PHY*chip* Corporation

SCU Nanotechnology Course presentation

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President & CEO

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Course Books

- **(1) Primary Book: Introduction to Nanoscale Science and Technology**

  Edited by Massimiliano Di Ventra, Stephane Evoy and James R. Heflin, Jr.

  Kulver Academic Publishers

- **(2) Other Books: Nanosystems. Molecular Machinery, Manufacturing and Computation**

  Author: K. Eric Drexler

  Wiley Interscience Publication

- **(3) NANOTECHNOLOGY & HOMELAND SECURITY. New weapons for new wars.**

  Authors: Daniel Ratner & Mark A. Ratner.

  Forwarded by James Murday, Office of Naval Research

  ADDISON-WESLEY PROFESSIONAL PRENTICE HALL PTR

Scanning Probe Microscopes

- Sharp probe tip scans across the surface and provides nanometer scale information of the sample
- The first scanning probe microscope, the Scanning Tunneling Microscope (STM) was invented in early 1980s
- In an STM, a probe is positioned and scanned very close to the surface of the sample, then a voltage is applied between the tip of the probe and the sample this causes a tunneling current
- Distance from tip to sample is measured by measuring the tunneling current that depends on the distance and the local electronic properties of the sample
- The tip of an STM can also be used to manipulate individual atoms on the sample surface

Atomic Force Microscopes

- Major limitation of Scanning Tunneling Microscope is that it can only image conducting surfaces
- In Atomic Force Microscope, the probe makes direct contact with the surface and follows the topography, the probe deflection is used to generate an image
- Because interaction force between the probe and the surface is measured, this type of microscope is called Atomic Force Microscope or Scanning Force Microscope (SFM)
- AFM provides information on the mechanical properties of the surface
- Can be used for insulating or semi-conducting surfaces, directly in ambient atmosphere or even in liquids

Main parts of Scanning Probe Microscopes (SPMs)

- **THE SENSOR:** Variety of sensors or sensing methods can be used to probe a particular surface property. Additional electronics appropriate to the sensing technique is also required. If the measured property can be converted to voltage, it is possible to feed the data to commercial SPM electronics for control and data processing purposes.
- **THE SCANNER:** The Scanner physically holds the sensor and provides the scanning motion along the sample surface. In most cases, the scanner can move the sensor in all three directions. The scanner is constructed with piezoelectric components, they expand or contract to produce the motion when a voltage is applied. The scanner can move the probe over several thousand angstroms with the fraction of an angstrom in resolution

Continued …

Main parts of SPMs – continued …

- **THE FEEDBACK CONTROL:** If the surface is rough, the probe might crash in to the surface. The feedback control maintains the distance between the tip and the sample. The feedback circuit controls the scanner to ensure the measured value stays close to a preset value. Most commercial SPMs use a standard feedback loop for this purpose.
- **THE COARSE CONTROL:** The piezoelectric scanner can provide only a few thousand angstroms of motion. So all SPMs use a coarse long range motion to place the probe safely close to the sample. This is accomplished by use of mechanical machines (differential springs, fine thread screws, levers, etc.), modern SPMs use Piezoelectric motores.

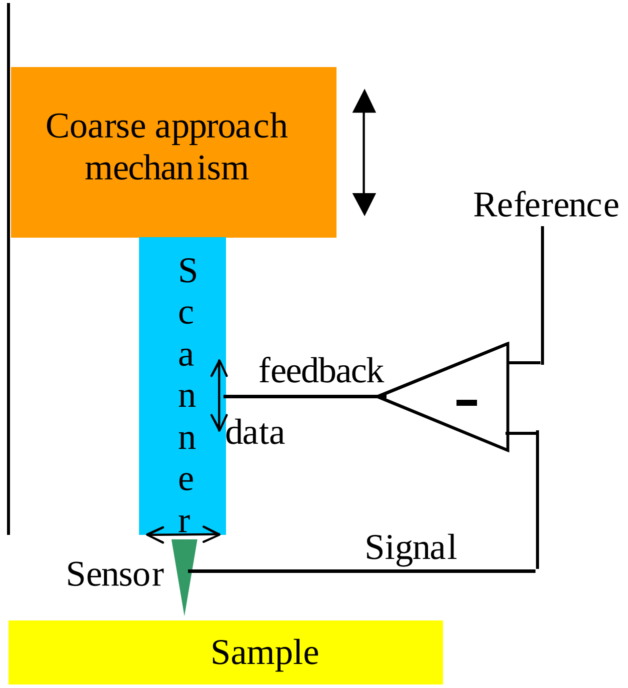

Figure 3.1. Schematic showing all major components of an SPM. In this example, feedback is used to move the sensor vertically to maintain a constant signal. Vertical displacement of the sensor is taken as topographical data

STM Operation Modes

- For rough surfaces, safe distance maintained with feedback loop ON, the STM operates in constant current mode.
- Reduced measurement speed and resolution, but avoids crash
- Use this as the first step

- After confirming flatness it is advisable to image again with the feedback loop off
- Gives high resolution and is used for small surface areas

- Loose atoms on a smooth surface can be picked up or released by careful manipulation of the tip voltage

