Comment by M. T. Lilburne on a Letter by Dr J. J. Bikerman

Bikerman has raised four points.

Firstly, it is not assumed that there is zero elastic strain around a gas filled bubble in a solid, but that the strain present is negligible at equilibrium compared with the surface energy term for the particular size of bubbles considered. This was discussed in the paper and reference should be made also to the work of Lidiard and Nelson [1]. Elastic strain produces contrast in an electron microscope (see Brown and Mazey [2] for example) and was observed. This phenomenon only occurs when copper foils are annealed for short times at low temperature, say 400° C. Obviously, equilibrium has not been established.

Secondly, although it can be shown that $P = 2\gamma/r$ for faceted bubbles by using a virtual work argument, results were not used for such bubbles. (P is the gas pressure within a bubble and γ is the surface energy. The exact value assigned to r must be an average of the shortest distance from the centre of the bubble to the planes of the facets.) As was stated in the paper, faceted bubbles were thought to be severely contaminated by oxygen. Bubbles with clean surfaces were essentially spheres and thus exhibited little anisotropy of surface energy. Any error in considering these bubbles as spheres is within experimental error.

The third point, marked 2 in Bikerman's letter, has no relevance to this work.

The final sentence of Bikerman's comment is a generalisation which apparently dismisses the rigorous and accepted theoretical work of Herring [3] and of Mullins [4] and a large body of experimental evidence.

References

1. A. B. LIDIARD and R. S. NELSON, *Phil. Mag.* **17** (1968) 425.
2. L. M. BROWN and D. J. MAZEY, *ibid* **10** (1964) 1081.
3. C. HERRING, "Structure and properties of solid surfaces", edited by R. Gomer and C. S. Smith (The University of Chicago Press, 1953) p. 5.
4. W. W. MULLINS, "Metal Surfaces" (The American Society for Metals, 1963) p. 17.

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Validity of Kovacs and Nagy Equation

Kovacs and Feltham [1] and Kovacs and Nagy [2] derived an equation for the total equivalent mean shear strain $\bar{\gamma}$ of a wire plastically twisted about its axis at constant tensile load. In this equation, $\bar{\gamma}$ consists of the torsional shear strain ND/L and the shear strain component equivalent to the associated tensile strain $\Delta L/L_0$ as follows:

$$\bar{\gamma} = \alpha\pi ND/L + \beta\Delta L/L_0 \qquad (1)$$

where N is the number of turns of twist, D is the diameter of the wire, and L_0 and L are initial and instantaneous lengths of the wire. α and β are constants. The numerical values of α and β were taken to be 1/3 and 2.24 respectively [1]. Kovacs and Feltham [1] also indicated that these values were underestimated because the mean torsional strain was evaluated on the assumption that the wire was purely elastic. They pointed out that the assumption of ideal plasticity of Gaydon [3] would be more appropriate. Recent work [4, 5] has also indicated that the values of α or β are $2\pi/3$ and 3 respectively.

Equation 1 could be written in the form:

$$\Delta L/L_0 = -(\alpha/\beta)\, ND/L + \bar{\gamma}/\beta$$
$$\epsilon = -(\alpha/\beta)\,\theta + \bar{\gamma}/\beta \qquad (2)$$

or

where $\epsilon = \Delta L/L_0$ and $\theta = ND/L$.

By partial differentiation of ϵ with respect to θ at constant $\bar{\gamma}$ and substituting for the values of α and β we get:

$$\left(\frac{\partial\epsilon}{\partial\theta}\right)_{\bar{\gamma}} = -(\alpha/\beta) = -2\pi/9 = -0.698 \qquad (3)$$

Equation 3 shows that the rate of change of tensile strain per unit torsional strain at constant $\bar{\gamma}$ has a constant value of -0.698. Since the value of $(\partial\epsilon/\partial\theta)\bar{\gamma}$ could be determined experimentally, the validity of the Kovacs-Nagy equation (equation 1) and the ratio α/β could be determined. The purpose of this work is to use this approach for determining the validity of Kovacs-Nagy equation (K-N).