that vacuoles with tonoplasts typical of plant cells occupy 8 to 13 percent of the cell volume, depending on the stage of the cell cycle. The vacuoles tend to fragment prior to cytokinesis, and calculations based on a simplified model in which four spherical vacuoles total 10 percent of the volume of a spherical cell with a radius of 3 μm show that the surface area of the tonoplast is nearly 35 percent of that of the plasma membrane. Further fragmentation and distortions from the spherical state (which are routinely observed) would raise the figure considerably.

These observations and calculations reveal nothing about the physiology of the tonoplast, but they do indicate that it should not be ignored.

A. W. ATKINSON, JR.
B. E. S. GUNNING
P. C. L. JOHN
W. MCCULLOUGH
*Department of Botany,
Queen's University of Belfast,
Belfast, Northern Ireland*

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Chlorella pyrenoidosa is classically considered a nonvacuolate system, consisting essentially of a cup-shaped chloroplast and cytoplasm. It has been used extensively as a test organism in nutritional studies (*1–3*), and ultrastructures like microvacuoles have been recorded in a few strains cultured under certain conditions. The strain of *Chlorella pyrenoidosa* that I used in my experiments (*4*) is 7-11-05 (*5*), in which a well-developed central vacuole compared to those in higher plant cells is absent.

SESHADRI KANNAN
*Biology and Agriculture Division,
Bhabha Atomic Research Centre,
Bombay 85, India*

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Nucleation and Lattice Disregistry

In the report of their experiments on the nucleation of ice by silver iodide containing bromine, Vonnegut and Chessin (*1*) use a very simple relation between supercooling and lattice disregistry δ^2. Unfortunately, things are not that simple.

In 1914 Lamplough and Scott (*2*) discovered that nucleation is a one-way street in the sense that, if crystal α nucleates crystal β at low supercooling, β does not nucleate α at low supercooling. This result was rediscovered by Sundquist and Mondolfo (*3*) and confirmed by Powell and Colligan (*4*). More than 20 metallic systems have been investigated so far, and in none of them has two-way nucleation been detected. This result is irreconcilable with the idea that disregistry is the controlling factor in nucleation; in many cases the disregistry from α to β is larger than from β to α. This and other findings have led Crosley *et al.* (*5*) to derive the following relation between supercooling for nucleation and the balance of interfacial energies:

$$\left(\frac{\Delta T_{\mathrm{R}}}{\Delta T_{\mathrm{H}}}\right)^{2/3} = (YZ)^{1/3}\left[1 - X\left(\frac{\sigma_{\mathrm{SL}} + \sigma_{\mathrm{NL}} - \sigma_{\mathrm{NS}}}{\sigma_{\mathrm{SL}}}\right)\right]$$

where ΔT_{R} is the supercooling for heterogeneous nucleation; ΔT_{H} is the supercooling for homogeneous nucleation; Y is the energy factor, ranging from 1 to 1.5; Z is the shape factor, ranging from 1 upward; X is the contact factor, ranging from 0 to 1, with 0.5 as the most probable value; σ_{SL} is the interfacial energy between nucleus and liquid; and σ_{NL} is the interfacial energy between nucleant and liquid, and σ_{NS} is the interfacial energy between nucleant and nucleus.

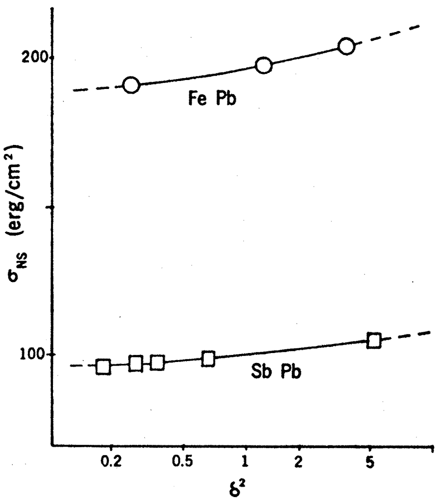

Fig. 1. Disregistry δ^2 as a function of the interfacial energy between nucleant and nucleus σ_{NS} for the nucleation of lead by iron and antimony.

In this formula the disregistry enters as part of the term σ_{NS}: the larger the disregistry, the larger the value of σ_{NS}, as shown in Fig. 1 for the nucleation of lead by iron and antimony, with the different orientation relations experimentally determined.

However, the energy balance is the controlling factor that decides whether nucleation at low supercooling is possible or not, and that balance can be favorable in only one direction. The similarity of the crystal structure and low disregistry are only minor factors, as evidenced, for example, by the nucleation of zinc (hexagonal close-packed) by bismuth (rhombohedral) or of lead by copper ($\delta = 37$ percent, $\Delta T = 0$).

L. F. MONDOLFO
*Research and Development Center,
Revere Copper and Brass, Inc.,
Rome, New York 13440*

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The relation in question was derived by Turnbull and Vonnegut (*1*) to describe coherent nucleation by catalysts having disregistries of a few percent or less. We pointed out that in the nucleation of aluminum by titanium carbide, titanium boride, and aluminum boride, for which the disregistries are only 4 to 6 percent, the equation gives values for supercooling that are orders of magnitude larger than those found by experiment. The equation clearly should not be applied to cases such as those cited by Mondolfo, where the lattice disregistries are 30 percent or more.

B. VONNEGUT
*Atmospheric Sciences Research Center,
State University of New York, Albany*
HENRY CHESSIN
*Department of Physics, State
University of New York, Albany*

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