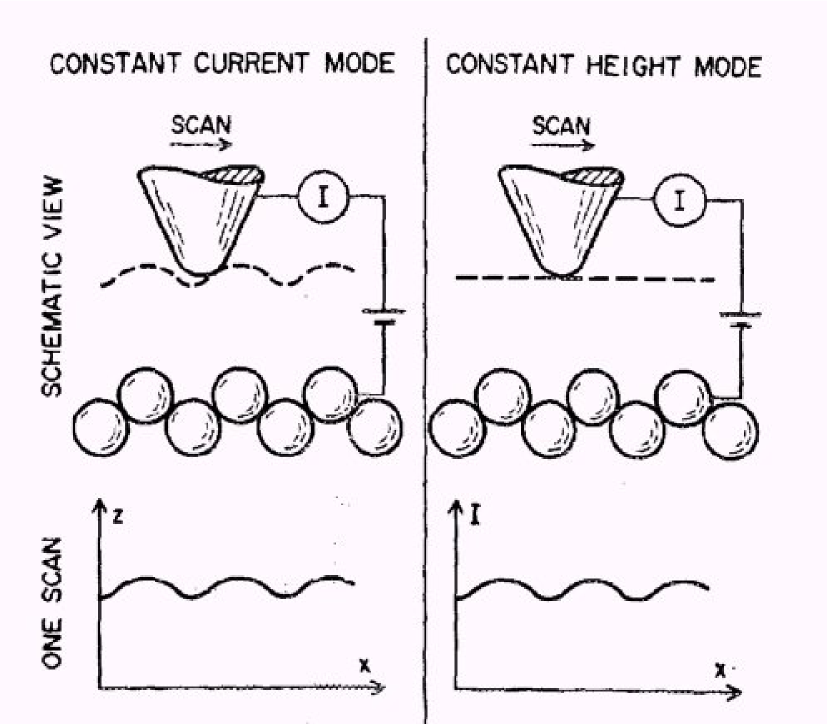

Figure 3.7. Left: Constant current mode, with feedback turned on to maintain a constant tunneling current. Right: Constant height mode, feedback is turned off. (From Ref. 8 by permission of American Institute of Physics.)

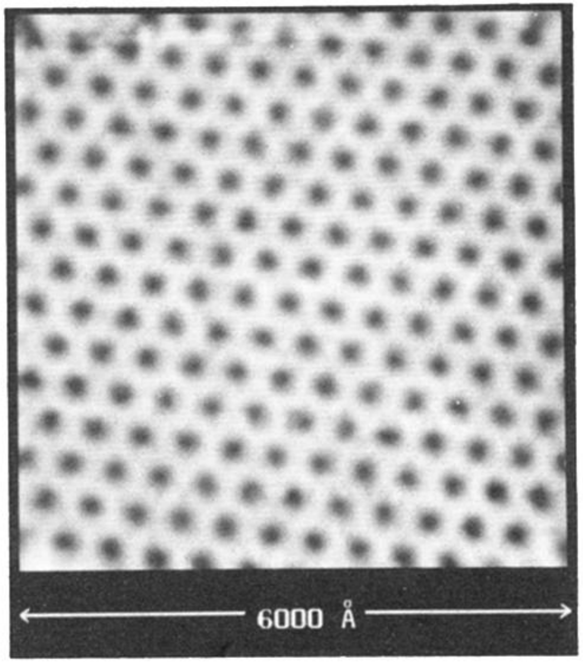

Figure 3.14 . STM vortex image of NbSe2 taken at 1.8K, with an external field of 1T. (From Ref. 11 by permission of American Physical Society.)

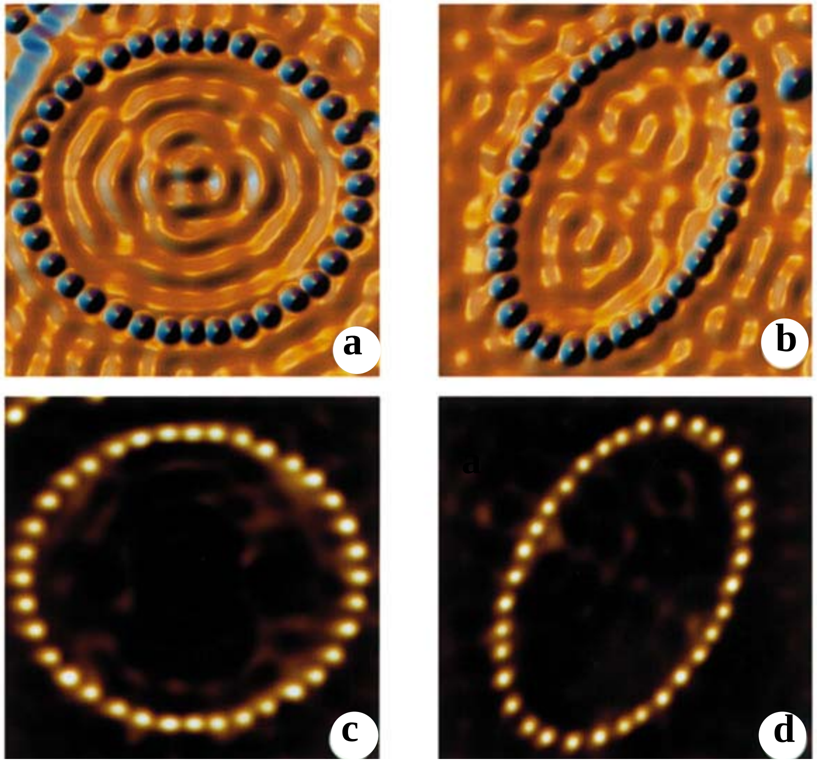

Figure 3.15. Co atoms on smooth Cu(111) surface. The Co atoms are moved to the desired pattern by carefully manipulating the position and voltage of the STM tip. Note how the electron waves in the background are being focused by the boundary. Lower pictures are dI/dV images of the top ones. (From Ref. 12 by permission of Macmillan Magazines Ltd.)

Atomic Force Microscopes (AFM)

- For topological imaging another type of microscope called AFM or Scanning Force Microscope (SCM) is used
- No current is involved, can image both conducting and insulating surfaces
- Resolution generally not as high as STM
- Probe is scanned on the surface and the deflection of the probe is measured
- When the surface and the probe are relatively far, Van Der Waals force is an attractive force
- When they are very close, Leonard Jones potential makes them repel each other
- Between the attractive and repulsive forces, there is an equilibrium point of minimum potential where the system settles, there is zero potential between the atoms of the probe and surface

