantities in this context is the radius of gyration r as a function

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of the length N of the SAW. This function is known to be a power law,

$$r \propto N^{\nu} \tag{1}$$

For free SAWs, that is, not interacting with their environment, the exponent $\nu = \nu_0$ is known to be 3/4 in two dimensions. However, when the SAWs interact with their surroundings, it is not yet well understood whether ν changes or not and, in the case it does, by how much. Several recent studies, however, put it close to the free-SAW value 3/4. Le Doussal and Machta [3] suggest that for anchored polymers $\nu > \nu_0$, while $\nu < \nu_0$ for non-anchored polymers — see also reference 4, while Honeycutt and Thirumalai [5] and Obukhov [6] suggest $\nu < \nu_0$ for both cases. In the case of extreme disorder, i.e. in the form of SAWs on lattices diluted down to the percolation threshold [7], recent studies [8,9] suggest that also in this case ν is close to ν_0 in two dimensions. The literature concerning *self-crossing* polymers suggests a much smaller exponent depending on the disorder in this case [10-13].

In this paper we describe an experimental system realizing a two- dimensional SAW interacting with a disordered environment, thus representing an "analog special-purpose computer." It is based on an air table designed to study random two-dimensional systems [14]. This air table consists of a horizontally-mounted porous bronze plate through which a uniform air jet is blown, as shown in figure 1. On top of this plate chains of circular disks are suspended, and move freely about. The disordered medium with which the SAWs strongly interact is modelled by simply placing heavy objects,and thus immovable, on the bronze plate, as seen in figure 2. The motion of the chain of disks is recorded with a video system and analysed as one would with data obtained with a digital computer. The advantage of this experimental set-up compared to conventional digital computers is the the speed at which the chains go from conformation to conformation: figure 2 shows three conformations photographed at intervals of 0.5 seconds, and therefore gives an impression of the speed at which the chain conformation changes.

The disks are made of polystyrene, have a diameter of about 6 mm and a thickness of 1 mm. We have detected no sign of static charges building up on the disks as they move about, which could lead to an attractive force between them. The disks are connected to form a chain by gluing a very thin silk thread at the centers of the disks which are spaced a little less than a centimeter apart. This silk thread was obtained by carefully pulling out single strands of a silk thread used in clothing. The thread used has a thickness about 0.05 mm. With this thin silk thread, we did not observe any line tension trying to straighten the chain. Human hair, for instance, was too stiff, and we did notice that the chains had a tendency to straighten out.

The size of the porous bronze plate is 50 × 50 centimeters [14]. It is held in place by 25 screws placed on a regular square grid with 8.5 centimeters apart. If a disk moves across one of these screws, it looses its lift and stops. In order to prevent this, we placed small heavy round objects on top of all the screws. This network of objects, 8.5 cm apart, which necessarily must be in place, represents partly our 'disordered' medium. In addition, other obstacles are placed at random using coordinates generated with the *random sequential absorption* algorithm [15]. The total numbers of objects placed on the bronze plate were 25 (thus only covering the screws), 75, and 150 objects.

The air speed through the porous bronze plate is regulated by a rheostat connected to two fans at the bottom of the wind tunnel, see figure 1. There is a linear relationship between the voltage supplied to the fans by the rheostat and the air speed at the bronze plate. Two kinds of defects generate the random motion of the chains: The spatio-temporal fluctuations in the air jet caused by small-scale turbulence, and geometrical defects because the discs are never perfectly horizontal. The chain of disks acts as if interacting with a heat bath at a high

