

Electrons in a spin

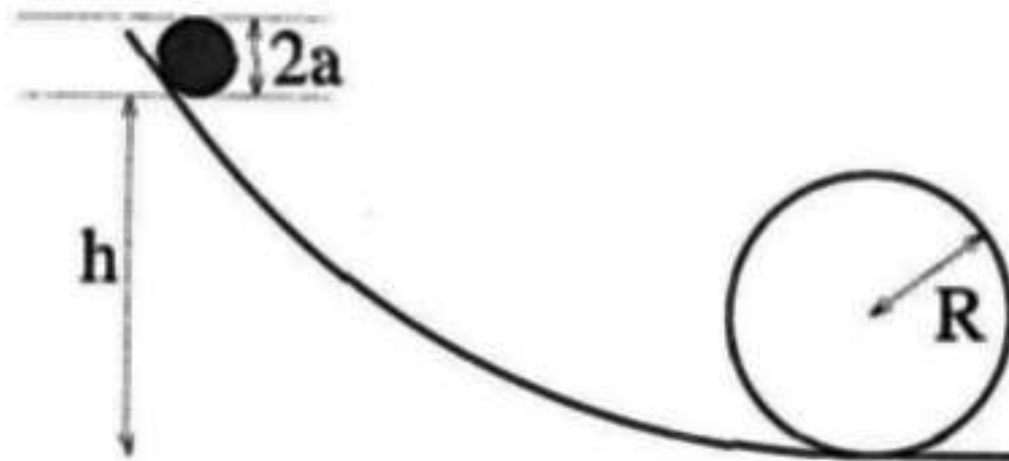


Gareth Conduit

University of Cambridge

Pt IA: Single-body physics

This cylinder is placed on a track as shown in the figure below. The track contains a downhill section which joins smoothly to a vertical circular loop of radius R , finishing with a horizontal section.



The cylinder is released from rest from a point at which its centre is at a height $h + a$ above the lowest point of the track. It rolls along the track without sliding, and

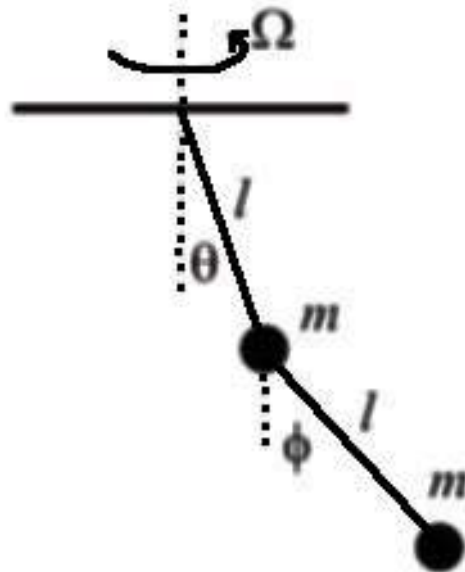
Pt IB: Two-body physics

The double pendulum, as shown below, rotates at a fixed angular velocity Ω . Write down the Lagrangian and hence the dynamical equations for this system.

Use this Lagrangian to show, for small θ and ϕ , that the angular frequencies, ω_1 and ω_2 , of the normal modes are given by:

$$\omega_{1,2}^2 = (2 \pm \sqrt{2}) \omega_0^2 - \Omega^2,$$

where $\omega_0 = \sqrt{g/l}$.



Find and sketch the normal modes. How will the double pendulum behave if Ω lies between ω_1 and ω_2 ?

Pt III physics

Study many-body phenomena driven by firmly established equations of motion

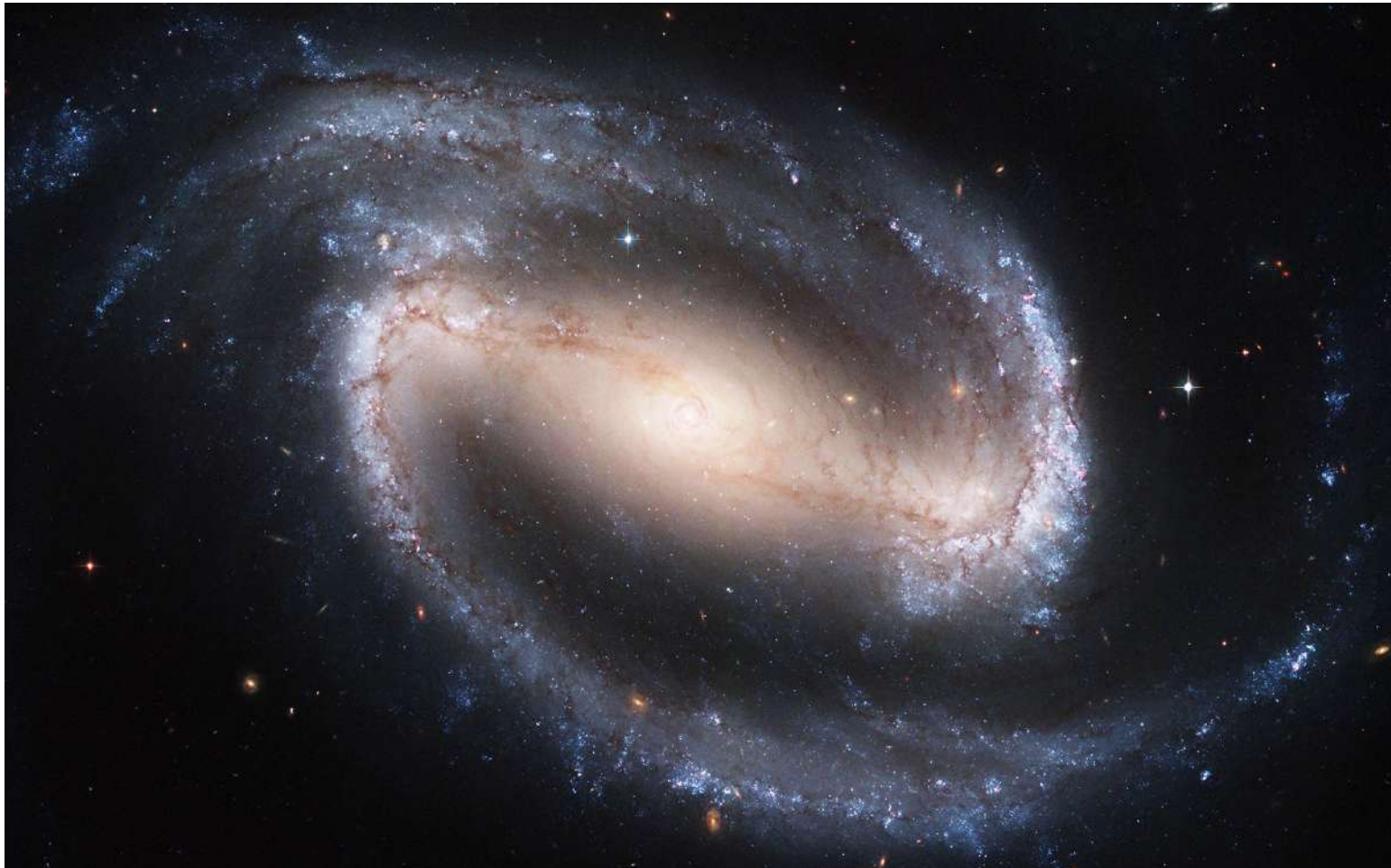
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Atmospheric Chemistry and Global Change
Atmospheric Physics
Atomic and Optical Physics
Biological Physics
Climate Change
Frontiers of Experimental Condensed Matter Physics
Materials, Electronics & Renewable Energy
Medical Physics
Non-linear Optics and Quantum States of Light
Nuclear Materials
Origin and Evolution of Galaxies
Phase Transitions and Collective Phenomena
Physics of Nanoelectronic Systems
Quantum Condensed Matter Field Theory
Quantum Field Theory
Superconductivity and Quantum Coherence