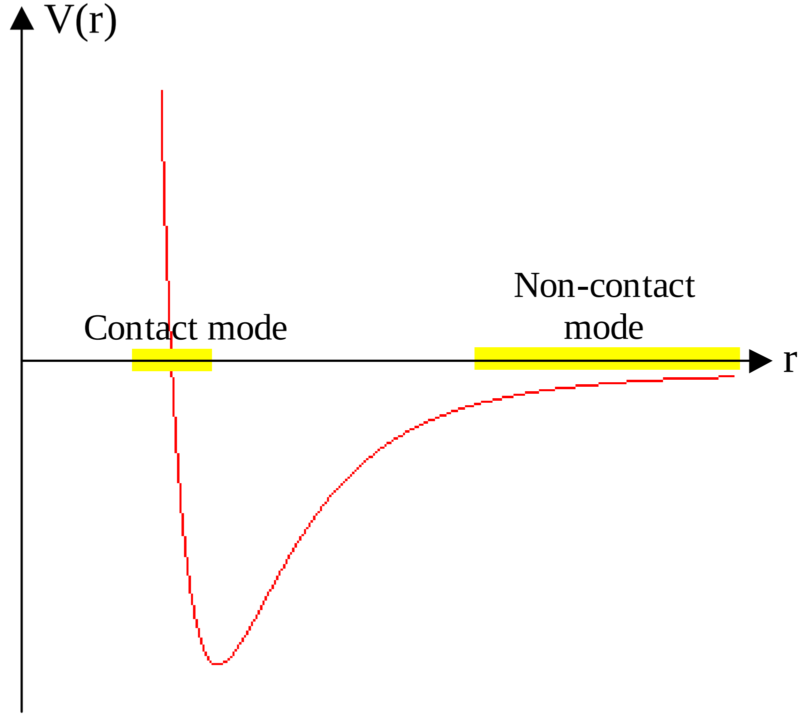

Figure 3.16. Potential energy between tip and sample as a function of the distance between them. The potential is attractive when they are far apart (non-contact), but it will become strongly repulsive when they are close together (contact).

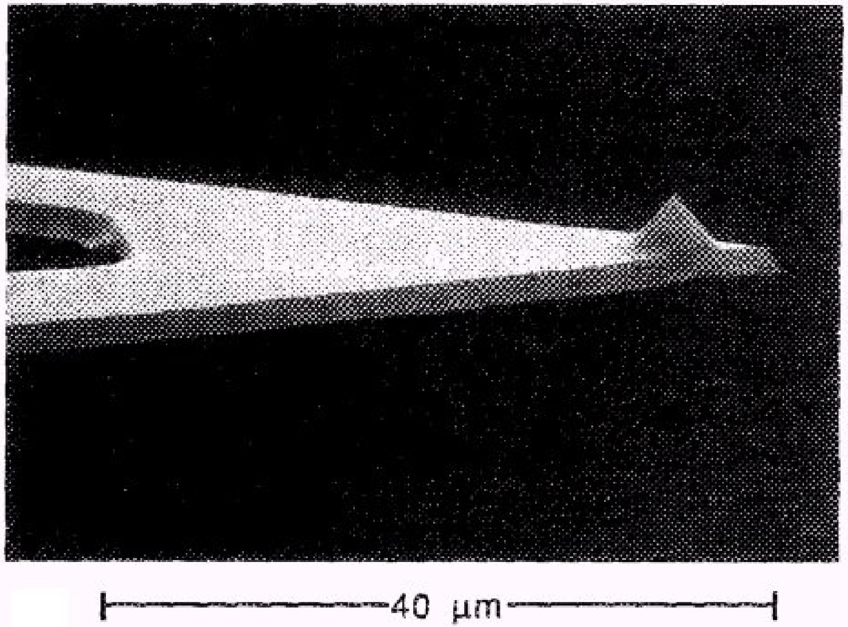

Figure 3.17. A SiO_2 AFM cantilever fabricated by photolithography. (From Ref. 13 by permission of American Institute of Physics.)

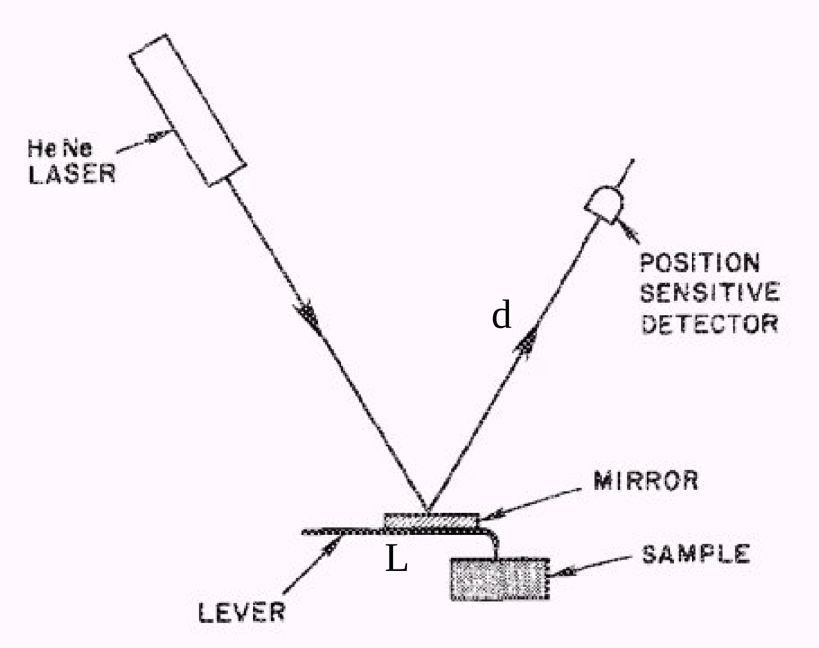

Figure 3.18. A laser optical system used to measure the deflection of the cantilever. This method is commonly used in many AFMs. (From Ref. 14 by permission of American Institute of Physics.)

Geometry of Nanoscale Carbon

- **Two carbon atoms can bond strongly by piling up charge above and below the direct line of interaction – II** states
- Because carbon can bond sideways in this manner, it can form two dimensional layered structures
- In graphene, each carbon layer is is tightly bonded in x-y plane to three neighbors, these planes are weakly bonded to each other forming graphite – the lowest energy state for carbon
- Graphene is on the borderline between metallic and semiconductor behaviour
- We can distort graphene sheet in third dimension to form a rich family of structures, for example by wrapping the carbon structure around itself and we get fullerenes
- The most stable structure that isolates pentagons is C_{60}

