

**Table 1** Stoichiometry of disproportionation of sulphite or thiosulphate by *Desulfovibrio sulfodismutans*

	Sulphite	Thiosulphate
Sulphur compound consumed (mmol)	15.9	8.9
Sulphate formed (mmol)	11.5	9.1
Sulphide formed (mmol)	3.6	8.5
Ratio of sulphate formed to sulphide formed	3.19	1.07
Cell dry mass formed (g mol of sulphite or thiosulphate)	3.2	2.1

Cells were grown for 12 days at pH 7.2 and 35 °C in 1.2-litre bottles with defined mineral medium<sup>2</sup> in the presence of 2 mM acetate as carbon source. Sulphite was added in three incremental portions to avoid toxic effects. Sulphate, sulphite, thiosulphate, sulphide, cell dry mass and protein were determined as in ref. 8. Cell dry mass contained about 70% protein.

growth of *D. sulfodismutans* ceased after the third transfer in acetate-free medium. A most probable number (MPN) enumeration of thiosulphate-disproportionating bacteria with mud from the freshwater ditch near Konstanz, revealed high numbers of  $2 \times 10^6$  sulphate- and sulphide-forming cells per ml mud.

The disproportionation of sulphite yields a free energy change of  $-58.9 \text{ kJ mol}^{-1}$  per sulphite, the disproportionation of thiosulphate  $-21.9 \text{ kJ mol}^{-1}$  (Table 2). Thus, sulphite disproportionation will not allow for the conservation of more than 1 ATP molecule per sulphite molecule, and the disproportionation of thiosulphate even less. The low growth yields of *D. sulfodismutans* (Table 1) are in agreement with this.

Further exergonic disproportionations to sulphate and sulphide are those of dithionite, or polythionates, whereas disproportionation of elemental sulphur is endergonic (equations (3) to (5)). *D. sulfodismutans* grew also by disproportionation of dithionite; however, because of its instability and the impurity of commercially available dithionite, the stoichiometry of dithionite disproportionation was not determined. The addition of tetrathionate to the culture resulted in the formation of elemental sulphur and sulphate; however, no growth was observed. Presumably, sulphide was produced, reacting chemically with tetrathionate to form elemental sulphur. Elemental sulphur was found to inhibit growth of *D. sulfodismutans*.

Other conceivable sulphite or thiosulphate disproportionations are those resulting in the formation of sulphate and elemental sulphur (equations (6) and (7)). These reactions would be accompanied by even greater changes of the free energy. However, formation of elemental sulphur was not observed in cultures of *D. sulfodismutans* supplied with sulphite or thiosulphate.

**Table 2** Gibbs free energy changes of disproportionation for some inorganic sulphur compounds

Reaction	$\Delta G^\circ$ (kJ mol <sup>-1</sup> ) (at 25 °C and pH 7)
(1) Sulphite $\rightarrow$ sulphate + sulphide $4 \text{ SO}_3^{2-} + \text{H}^+ \rightarrow 3 \text{ SO}_4^{2-} + \text{HS}^-$	-235.6 (-58.9 per sulphite)
(2) Thiosulphate $\rightarrow$ sulphate + sulphide $\text{S}_2\text{O}_3^{2-} + \text{H}_2\text{O} \rightarrow \text{SO}_4^{2-} + \text{HS}^- + \text{H}^+$	-21.9
(3) Dithionite $\rightarrow$ sulphate + sulphide $4 \text{ S}_2\text{O}_4^{2-} + 4 \text{ H}_2\text{O} \rightarrow 5 \text{ SO}_4^{2-} + 3 \text{ HS}^- + 5 \text{ H}^+$	-536.0 (-134.0 per dithionite)
(4) Tetrathionate $\rightarrow$ sulphate + sulphide $4 \text{ S}_4\text{O}_6^{2-} + 12 \text{ H}_2\text{O} \rightarrow 9 \text{ SO}_4^{2-} + 7 \text{ HS}^- + 17 \text{ H}^+$	-360.2 (-90.0 per tetrathionate)
(5) Sulphur $\rightarrow$ sulphate + sulphide $4 \text{ S}^0 + 4 \text{ H}_2\text{O} \rightarrow \text{SO}_4^{2-} + 3 \text{ HS}^- + 5 \text{ H}^+$	+40.9 (+10.2 per sulphur)
(6) Sulphite $\rightarrow$ sulphur + sulphate $3 \text{ SO}_3^{2-} + 2 \text{ H}^+ \rightarrow \text{S}^0 + 2 \text{ SO}_4^{2-} + \text{H}_2\text{O}$	-186.9 (-62.3 per sulphite)
(7) Thiosulphate $\rightarrow$ sulphur + sulphate $3 \text{ S}_2\text{O}_3^{2-} + 2 \text{ H}^+ \rightarrow 4 \text{ S}^0 + 2 \text{ SO}_4^{2-} + \text{H}_2\text{O}$	-106.5 (-35.5 per thiosulphate)

Free energy changes calculated after Thauer *et al.*<sup>9</sup>

The mechanisms of energy conservation during disproportionation of sulphite or thiosulphate have not been studied so far. There are at least two conceivable strategies of energy conservation. In the first, bacteria could utilize the ATP (or ADP) sulphurylase during sulphate formation. Usually, this enzyme acts in the reverse direction and catalyses the ATP-consuming activation of sulphate in sulphate-reducing bacteria. Such a process in *D. sulfodismutans* would be similar to reactions known from aerobic sulphur-oxidizing<sup>6</sup> and from phototrophic sulphur bacteria<sup>7</sup>, and would represent a substrate-level phosphorylation of the sort typical of fermentations. Second, during disproportionation of sulphite, energy might be conserved through the building up of a chemiosmotic gradient coupled to sulphide formation. During disproportionation of thiosulphate, the oxidation states of the two sulphur atoms of the thiosulphate molecule are not changed; thus, electron transport phosphorylation is less probable in this case.

We thank Professor Dr N. Pfennig and Dr F. Widdel for valuable discussions. This work was supported by the Deutsche Forschungsgemeinschaft.

Received 5 December 1986; accepted 19 February 1987.

1. Postgate, J. R. *The Sulphate-reducing Bacteria* 2nd edn (Cambridge University Press, 1984).
2. Widdel, F. & Pfennig, N. *Arch. Microbiol.* **129**, 395-400 (1981).
3. Schmidt, M. in *Sulfur, its Significance for Chemistry, for the Geo-, Bio- and Technosphere and Technology* (eds Müller, A. & Krebs, B.) 259-276 (Elsevier, Amsterdam, 1984).
4. Belkin, S., Wirsen, C. O. & Jannasch, H. W. *Appl. Environ. Microbiol.* **49**, 1057-1061 (1985).
5. Bak, F. & Pfennig, N. *Arch. Microbiol.* (in the press).
6. Kelly, D. P. *Phil. Trans. R. Soc. P298*, 499-528 (1982).
7. Trüper, H. G. *Phil. Trans. R. Soc. B298*, 529-542 (1982).
8. Cypionka, H. & Pfennig, N. *Arch. Microbiol.* **143**, 396-399 (1986).
9. Thauer, R. K., Jungermann, K. & Decker, K. *Bact. Rev.* **41**, 100-180 (1977).

## Erratum

### Optical technology: Novel optical properties of liquid-crystal polymers

George Attard & Graham Williams  
*Nature* **326**, 544-545 (1987).

IN this News and Views piece this figure was poorly printed and details of shading lost. It is a schematic representation of the rich molecular architecture of liquid-crystalline polymers, showing side-chain types with disk- and cigar-type moieties.