Search for new fundamental equations of motion

Advanced Quantum Field Theory
Formation of Structure in the Universe
Frontiers of Observational Astrophysics
Gauge Field Theory
Particle Astrophysics
Particle Physics
Physics of Nanoelectronic Systems
Quantum Field Theory
Quantum Information
Relativistic Astrophysics and Cosmology

10^{11} -body physics

Stars **all interact** and obey classical laws of motion



10¹¹-body physics

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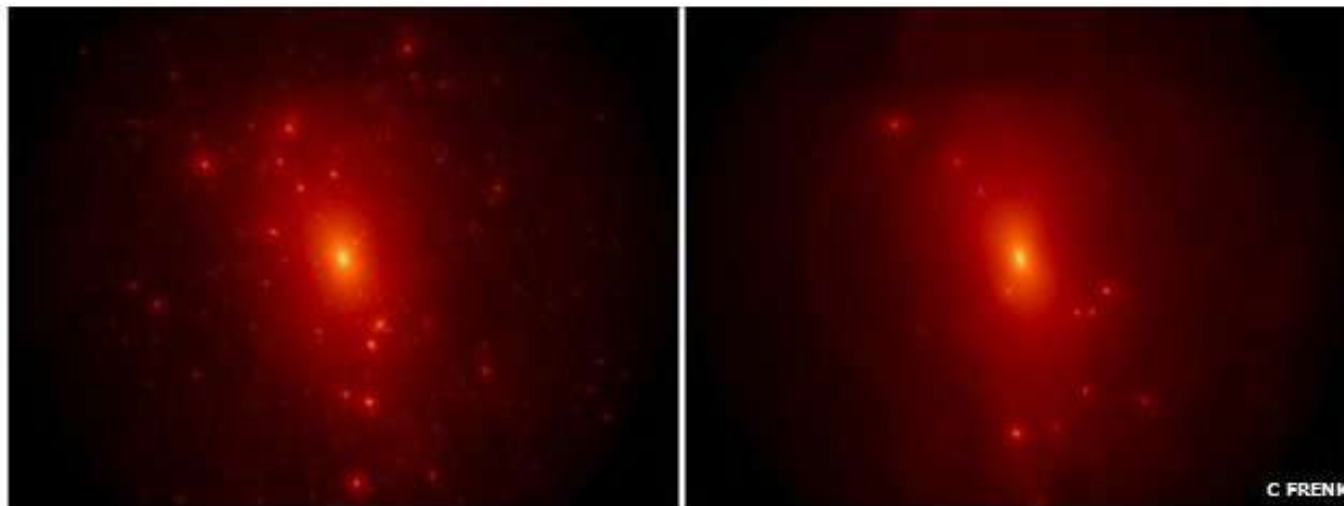
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Dwarf galaxies suggest dark matter theory may be wrong

By **Leila Battison**
Science reporter, Bradford

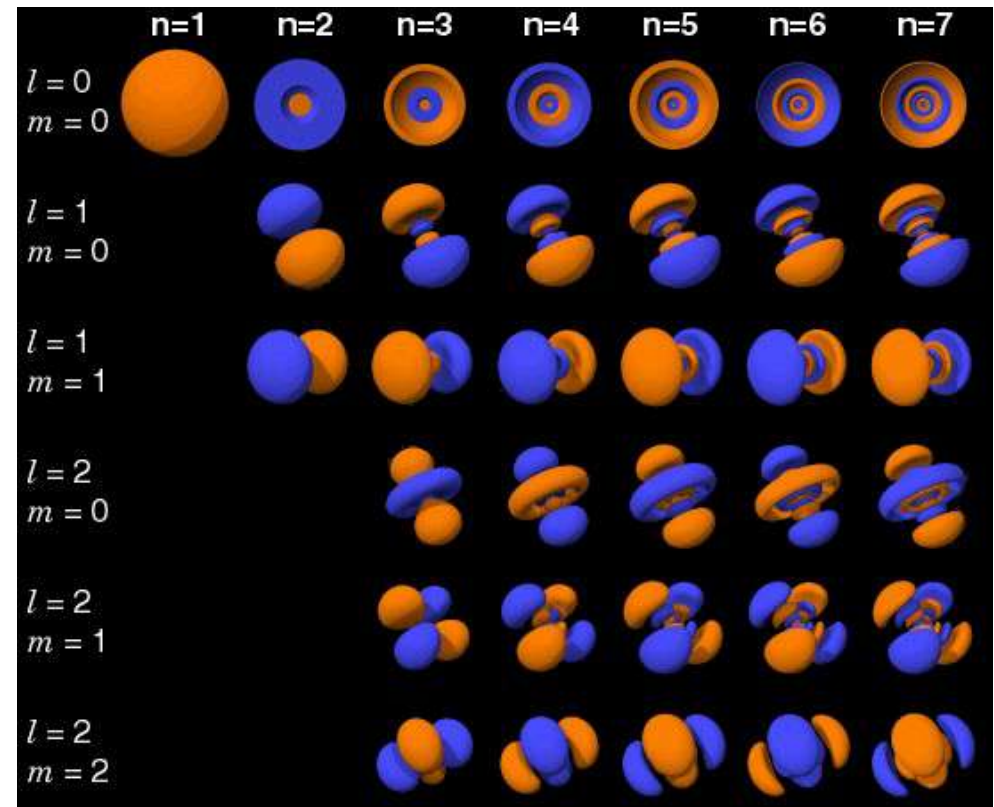


Dwarf galaxies around the Milky Way are less dense than they should be if they held cold dark matter

Classical vs. quantum orbitals

- 10^{11} bodies **all interact**
- Follow circular orbits

- 10^{24} electrons in solids **all interact** and are **quantum degenerate**
- Follow complicated orbits



10^{24} -body physics

- Why is gold shiny, does not tarnish, gold-colored, a good conductor, and so malleable?



- Why does a superconductor expel magnetic fields and conduct electricity perfectly?



10^{24} -body physics

- How is the magnetic field generated?



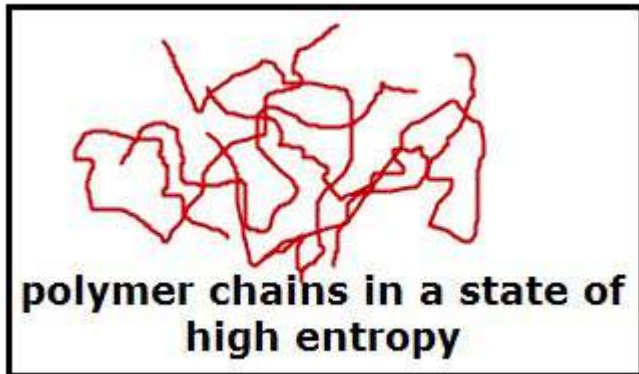
- How does a hard disk drive store so much data?