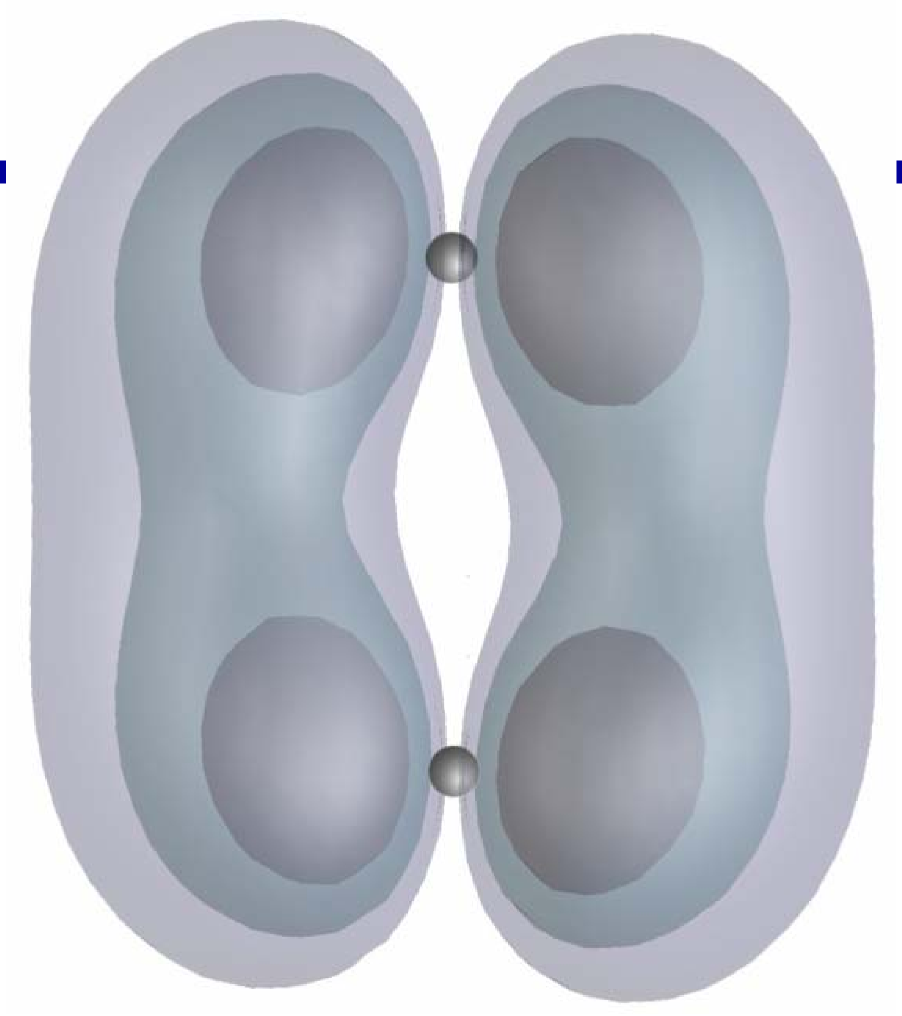

Figure 4.1. Charge density of a carbon dimer π state.

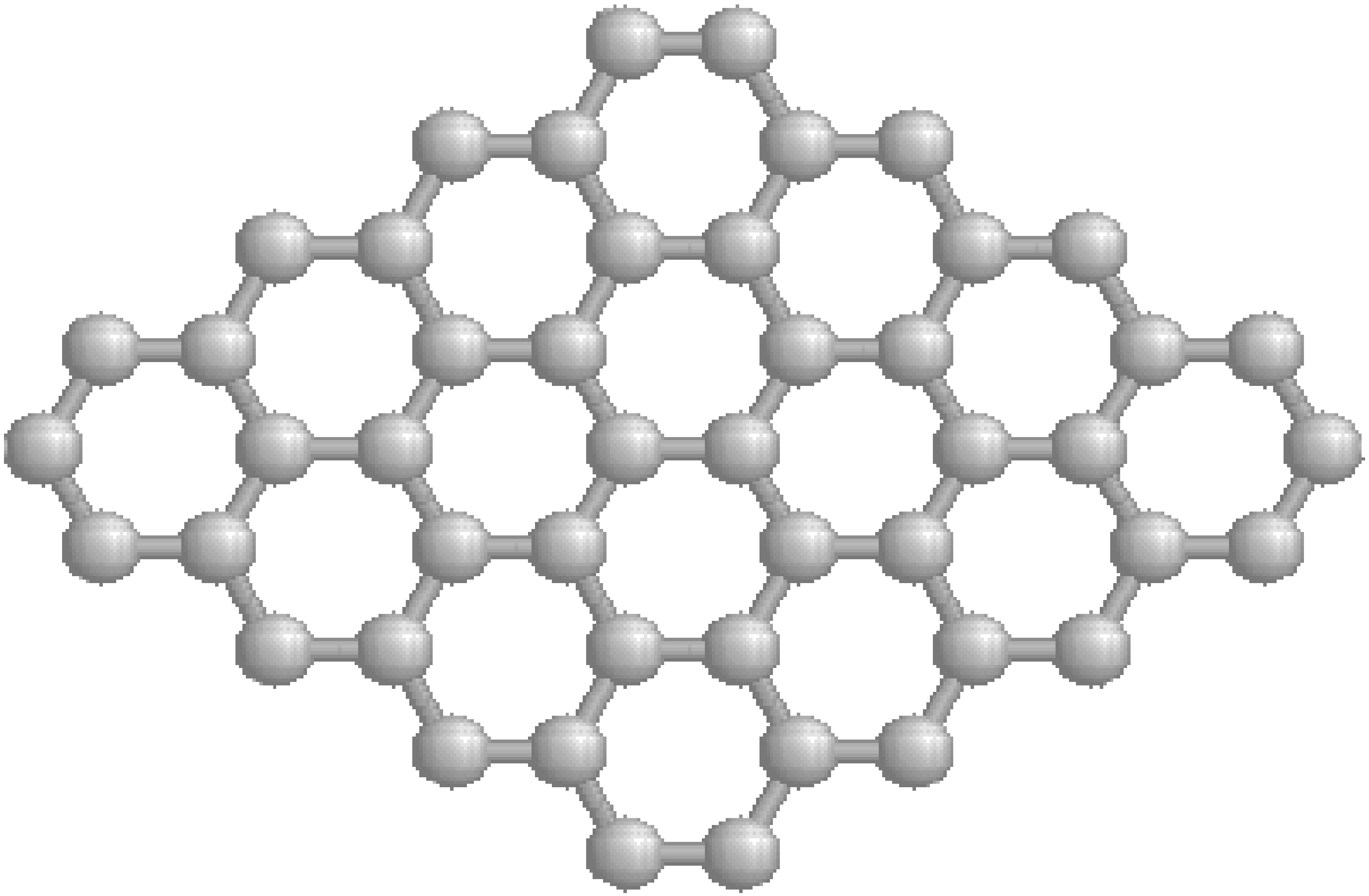

Figure 4.2. Graphene.