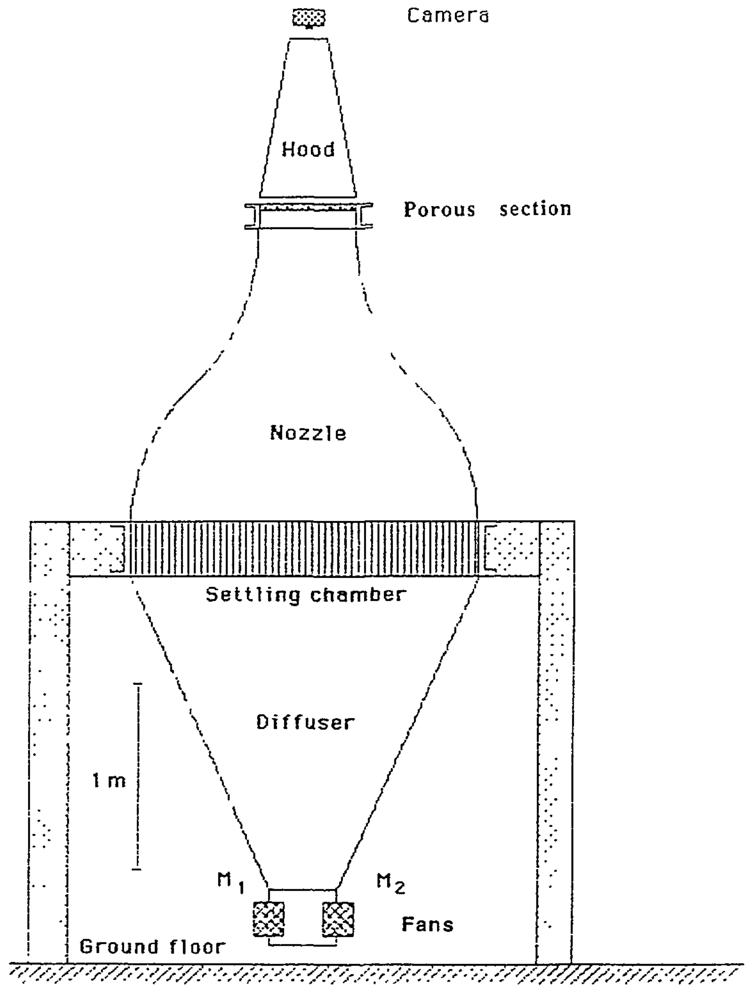
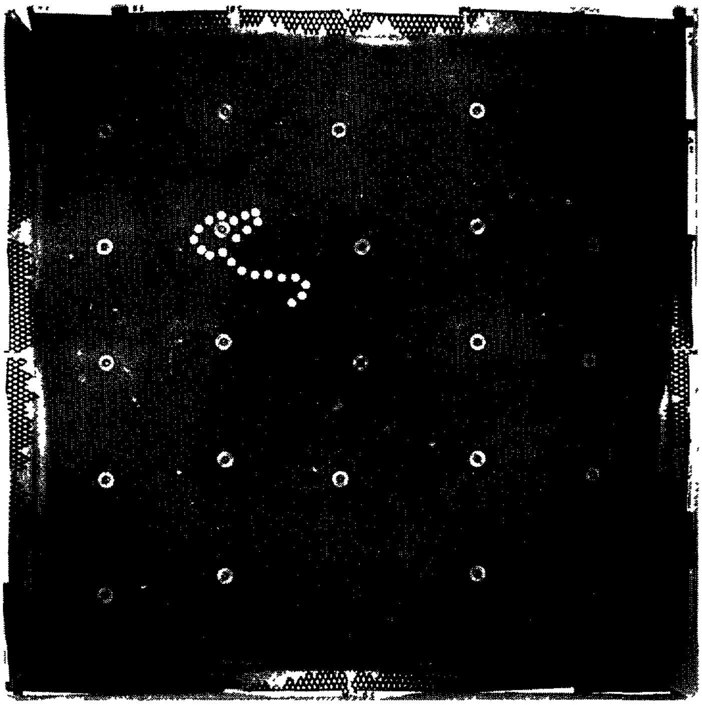


Fig. 1. — A schematic drawing of the air table.