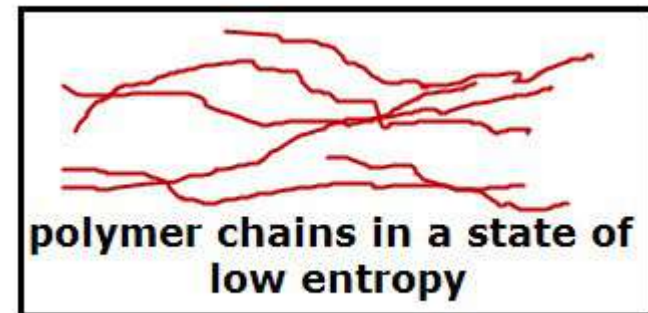
Elastic bands

Elastic bands consist of long polymer chains that interact strongly, but obey classical laws of motion

Natural state



Stretched



Energy stored

- Potential energy stored in elastic band

$$E = \frac{1}{2} kx^2 = \frac{1}{2} Fx = \frac{1}{2} 10 \times 0.1 = 0.5 \text{ J}$$

Energy stored

- Potential energy stored in elastic band

$$E = \frac{1}{2} kx^2 = \frac{1}{2} Fx = \frac{1}{2} 10 \times 0.1 = 0.5 \text{ J}$$

- Kinetic energy in handgun bullet

$$E = \frac{1}{2} mv^2 = \frac{1}{2} 0.005 \times 400^2 = 400 \text{ J}$$

Energy stored

- Potential energy stored in elastic band

$$E = \frac{1}{2} kx^2 = \frac{1}{2} Fx = \frac{1}{2} 10 \times 0.1 = 0.5 \text{ J}$$

- Kinetic energy in handgun bullet

$$E = \frac{1}{2} mv^2 = \frac{1}{2} 0.005 \times 400^2 = 400 \text{ J}$$

- Potential energy in enormous elastic band

$$E = \frac{1}{2} kx^2 = \frac{1}{2} Fx = \frac{1}{2} 100 \times 10 = 500 \text{ J}$$

Effect of material thickness

Thin band: $<10\text{ms}^{-1}$



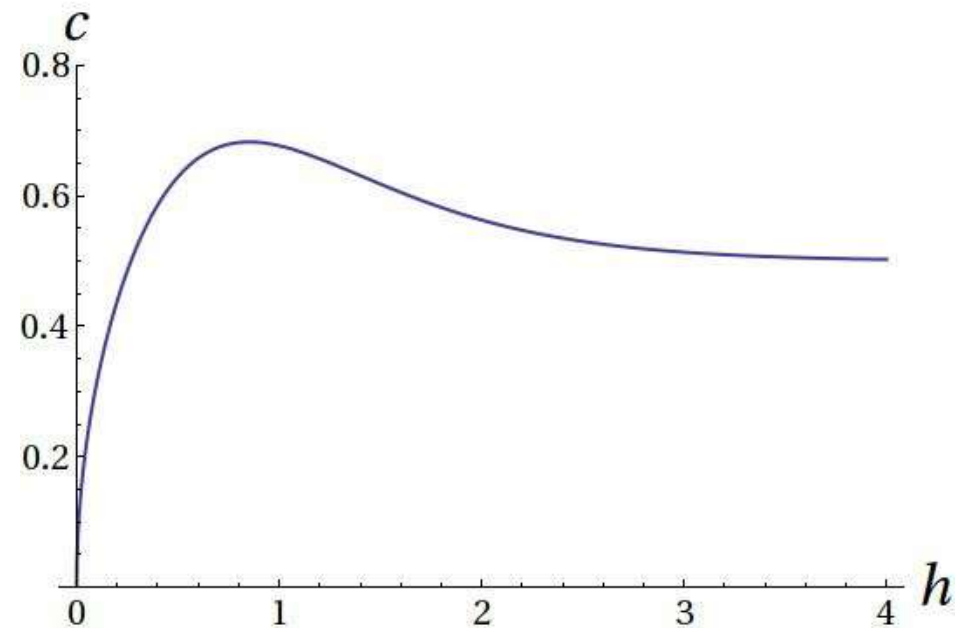
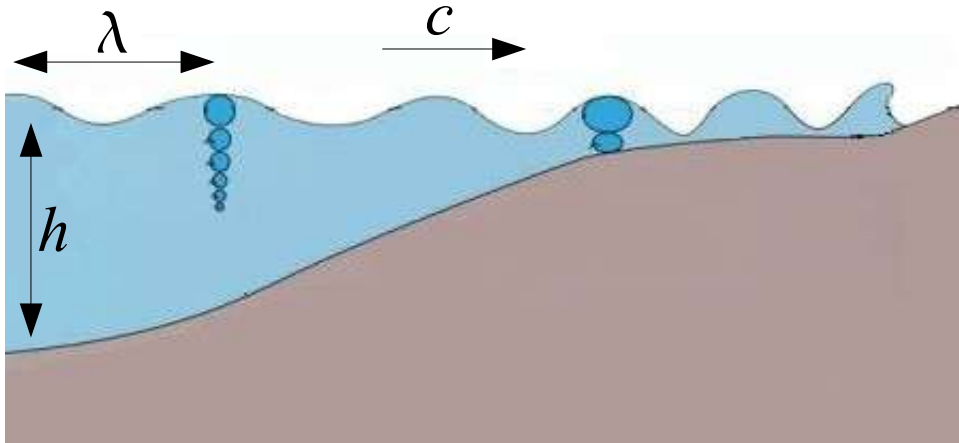
Cylindrical: $>100\text{ms}^{-1}$



Wave velocity

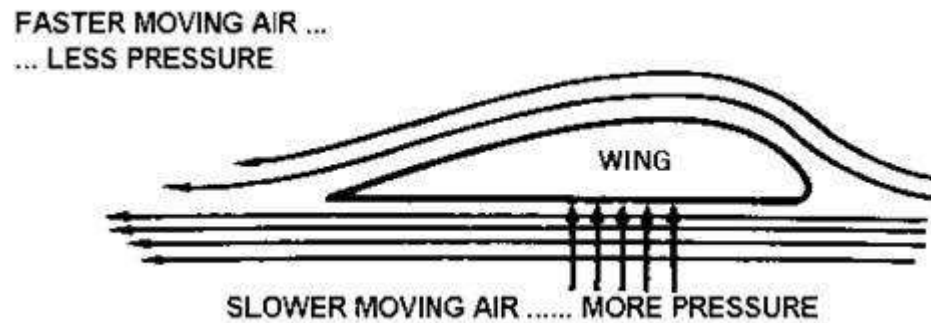
$$c = \frac{\sqrt{gh}}{2} \left(\sqrt{\frac{\tanh kh}{kh}} + \sqrt{\frac{kh}{\tanh kh}} \right)$$

$$k = \frac{2\pi}{\lambda}$$



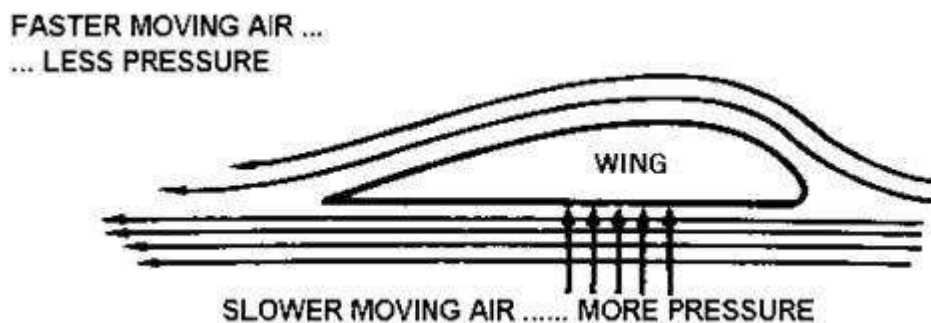
How does an aircraft generate lift?

- Bernoulli's principle:



How does an aircraft generate lift?

