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Investigation of the fractal structure of deciduous and coniferous trees using small-angle neutron scattering simulation experiments

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Fractals are objects that are fragmented to such an extent that measuring them with the measures we are accustomed to (length, area, volume) gives different results depending on the choice of the measuring segment (scale). The concept of "fractal" was introduced by Benoit Mandelbrot [1], who also laid the foundation for a new "fractal" geometry. Using modeling experiments on small-angle light scattering using the numerical Fourier transform, our team developed a classification of fractal and non-fractal objects in two-dimensional space [2]. Logarithmic fractals are a class of fractals whose representatives have a hierarchical branching structure and obey the law of equality of area at different levels of their hierarchy (different scales).
In our work [3], it was shown that the lateral projection of a mature deciduous tree is a logarithmic fractal. We concluded that during growth and branching, a tree obeys the law of conservation of area when scaling from several meters to several decimeters: the total area of the lateral surface of the "daughter" branches is equal to the surface area of the branch from which they grow. In a huge number of experimental scattering curves in the region of large transmitted impulses (on small scales), a crossover to another regime is observed, which is distinguished by a different exponent when scaling from decimeters to centimeters (the scale of young branches). We proposed a mathematical model that distinguishes the organization of young branches and young trees in general from the structure of an adult tree and adult branches. The model is based not on the law of conservation of area, as for an adult tree, but on the law of conservation of branch volume: the total volume of "daughter" branches is equal to the volume of the branch from which they grow.
We also used the numerical Fourier analysis method for experimental study of the fractal structure of spruce branches. Images of spruce branches of an adult tree over 10 meters in size at different tree heights were studied. Fourier images of photographs of spruce branches demonstrate the same structure of the small-angle scattering curve: the Guinier region, two sections with a linear character of intensity decrease, the Gaussian region. We proposed a mathematical model describing the obtained curves: I(q) = A·exp((qb)2/3) + P·q^(-N) in the region of small transmitted impulses (large scales) and I(q) = R·q^M + S·exp(-2·(q - L)^2/F^2 in the region of large transferred impulses (small scales). It is shown that the exponent N is close to 2, which corresponds to a logarithmic fractal, the Gaussian function describing the behavior of the curve in the region of large transferred impulses corresponds to needles. It is shown that since on large scales the spruce paws are formed taking into account the needles covering them, obeying the law of a logarithmic fractal in two-dimensional space, the rule of preserving the area of branches with needles before and after branching is fulfilled for them.

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