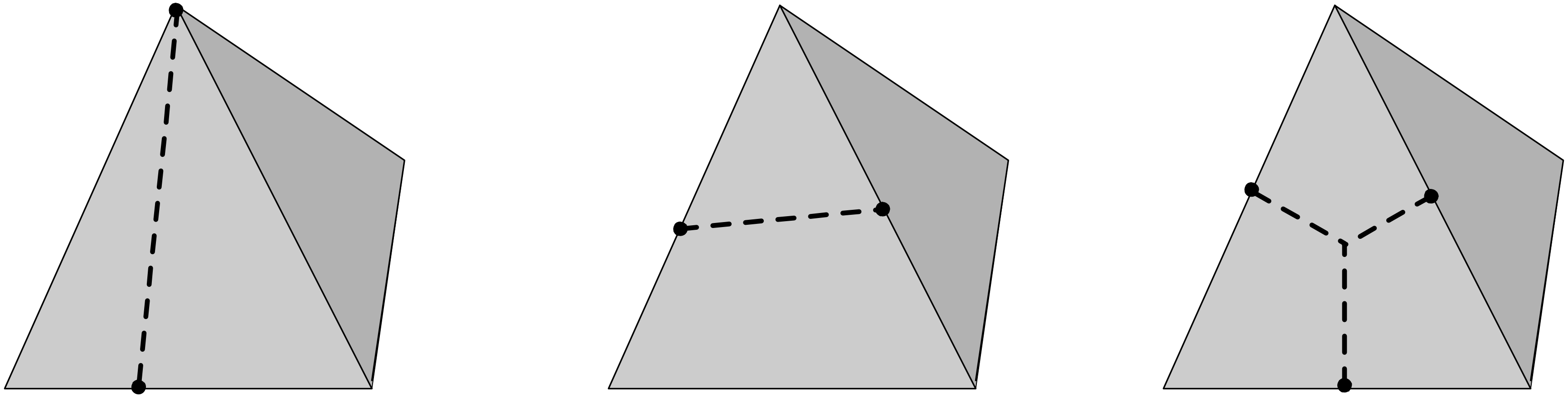

Figure 4.3. Euler's rule in a tetrahedron.

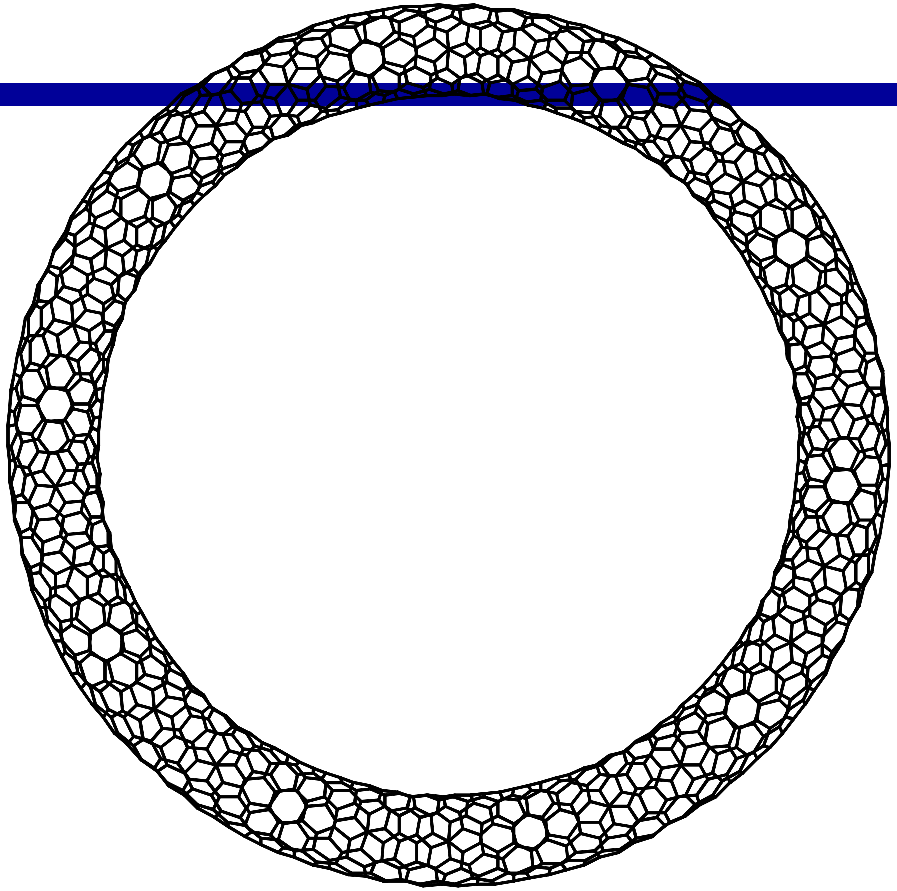

Figure 4.4. A Ring.

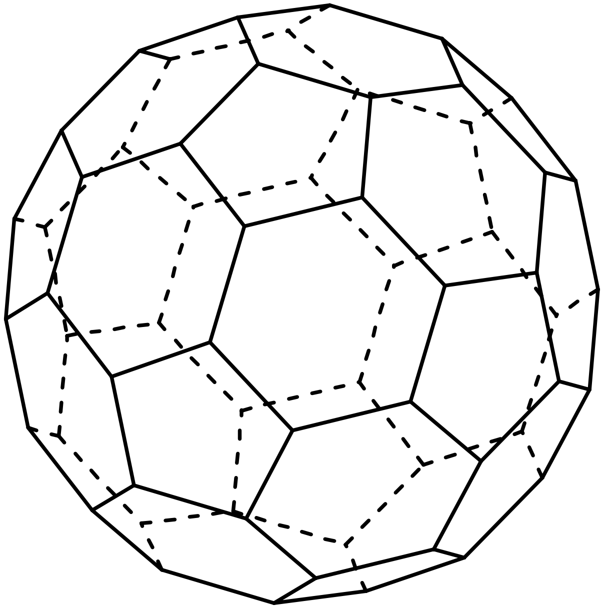

Figure 4.5. C_{60}.