- Bernoulli's principle:



- Air is not incompressible
- Violation of Newton's 3rd law

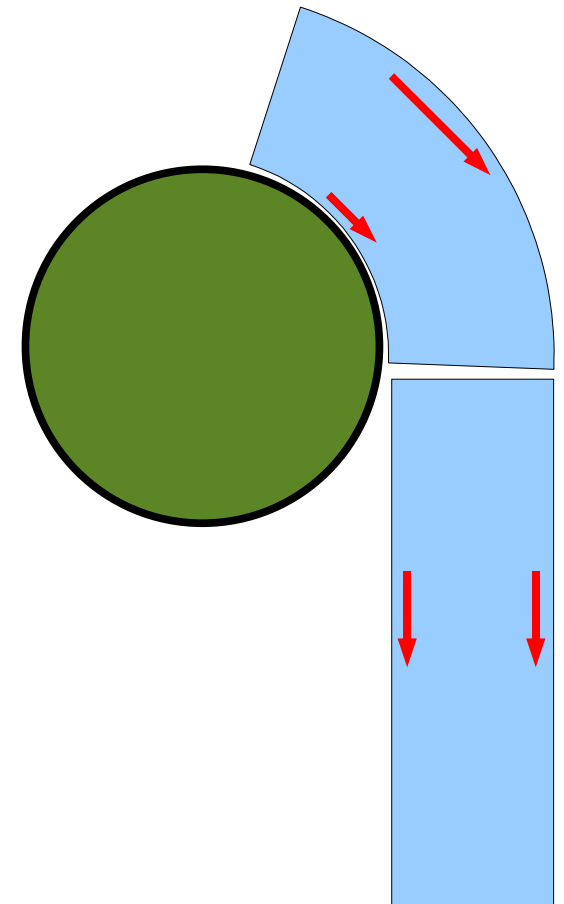
Coandă effect



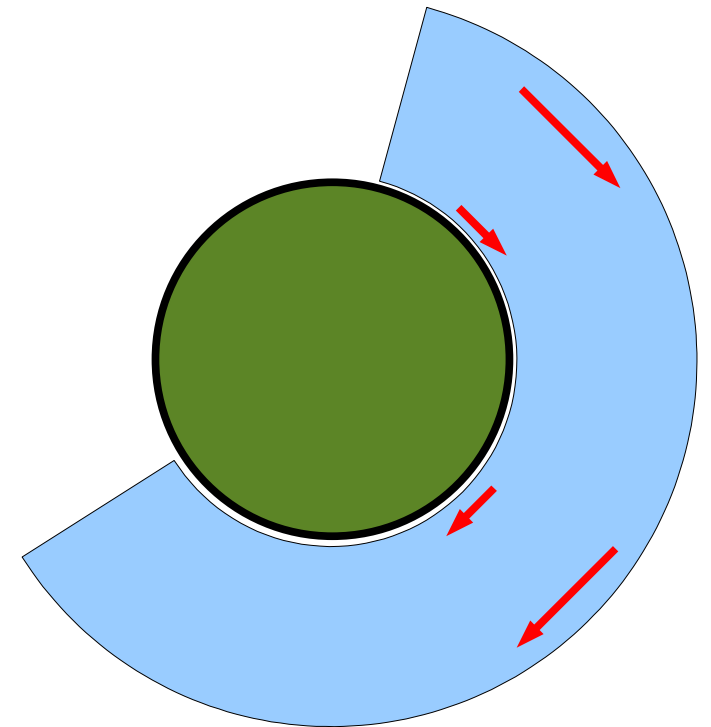
Coandă effect



Coandă effect

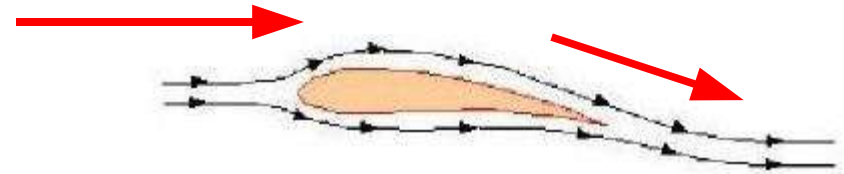
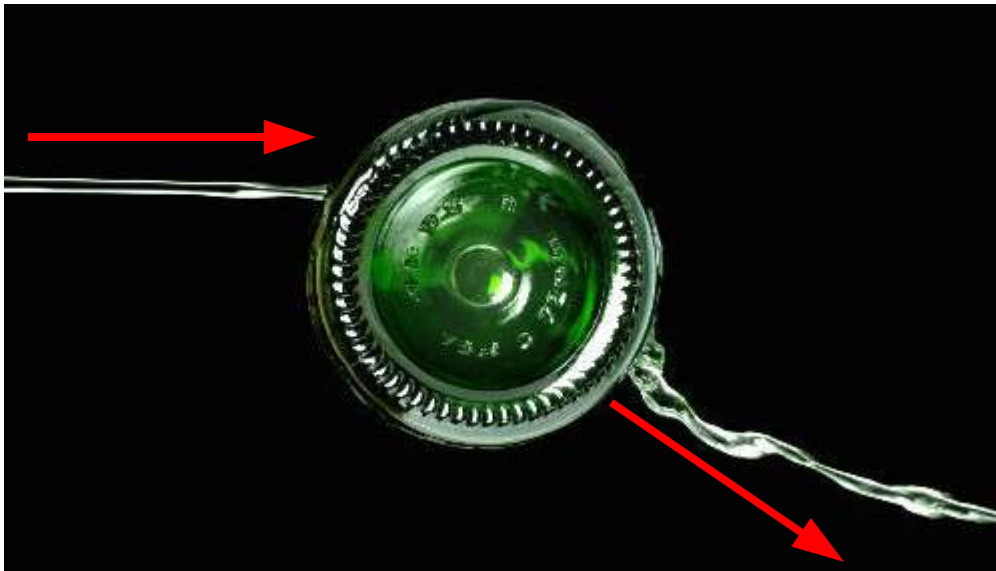


Coandă effect



How does an aircraft generate lift?

Expels mass downwards so Newton's Law pushed plane upwards



Upper surface of a wing generates lift



Quantum mechanics: electrons in solids

Atoms:

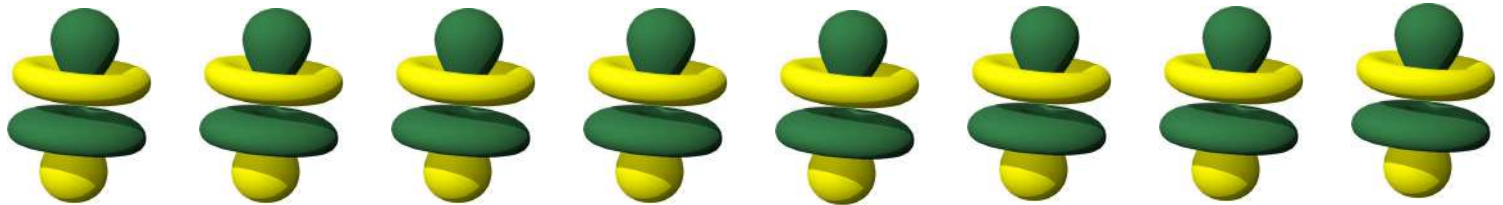


Quantum mechanics: electrons in solids

Atoms:



Orbitals:

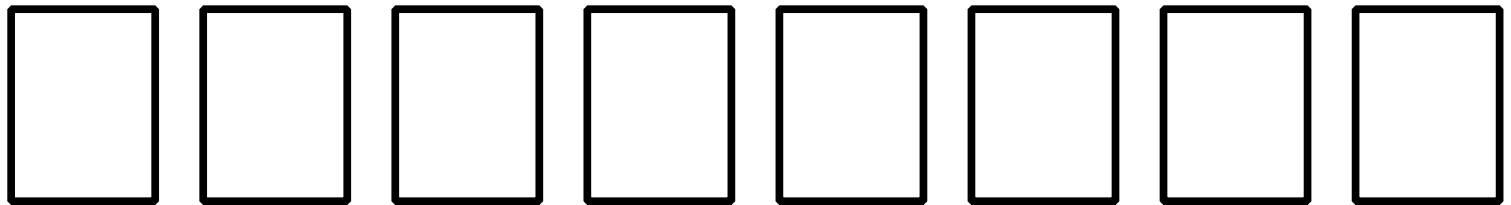
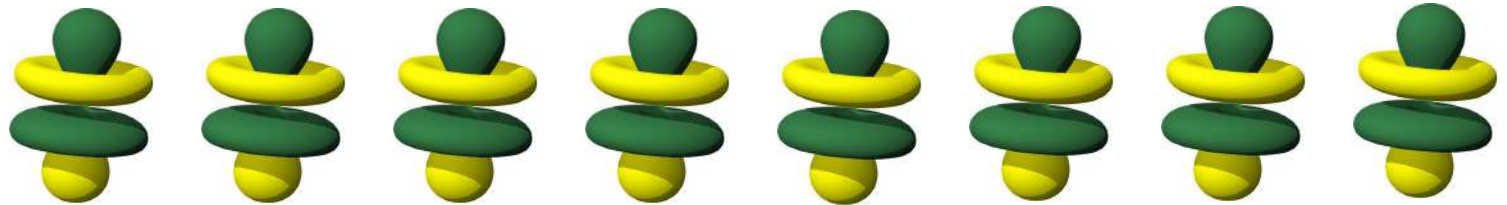


