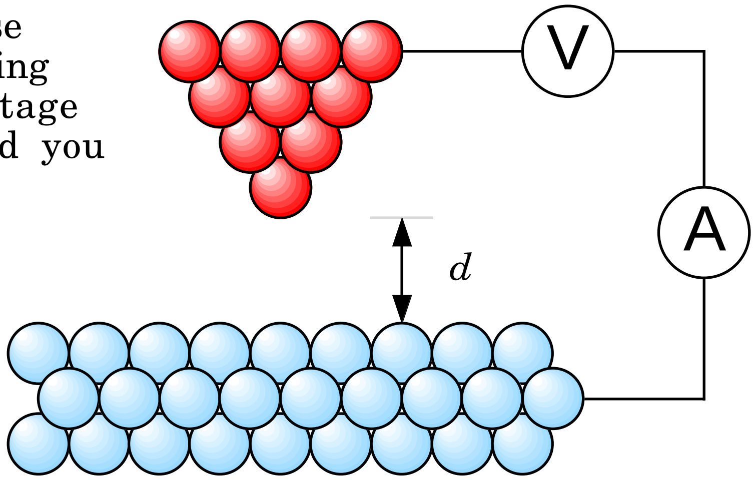
Scanning Tunnelling Microscopy

Imaging using quantum mechanics

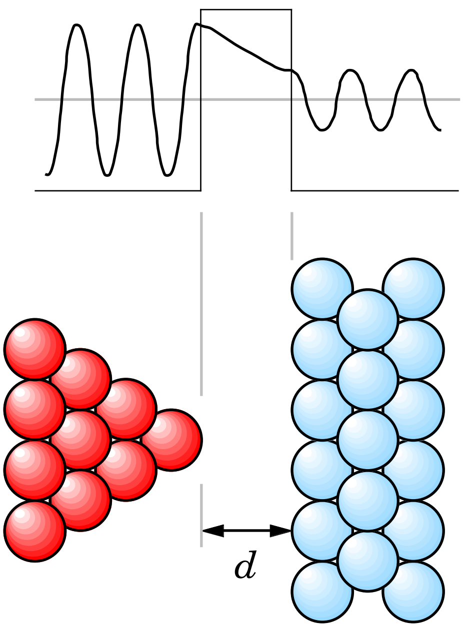


Bring a sharp metal tip close to a metallic or semiconducting surface and apply a voltage between them. What would you expect to happen?

Classically, zero current flows between the tip and the sample unless they actually touch. According to quantum mechanics, a small current will flow even when they are separated because electrons can ‘tunnel’ from the tip, through the vacuum (where, classically, they should not exist) and into the sample. The current depends exponentially on the separation, d, of the tip from the sample surface

$$I \propto \exp(-20\,d) \qquad \text{where } d \text{ is measured in nm.}$$

Note that the I is very sensitive to small changes in d – increasing d by 0.1 nm will decrease I by a factor of ~10.Thus, although the currents are typically only ~nA, the large changes produced by atomic-scale variations in the separation of tip and sample can be detected and used to produce images of a surface.



Tunnelling between the tip and the sample can be modelled in quantum mechanics by solving the equations that describe a wave (the wavefunction of the electron) hitting a barrier. Some of the wave is reflected from the barrier and some passes through, or tunnels, to the other side. The intensity of the transmitted wave, relative to that of the incident wave, gives the probability of tunnelling.