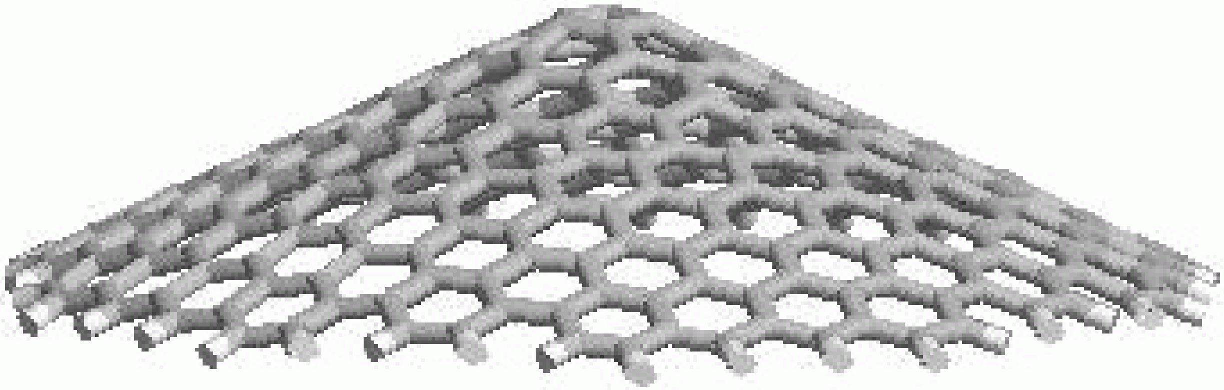

Figure 4.6. Cone.

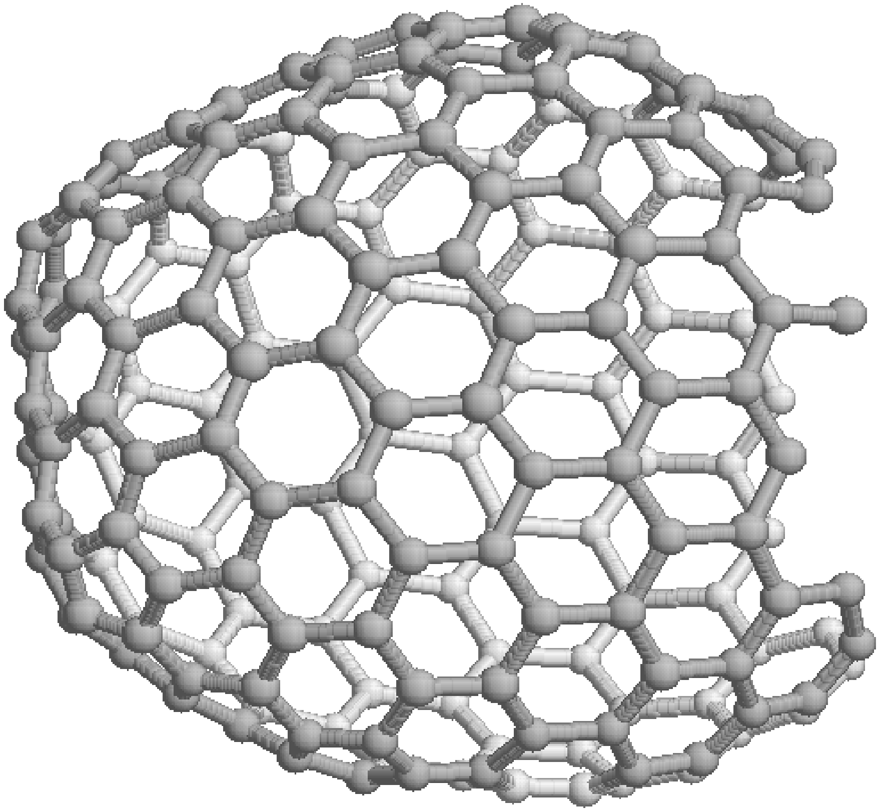

Figure 4.7. Taper.

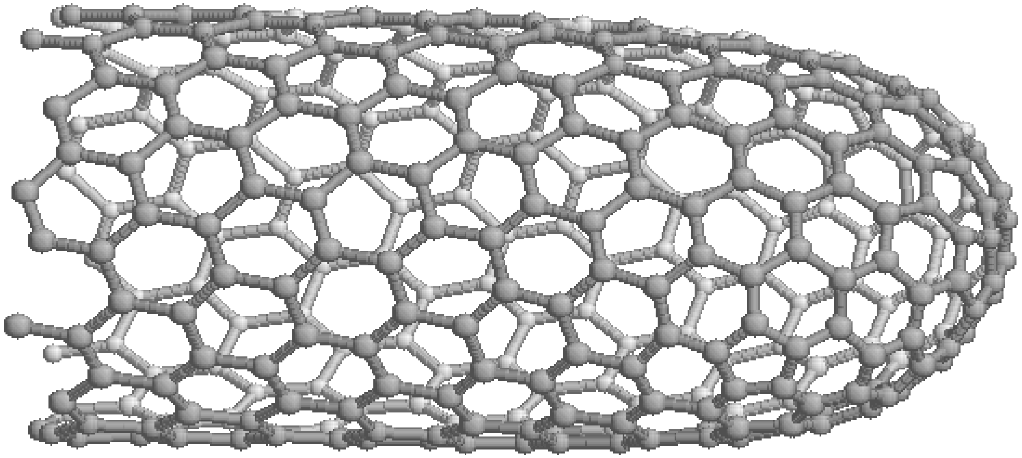

Figure 4.8. Tube closed on one end.

