Toward “perfect” 1D electrical conduction

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CEE Bite of Science

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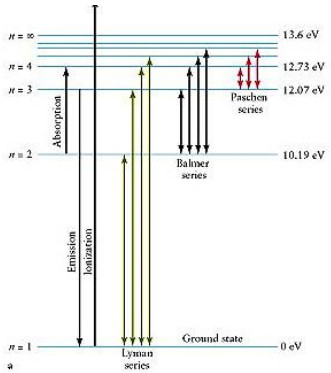
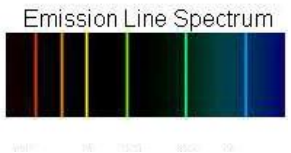
Electrons in Nanostructures: Mesoscopic Physics





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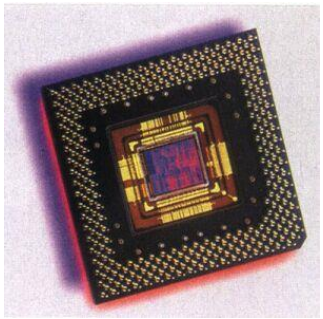
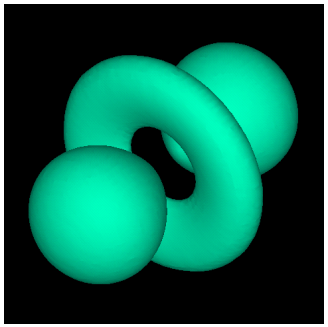


Microscopic **Mesoscopic** **Macroscopic**

... ...



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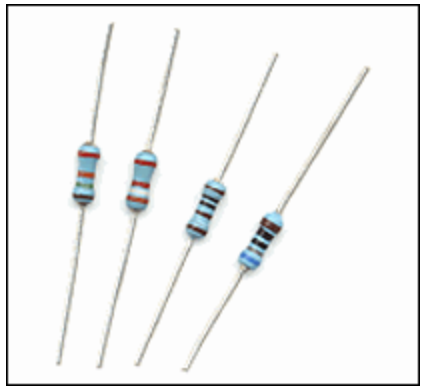
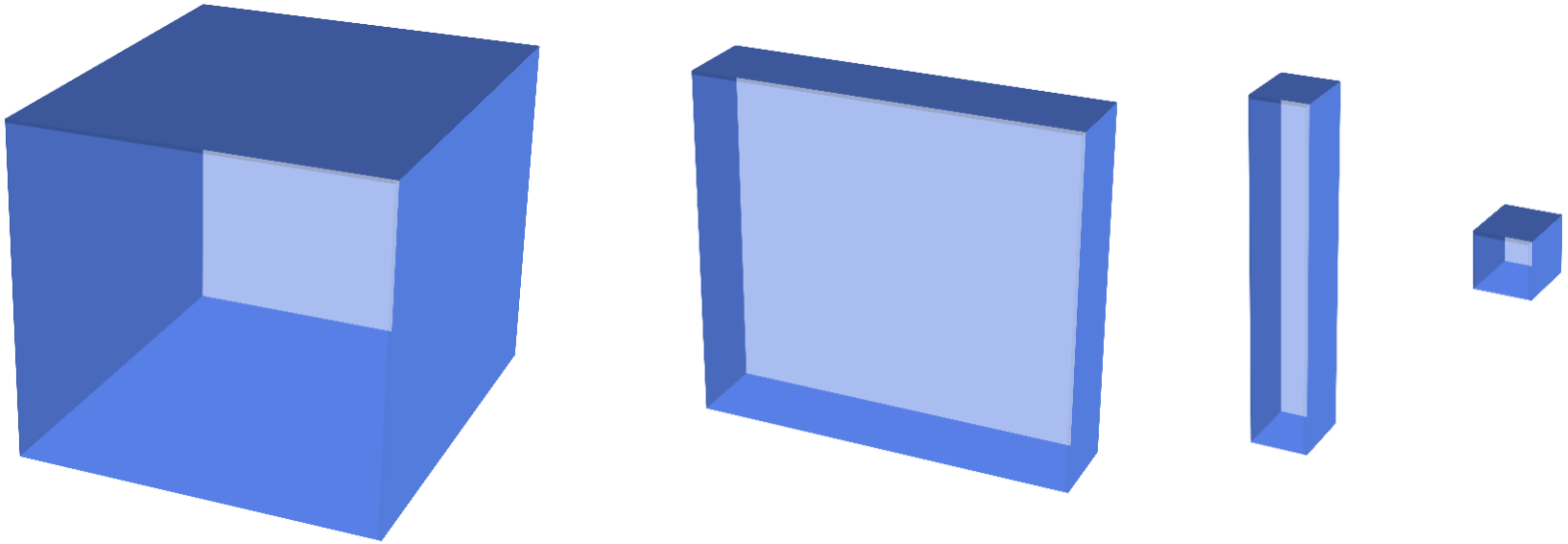


What's distinctive about nano?