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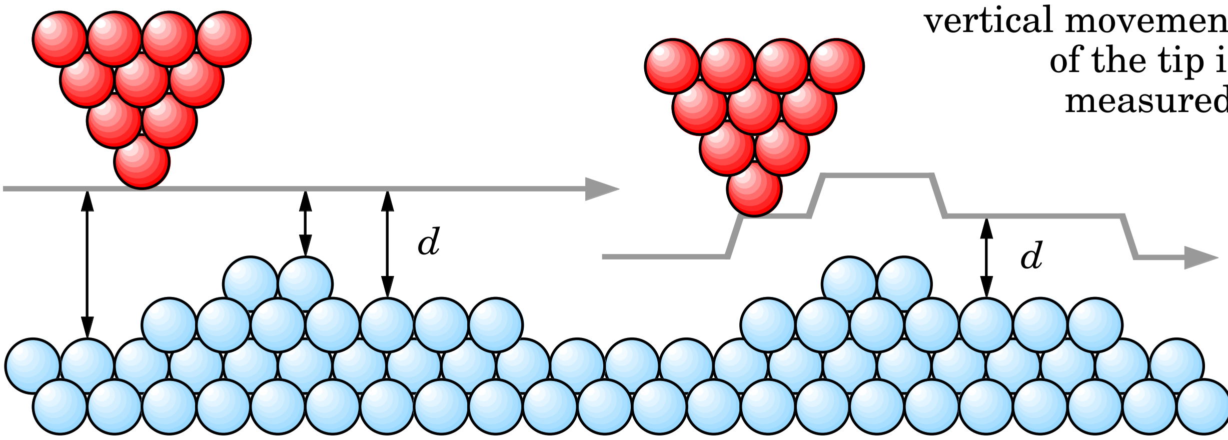
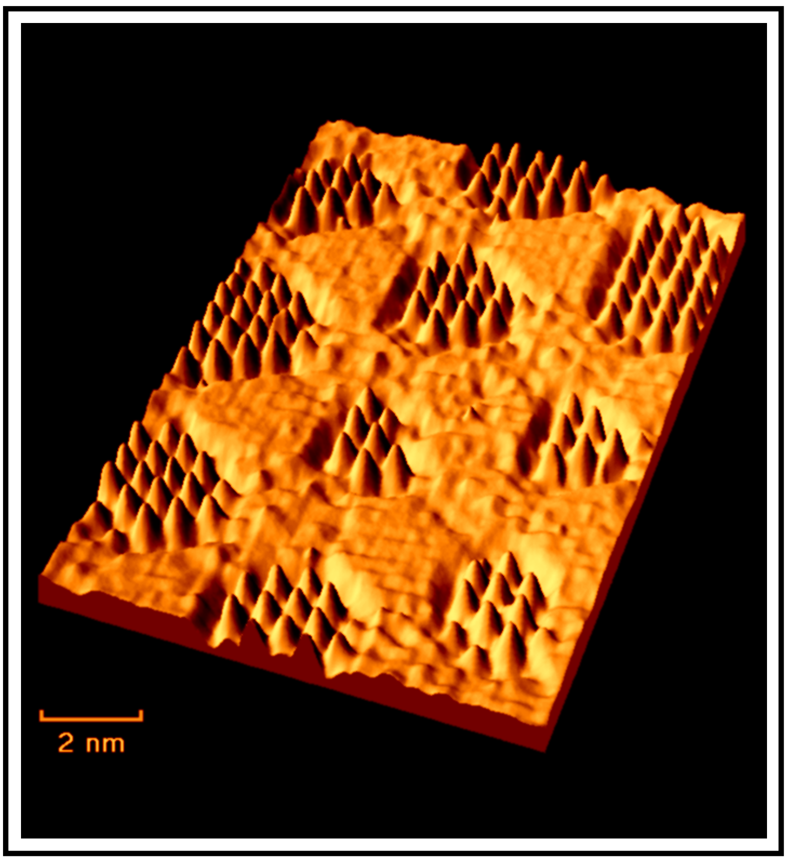
An STM image can be created by scanning the tip in one of two modes. In constant height mode (left) the tip is moved horizontally at a constant height and the changing value of I that results from the changing value of d is measured. In constant current mode (right) the tip is moved such that I remains constant by keeping d constant and the vertical movement of the tip is measured.





The STM image on the left is the surface of the mineral magnetite (Fe_3O_4) after being exposed to oxygen and heated up. Various phases of iron oxide are formed, each co-existing with the others in this rather unusual pattern.

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