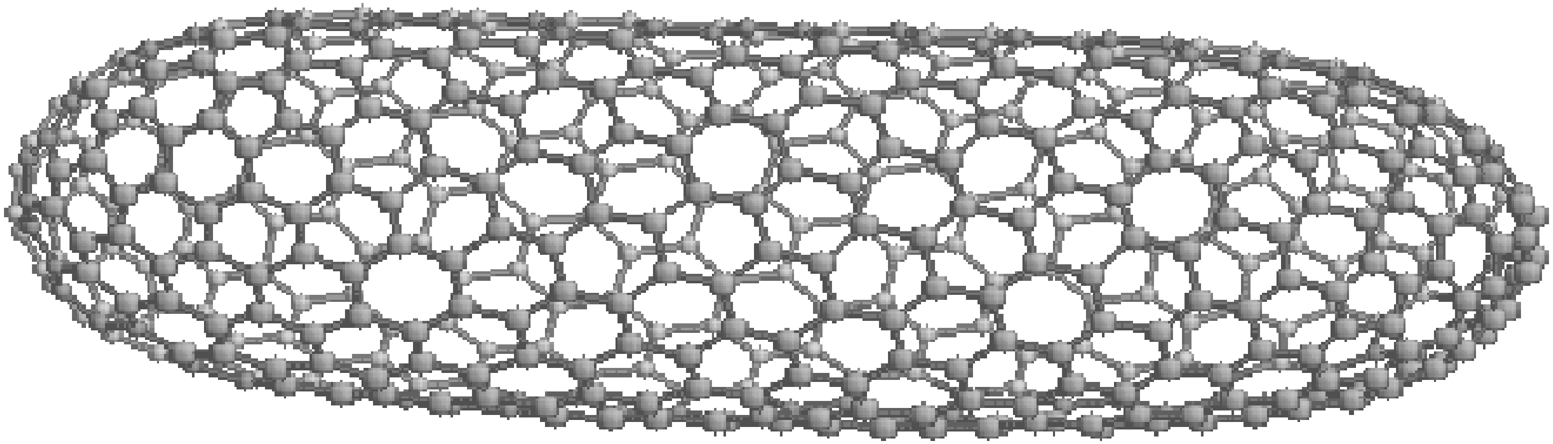

Figure 4.9. Tube closed on both ends.

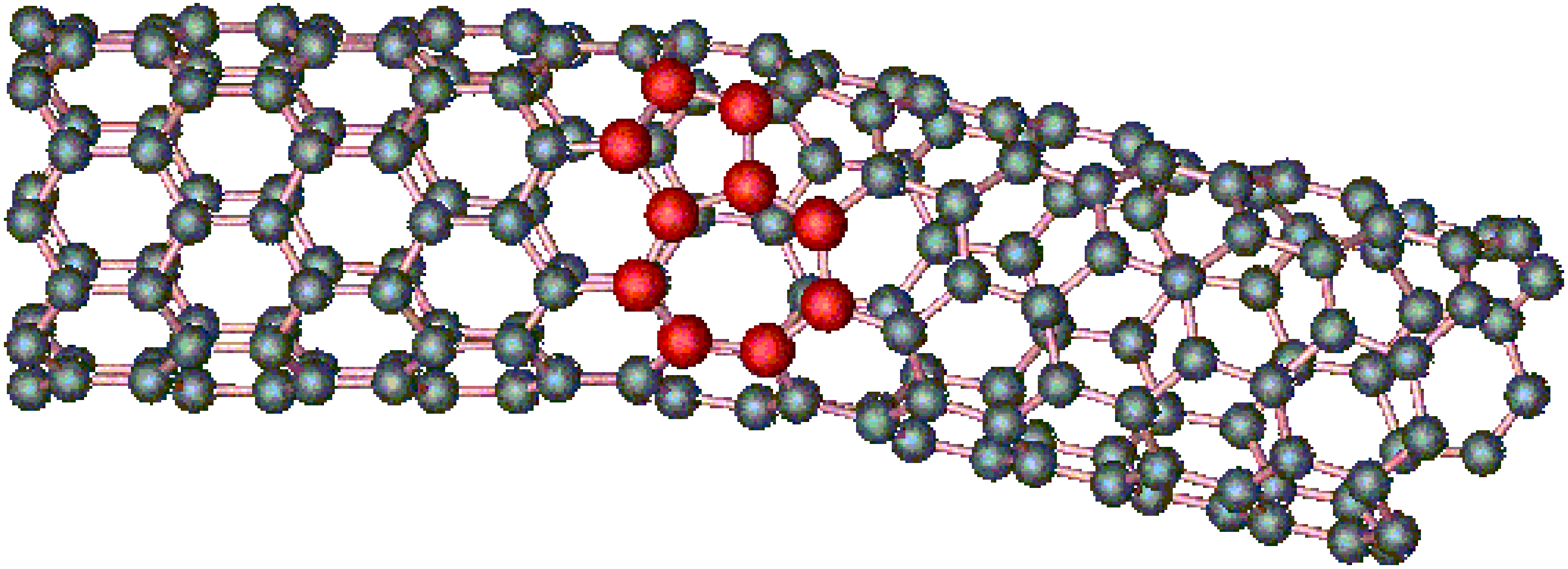

Figure 4.10. Junction.

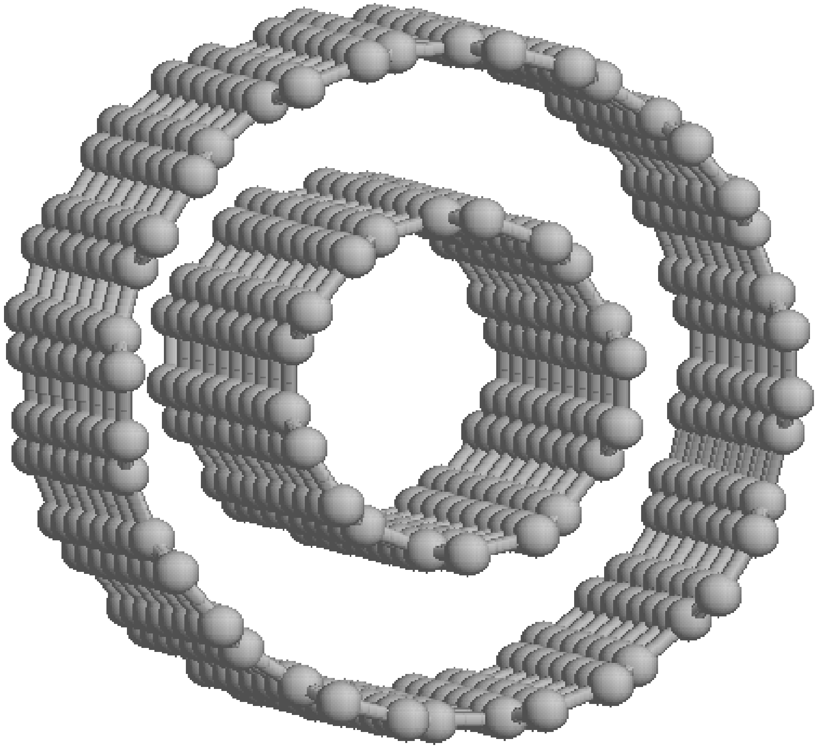

Figure 4.11. Two-walled tube.