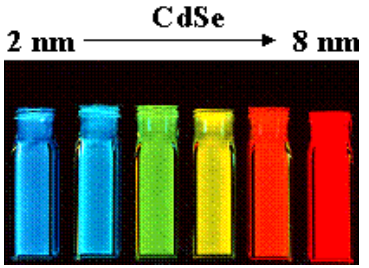
- **Small structures have associated energy scales: the smaller the size, the larger the energy**
- **Crossover: e.g. energy scale > thermal energy**
- **Electrons can be confined in zero, one, two, or all three spatial dimensions**



Example: Quantum confinement

- For an electron in a “box”, only certain quantized energies are allowed
- The smaller the box, the larger the kinetic energy: Heisenberg uncertainty principle

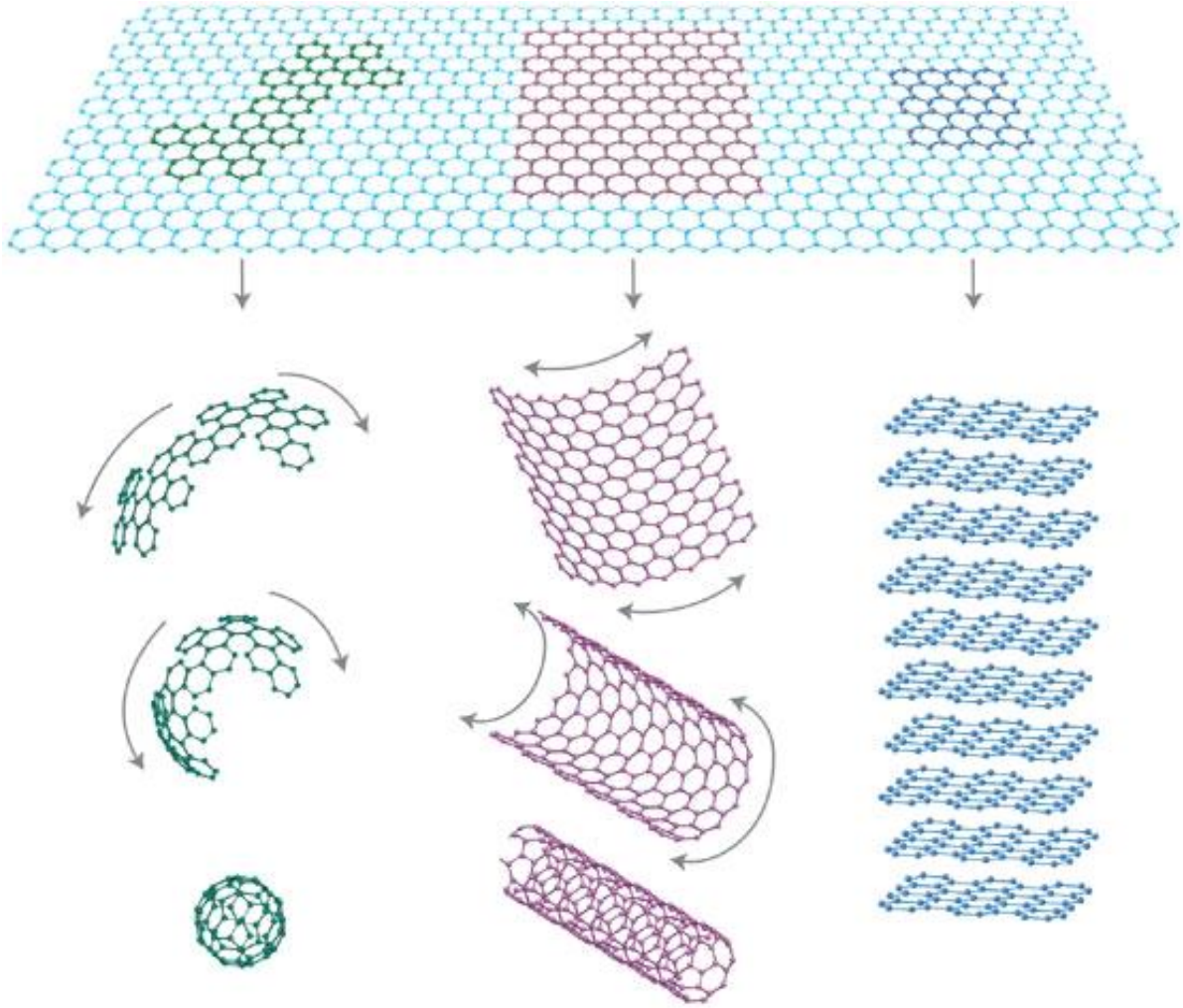
  - Energy spacing gets larger too
  - Electrons may be restricted to the lowest energy, or the lowest few energies