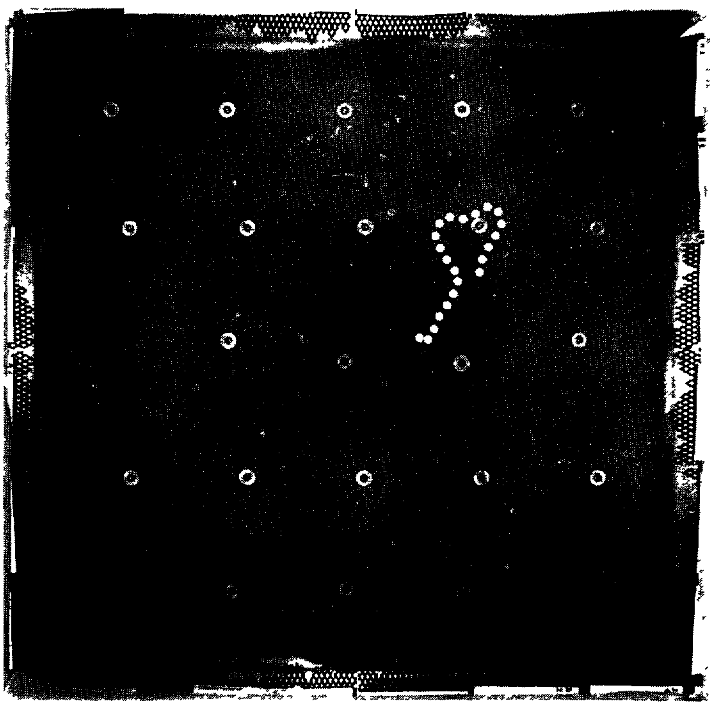
temperature. When the voltage applied to the fans is changed, the height of the discs and the small scale turbulence are modified. In this manner we can act on the "pseudo temperature" of the polymer.

We recorded the motion of the chains with a videocamera placed above the bronze plate. Afterwards, the recorded motion was played back on a standard 22 inch television set. Every 2 seconds, the film was stopped, and the contour of the chain was drawn by hand by placing a semitransparent paper on the screen of the monitor. We found that this simple technique is very efficient and the results as reliable as those from a more sophisticated image analysis equipment.

In this paper we report our results on the average radius of gyration, r as a function of the number of disks it contains N. Several hundred conformations for each chain length — ranging from $N = 3$ to $N = 52$ — were recorded, and the corresponding radius of gyration measured. This was done for a wide range of airspeeds in the case of 25 obstacles placed on the plate,

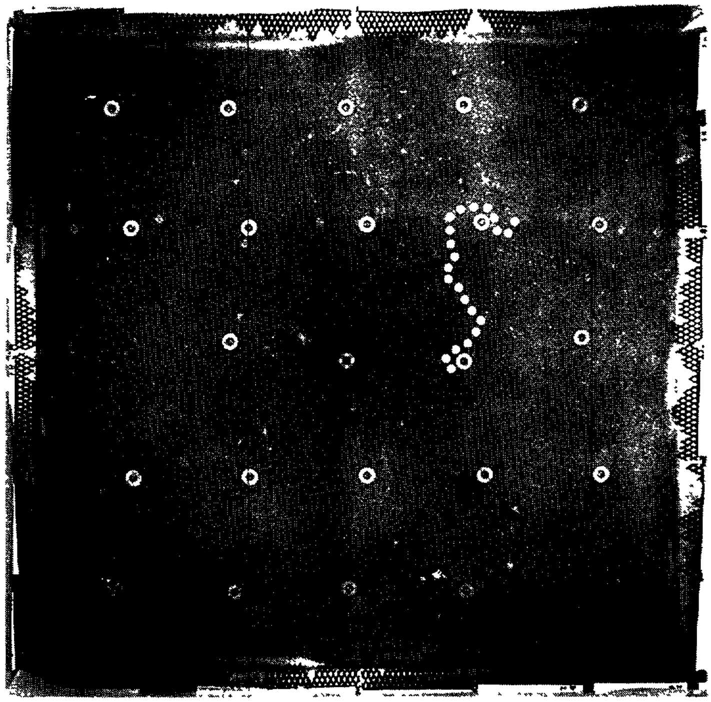


a)



b)

Fig. 2. — Three photographs taken 0.5 seconds apart of a chain consisting of 25 disks of diameter 0.6 cm on the air table. The dark circular objects represent the disordered medium.



c)

Fig. 2. — (continued)

and for a fixed airspeed for the other two densitities of obstacles.