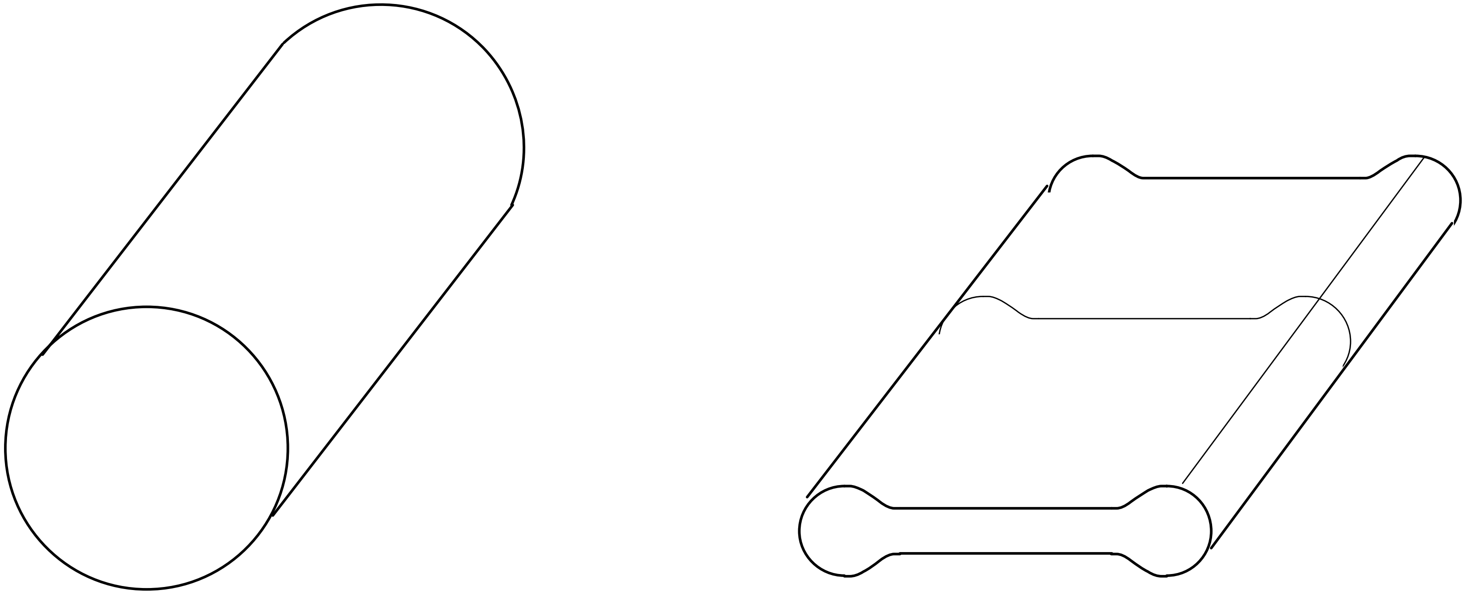

Figure 4.12. Flattened tube

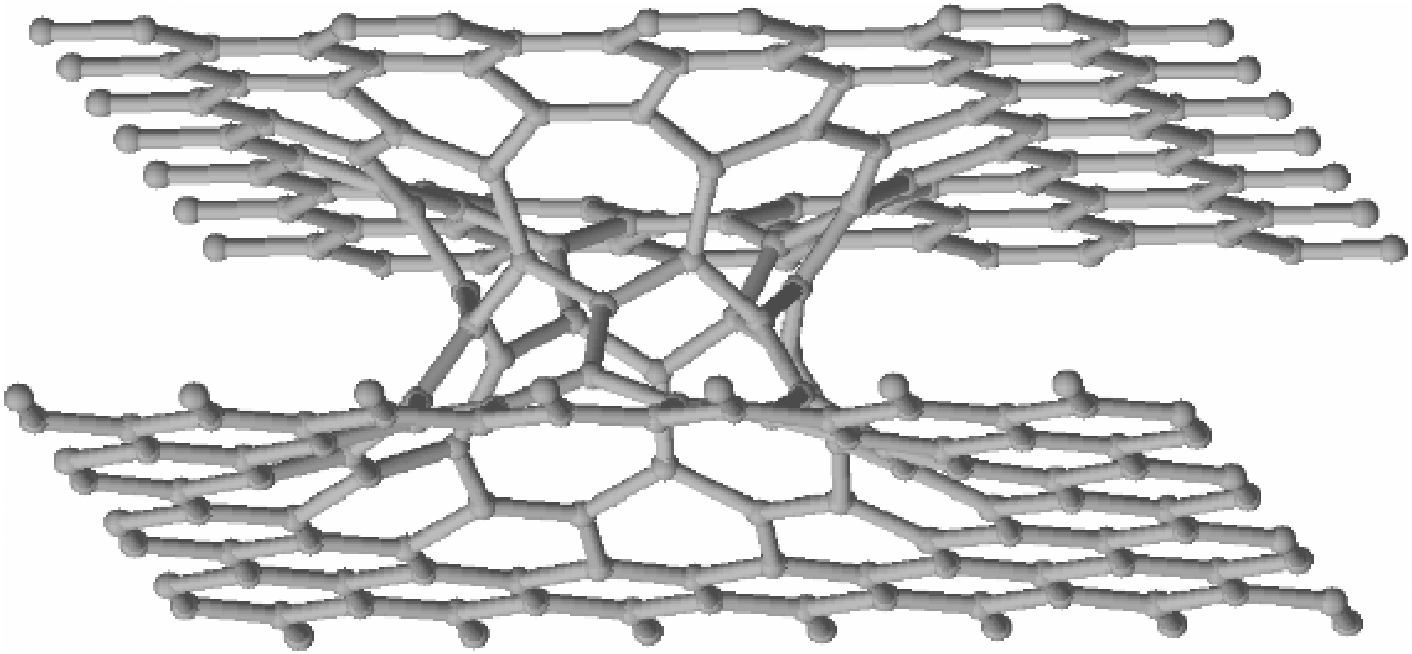

Figure 4.13. Wormhole.