

## Citation Classics

**Brunauer S, Emmett P H & Teller E.** Adsorption of gases in multimolecular layers. *Journal of the American Chemical Society* **60**:309-19, 1938.

**This paper recognized that gases adsorb on solids in multilayers when the pressure is gradually increased at the boiling point of the gas being studied. It contains a derivation of an adsorption equation (the BET Equation) based on an extension to multilayers of the Langmuir treatment of monomolecular adsorption. [The *SCI*<sup>®</sup> indicates that this paper was cited 1,008 times in the period 1961-1975.]**

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"Speaking for my colleagues, Dr. Stephen Brunauer and Dr. Edward Teller and myself, I can say that we are all flattered to have our paper and names included in the 'most cited paper' list. Perhaps a little background of the history of the work leading to the BET method for plotting isotherms for multilayer adsorption and measuring surface areas of porous and finely divided substances should be given.

"After some preliminary work it had become evident that some method for measuring the internal surface area of the porous iron catalysts was needed. Means of differentiating between qualitative changes in the surface and quantitative extension of the surface area had to be found. Some time earlier I had furnished a sample of pure iron catalyst for adsorption measurements to Dr. A.F. Benton of the University of Virginia who first interested me in adsorption and catalysis and supervised my thesis work. The adsorption data that he obtained included adsorption isotherms for N<sub>2</sub> at -191.5°. The isotherm for 191.5° contained two distinct kinks, one at about 13 and the other at 48 cm. pressure. Dr. Benton suggested that the first of these might correspond to the formation of a statistical monolayer of adsorbed nitrogen and the other might mark the completion of a second layer. This seemed to me to be a good place to start so Brunauer immediately undertook an extended series of measurements of various gases near their boiling points.

"The first discovery we made was that the two kinks for the nitrogen isotherms disappeared when correction was made for

the fact that nitrogen at -195°C is about 5% imperfect at atmospheric pressure, the correction being a linear function of the pressure. Instead of a curve with kinks a smooth S-shaped isotherm was obtained with nitrogen at -195°C. The portion between about .05 and 0.35 relative pressure was linear. It joined a curved portion concave at the pressure axis below 0.05 to 0.1 relative pressure and a curved portion convex to the pressure axis above about 0.35 relative pressure.

"About this time Brunauer and I arrived at the conclusion that the linear part of the S-shaped isotherms corresponded to a completion of the first layer and the beginning of a second layer. We designated this part of the isotherm as 'point B' and proceeded to calculate the surface areas of the various adsorbents and catalysts by multiplying the number of molecules in the adsorbed monolayer by the estimated cross-sectional areas of the adsorbate molecules.

"While this work had been going on Dr. Edward Teller, a young Hungarian physicist, had joined the George Washington University in Washington, D.C. My Hungarian collaborator, Dr. Brunauer, suggested that he contact Teller and try to work out a theory for the S-shaped adsorption curves that might give more credence to the use of the isotherms for measuring the volume of gaseous adsorbate, V<sub>m</sub>, needed to form a monolayer. Out of this collaboration came the equation cited above. Testing it against our data confirmed its reasonableness and led to V<sub>m</sub> values in good agreement with those selected by the 'point B' method.

"The question naturally arises as to why the BET paper made the 'most cited' list. I suspect that the principal favorable factors were the rationalization of the S-shaped curves by the theory which led to the BET equation, the obtaining of a value for V<sub>m</sub> much more reproducible than one obtained by estimating the point of juncture of a curve and a straight line by the point B method and, finally, a critical appraisal of the application of this method to readily reproducible isotherms. At any rate, the paper is generally recognized after nearly forty years of use as the best approach to the measurement of the surface area of catalysts and other finely divided and/or porous materials."