Quantum mechanics: electrons in solids

Atoms:



Orbitals:

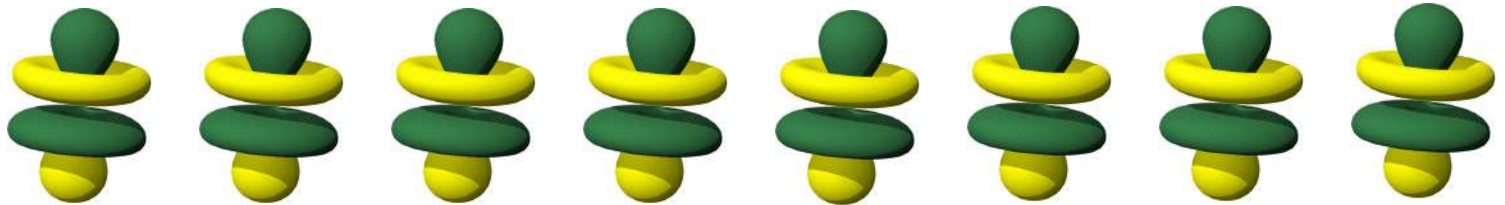


Quantum mechanics: electrons in solids

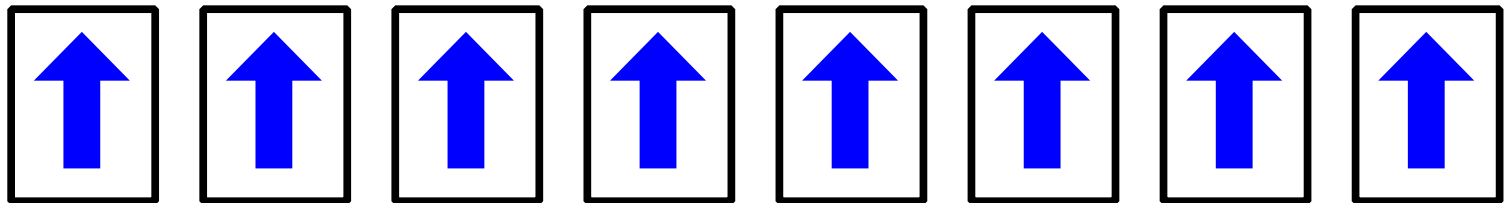
Atoms:



Orbitals:



Ferro:

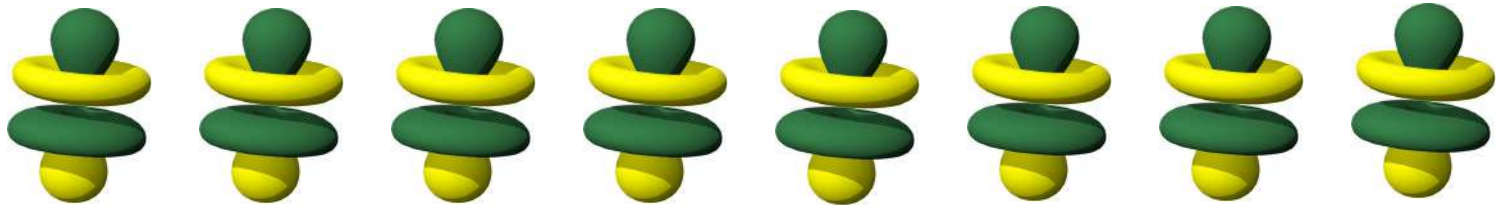


Quantum mechanics: electrons in solids

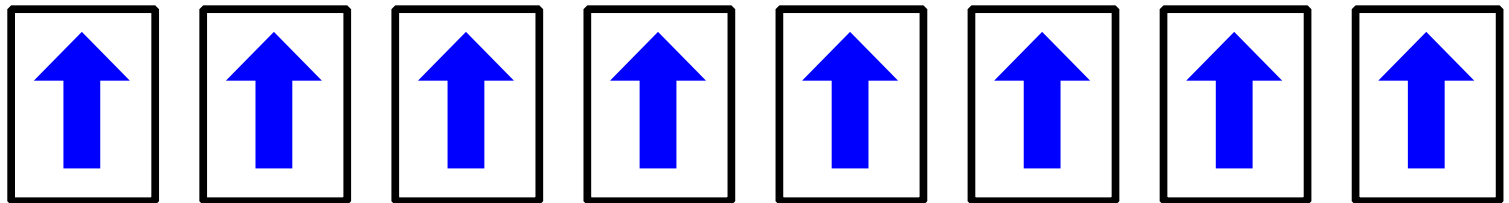
Atoms:



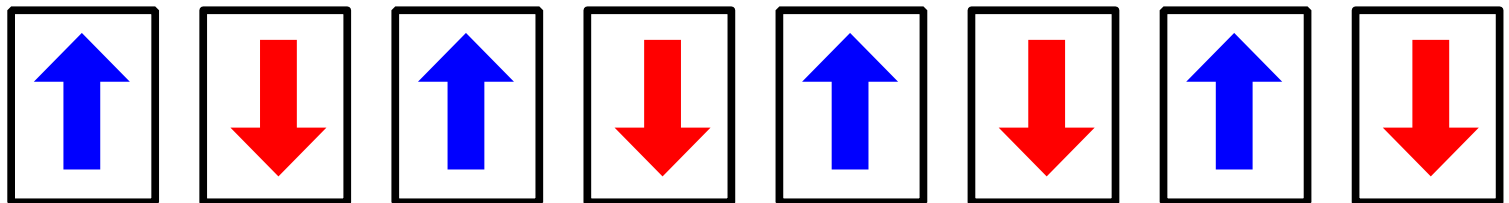
Orbitals:



Ferro:

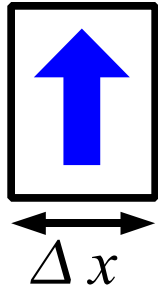


Antiferro:



Antiferromagnetic mechanism

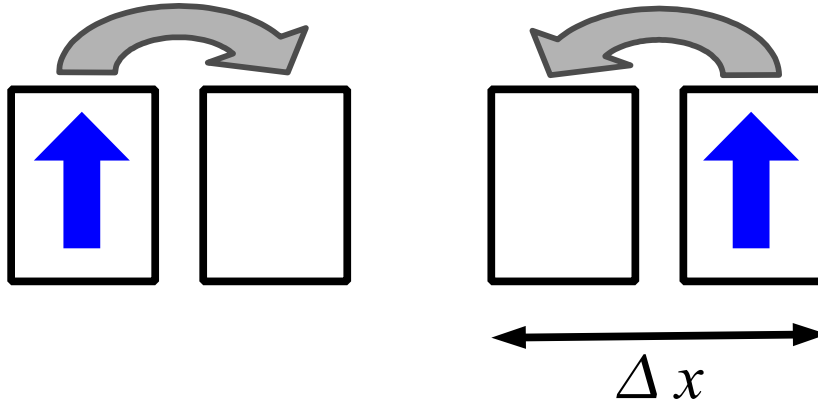
Heisenberg
uncertainty
principle



$$\Delta p \Delta x = \hbar$$
$$\Delta p = \hbar / \Delta x$$

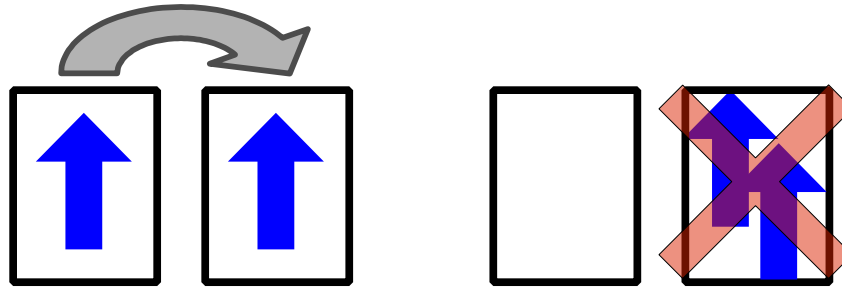
$$KE = \frac{\Delta p^2}{2m} = \frac{\hbar^2}{2m \Delta x^2}$$