In figure 3 we show our data for the three densities of obstacles, averaged over both conformations and airspeeds. We find the best fit $r = 1.17N^{0.68}$ in the case of 25 obstacles, $r = 1.05N^{0.68}$ for 75 obstacles and $r = 1.01N^{0.68}$ for 150 obstacles. The units of r and the prefactors are in centimeters. The finite-size corrections were stronger in the case of 25 obstacles than for the higher densities — where, in fact, they were hardly detectable.

These power laws are all consistent with equation (1), and strongly hint at a universal radius of gyration exponent $\nu = 0.68 \pm 0.03$, where the error ± 0.03 only reflects the statistical error.

We remark that the straightness of the data in figure 3 signals that the stiffness of the silk thread is sufficiently small not to play any role — if it had, there would have been a crossover somewhere along the curve in figure 3 from exponent $\nu = 1$ when the stiffness dominates and straightens the chains out, to the value 0.68 that we do see. Note that a measure of the end to end size gives the same results with respect of scaling arguments. The value we find for the effective exponent ν is *smaller* than the free-SAW exponent $\nu_0 = 3/4$. We may qualitatively argue for this by noting that conformations such as that shown in figure 4, where the chain is wrapped around an obstacle, appear quite often. This makes an abundance of compact conformations compared to the free SAWs, resulting in a smaller radius.

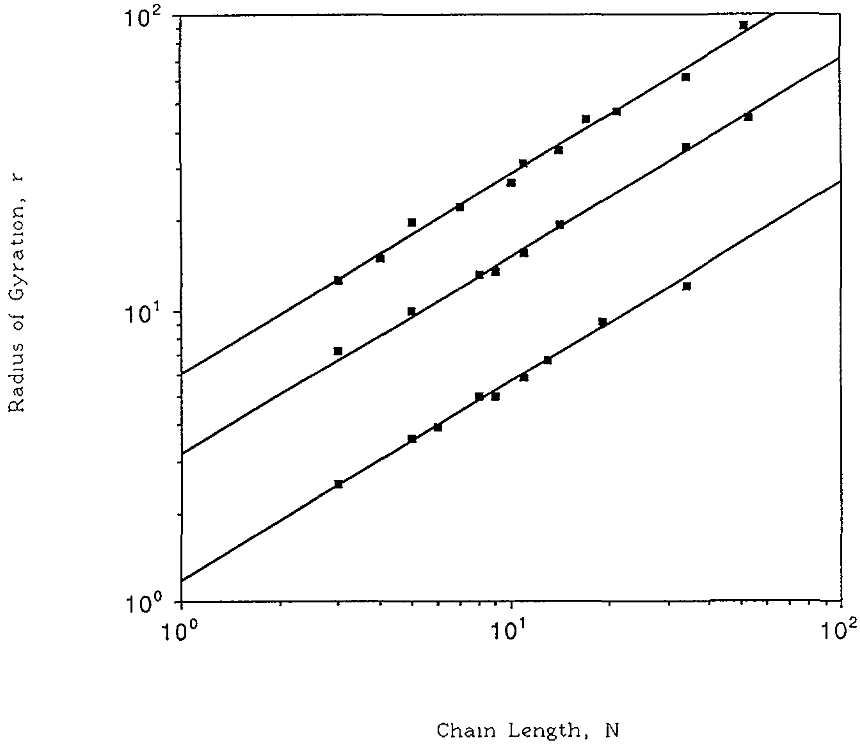


Fig. 3. — Radius of gyration r, as a function of chain length N for 25 (bottom curve), 75 (middle curve) and 150 (top curve) obstacles averaged over all samples (and in the lower curve is also over a number of different air speeds). The slopes are for all three curves $\nu = 0.68$. The data have been multiplied by 3 for the 75-obstacle samples, and by 6 for the 150-obstacle samples, in order to make the figure clearer.