Bawendi/Frankel

- Spacing comparable to room temperature thermal energy at 5 to 40 nm (depends on effective mass in semiconductor)
  - Realized by crystal growth or extreme lithography

Carbon nanotube: a 1D wire



Ballistic Transport in 1D

- In absence of interactions and obstacles, individual cars (or electrons) travel in 1D without scattering
- Each lane has limited conductance
  - For electrons, e^2/h per lane
  - Nanotube is 4-lane highway: 4 e^2/h or 6.5 kΩ
  - Resistive dissipation occurs at "on-ramp"

http://www.caa.ca/e/travel/highway.shtml

Interactions in 1D

www.nsft.no/_efficient_transport.html

http://www.tribuneindia.com/2002/20021007/ncr5.jpg

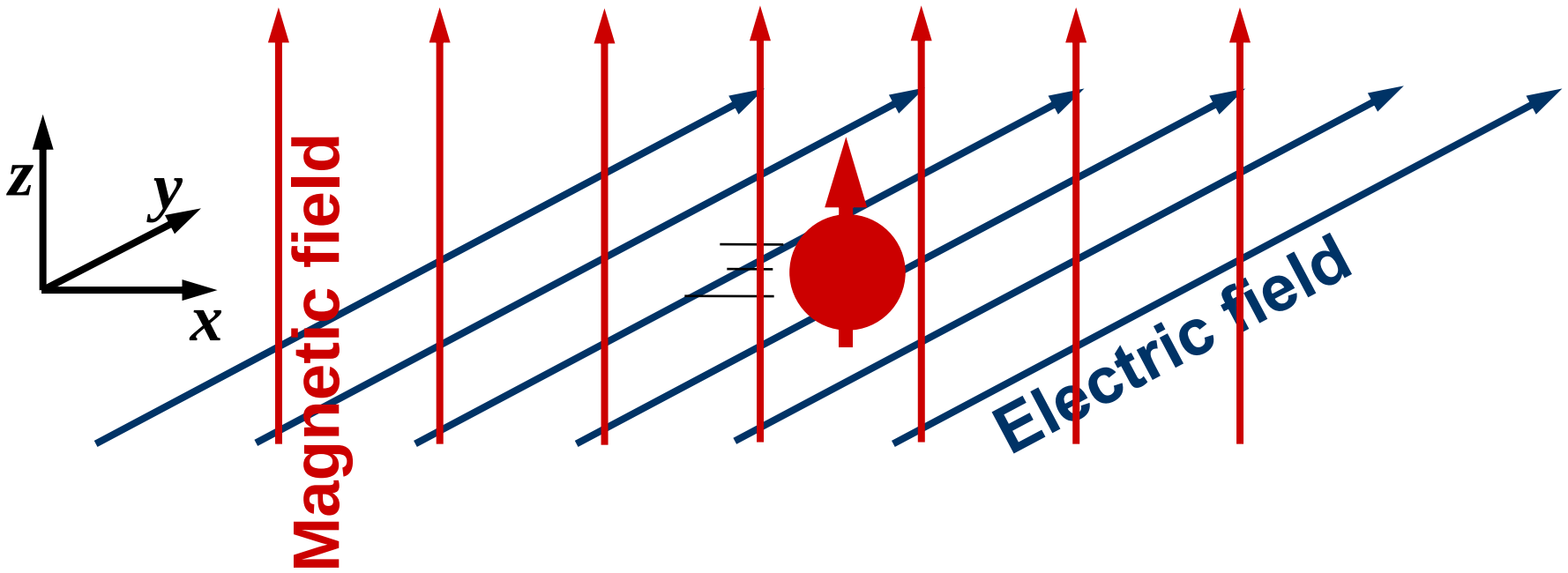
Effect of a small perturbation in 1D

- **Even the tiniest potential bump can bring “traffic” to a halt**

Can we make a two-lane highway for electrons?