Spreading
lowers
energy



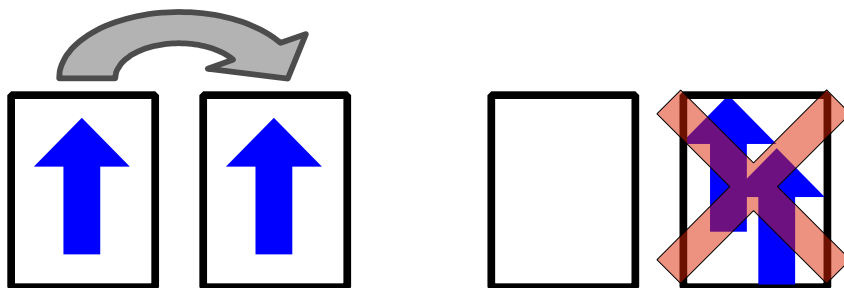
Antiferromagnetic mechanism

Pauli
blocked

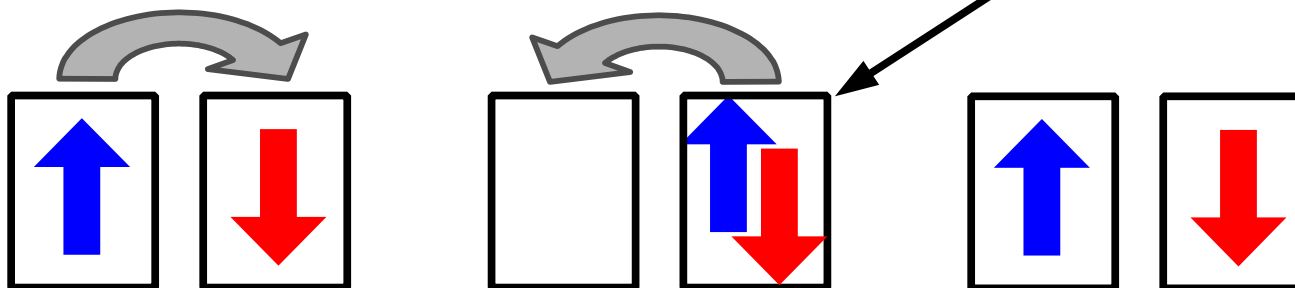


Antiferromagnetic mechanism

Pauli blocked

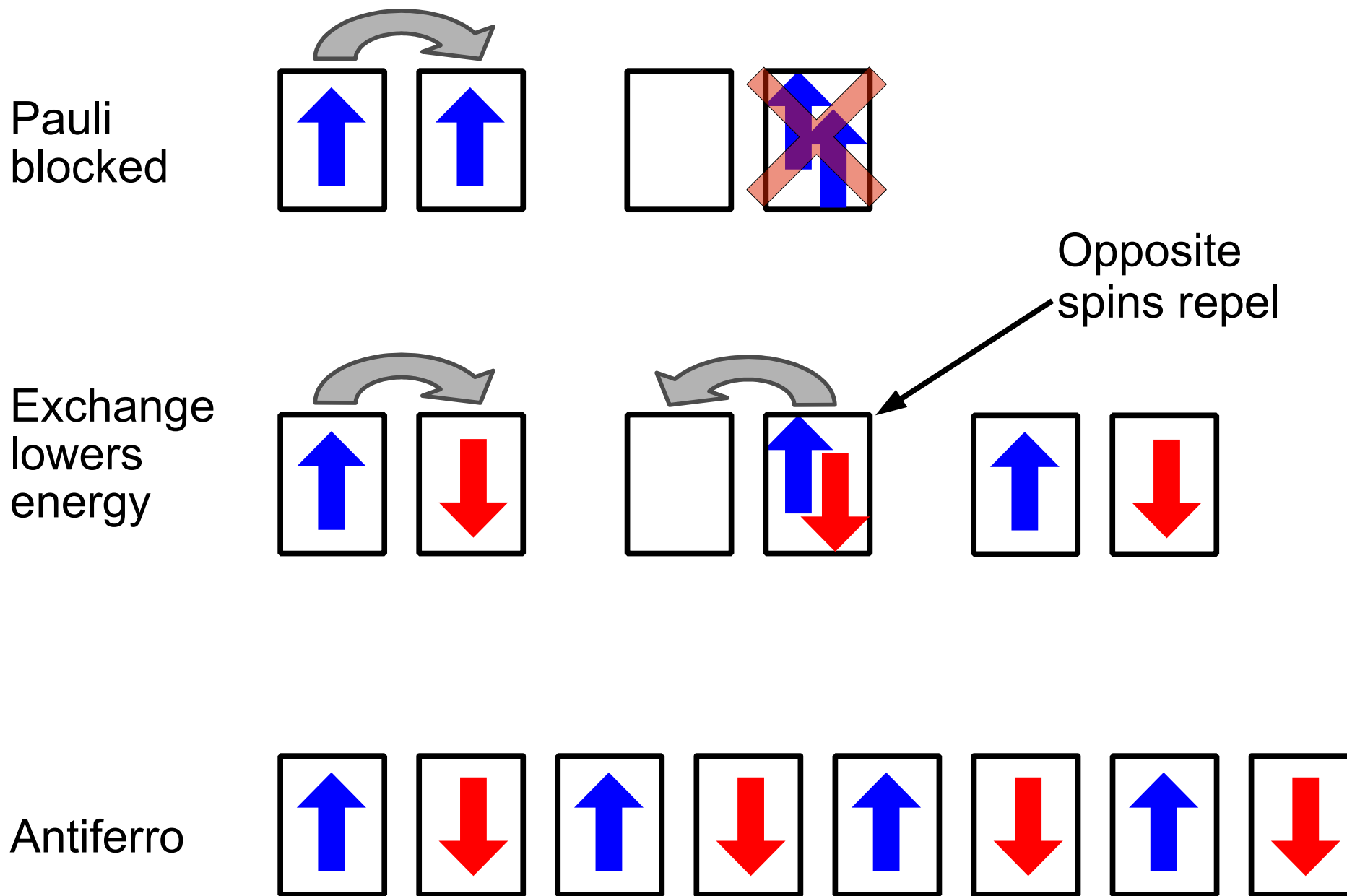


Exchange lowers energy



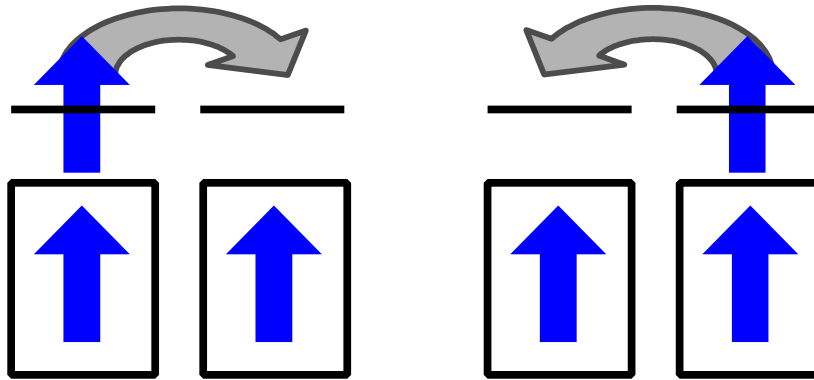
Opposite spins repel

Antiferromagnetic mechanism

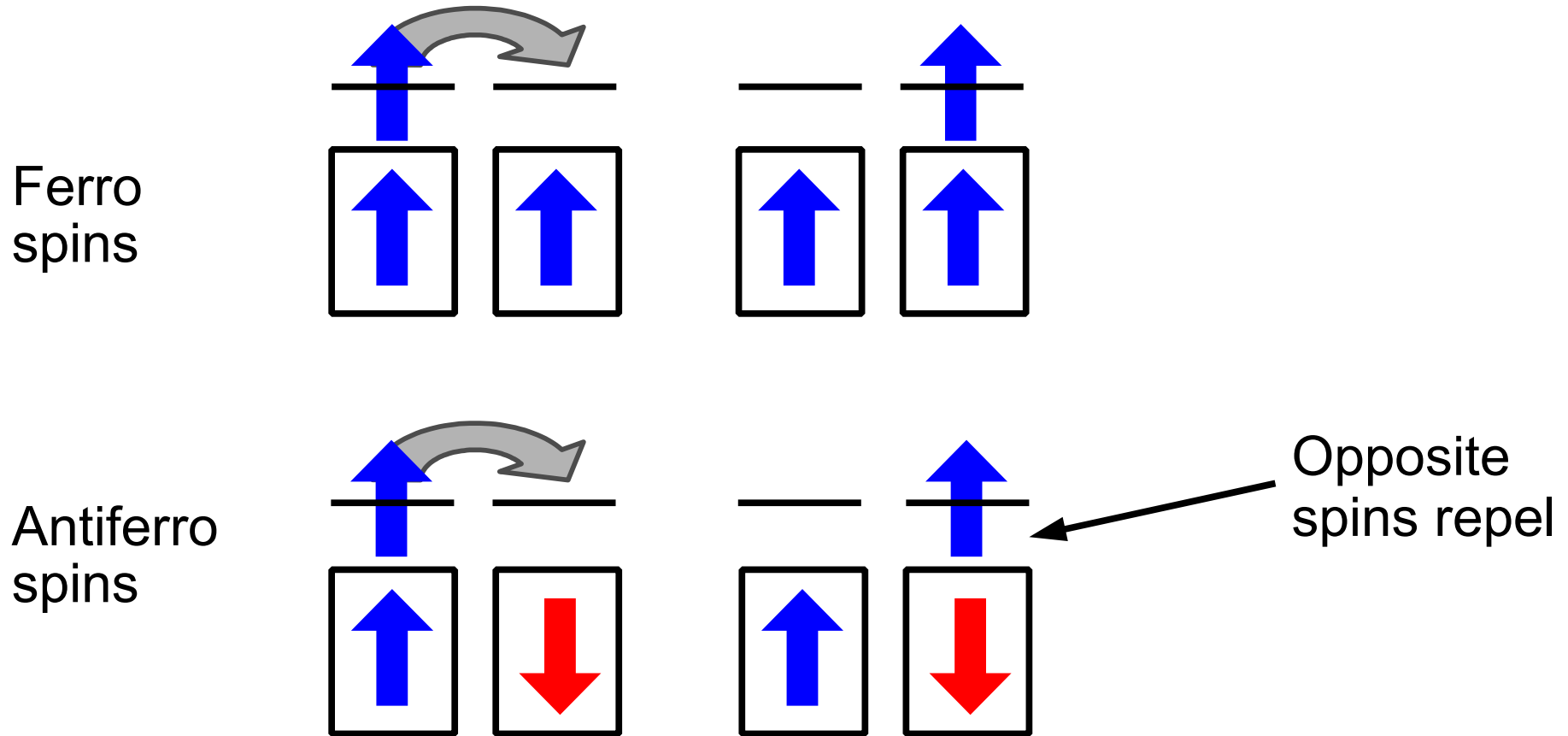


Ferromagnetism

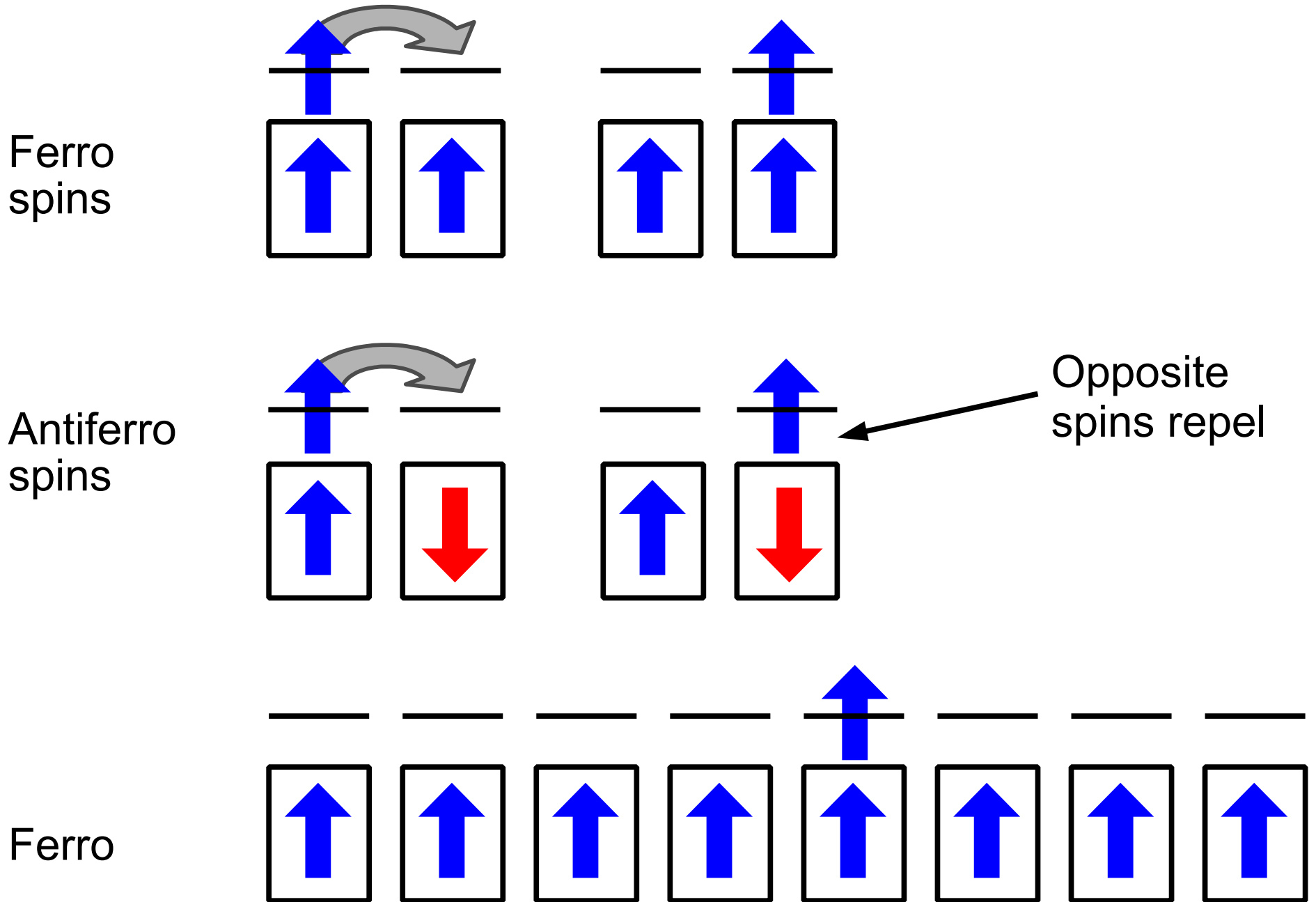
Ferro
spins



Ferromagnetism

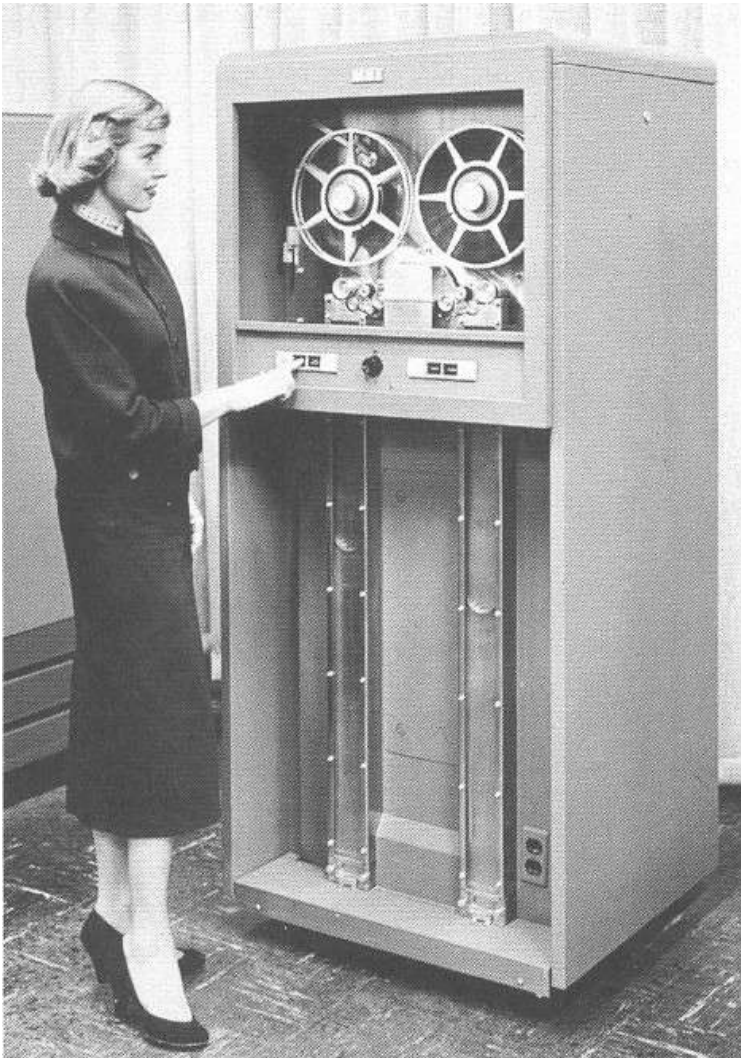


Ferromagnetism



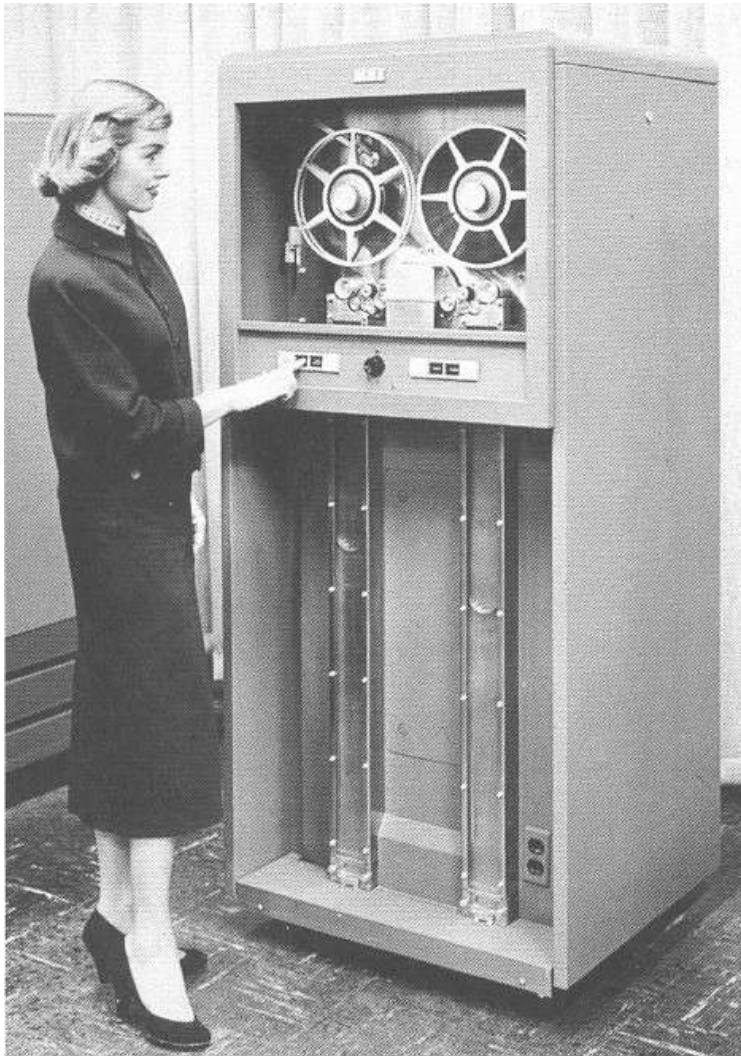
Magnetic data storage

10½-inch tape (1953) **5 MB**



Magnetic data storage

10½-inch tape (1953) **5 MB**



8-inch Floppy disk (1973) **250¼ kB**



Magnetic data storage

Cassette (1979) 660 KB



what are little girls really made of?