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References

[1] de Gennes P.-G., Scaling Concepts in Polymer Physics (Cornell University Press, Ithaca, 1979).
[2] Doi M. and Edwards S. F., The Theory of Polymer Dynamics (Oxford University Press, Oxford, 1986).
[3] Le Doussal P. and Machta J., *J. Stat. Phys.* **64** (1991) 541, and references therein.
[4] Machta J. and Guyer R. A., *J Phys. A* **22** (1989) 2539.
[5] Honeycutt J. D. and Thirumalai D., *J. Chem. Phys.* **93** (1990) 6851.
[6] Obukhov S. P., *Phys. Rev. A* **42** (1990) 2015.
[7] Chakrabarti B. K. and Kertész J., *Z. Phys. B* **44** (1981) 221.
[8] Lee S. B. and Nakanishi H., *Phys. Rev. Lett.* **61** (1988) 2022.

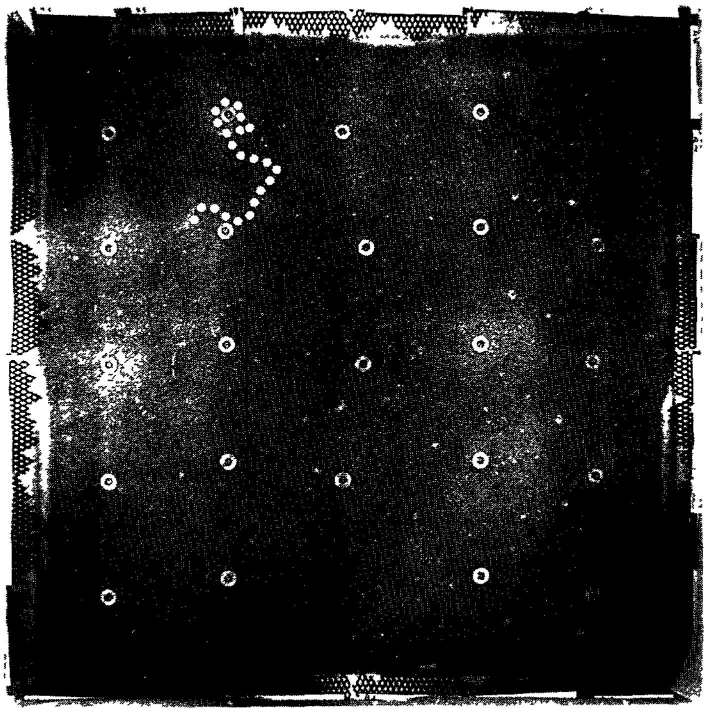

Fig. 4. — The chain is wrapped about two of the heavy objects representing the disordered medium.

[9] Meir Y. and Brooks-Harris A., *Phys. Rev. Lett.* **63** (1989) 2819.
[10] Baumgärtner A. and Muthukumar M., *J. Chem. Phys.* **87** (1987) 3082.
[11] Edwards S. F. and Muthukumar M., *J. Chem. Phys.* **89** (1988) 2435.
[12] Cates M. and Ball R. C., *J. Phys. France* **49** (1989) 2009.
[13] Nattermann T. and Renz W., *Phys. Rev. A* **40** (1989) 4675.
[14] Lemaître J., Gervois A., Peerhossaini H., Bideau D. and Troadec J.P., *J. Phys. D* **23** (1990) 1396.
[15] Feder J. and Giaever I., *J. Coll. Interface Sci.* **78** (1980) 144.