Spin-orbit coupling

Special Relativity: a particle moving in an electric field feels an effective magnetic field

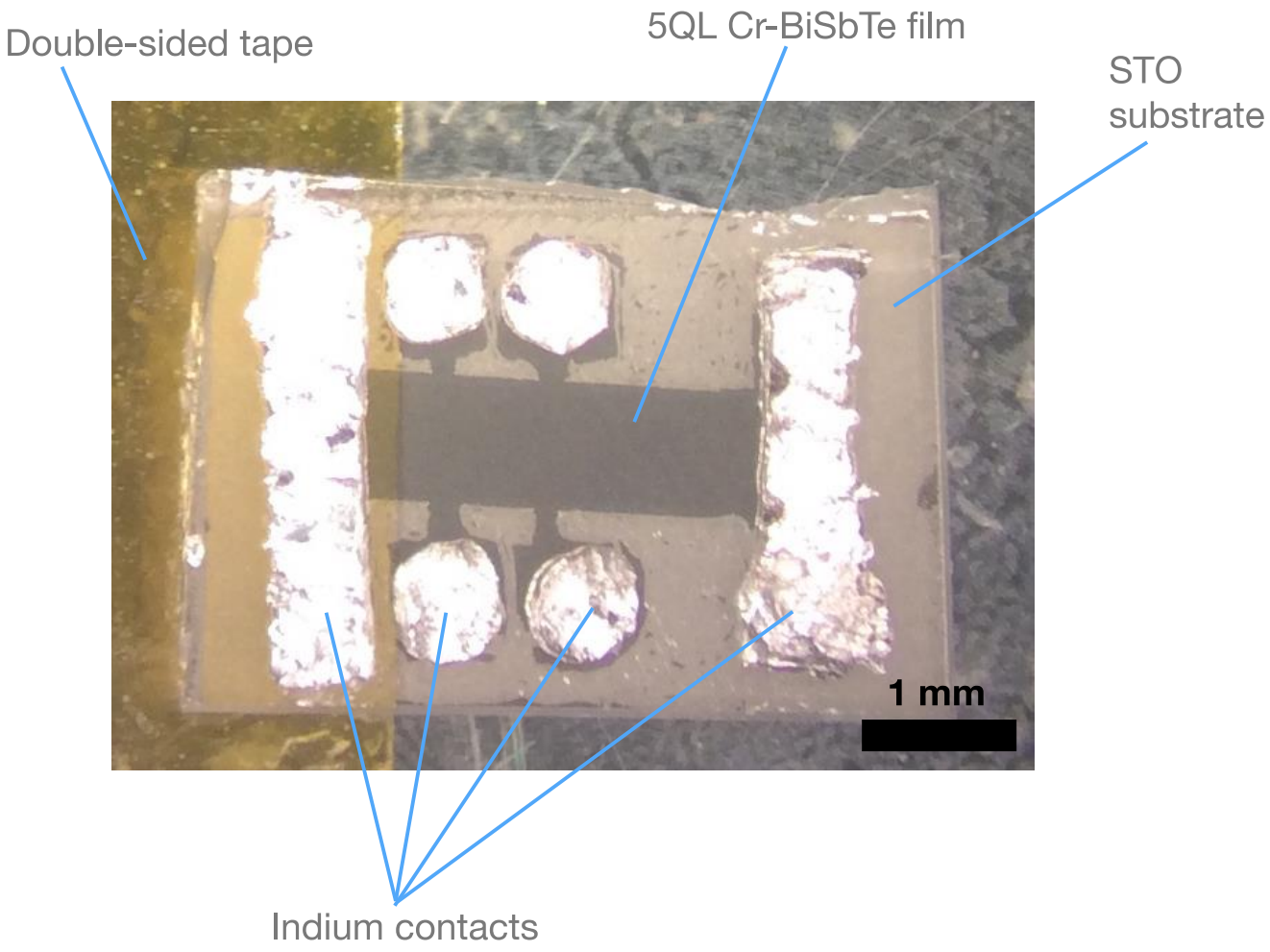


$$H_{SO} = \frac{\hbar}{4m^2c^2}(\vec{\nabla}V \times \vec{k}) \cdot \vec{\sigma} \equiv \vec{B}_{eff}(k) \cdot \vec{\sigma}$$

No U-turns on highways

- **Can set up:**
  - **Spin-up electrons move to the right**
  - **Spin-down electrons move to the left**
  - **Can’t turn around**

Divided highway without large magnetic field



Where have we come?

- **Small is different: new electronic (and optical, and mechanical, …) phenomena emerge in nanoscale structures**
- **Analogies between car traffic flow and electron flow**
- **Both new physics and promise for devices and applications**

Acknowledgments

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