Nobody how she's right there ready to help when you're making cookies? She's even beginning to take an active interest in sewing and housework! And, would you believe, helping with the dishes? Well, it's not all pretend and playing make-believe. Your little girl is growing up before your very eyes. She wants to know how everything is done. So teach her all you can know. There are the years that'll help make her the kind of woman... housewife... mother, who'll soon become the sound heart with love and affection, fill the joy of a happy home and a normal family life. Make Dad one of her favorite books, make her little confidante and share her secrets. Take an interest in all her activities... school, friends, pretty soon first dates with real boys. And though her choice of music may seem strange to you, and the songs too loud, try to understand her preferences (after all, your parents weren't exactly wild about rock!) and play her a little of yours. This exchange can be a bridge of understanding for both of you. And this is where TDK can help a little. TDK's high-quality tape cassettes don't choose the music. But they capture and reproduce sound so faithfully that rock, 'n roll, country western, or classical, it's about time you're listening to the original performers. So although it may seem, TDK is proud of its contribution to a happier family life. From our inception, TDK has been dedicated to producing ever finer products, including the highest quality cassettes and magnetic tape. By raising the standards of sound reproduction, we believe we are helping young people the world over develop an appreciation for the good things in life. And as they progress, so do we.

the new dynamic world of



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Magnetic data storage

Cassette (1979) 660 KB



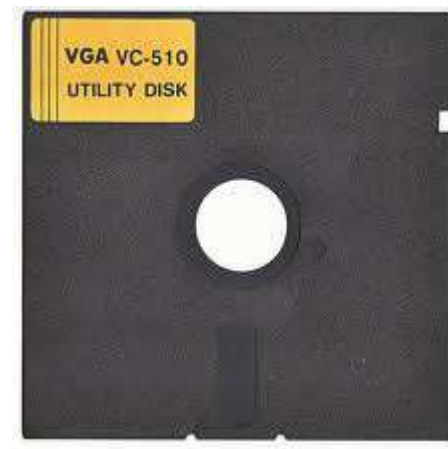
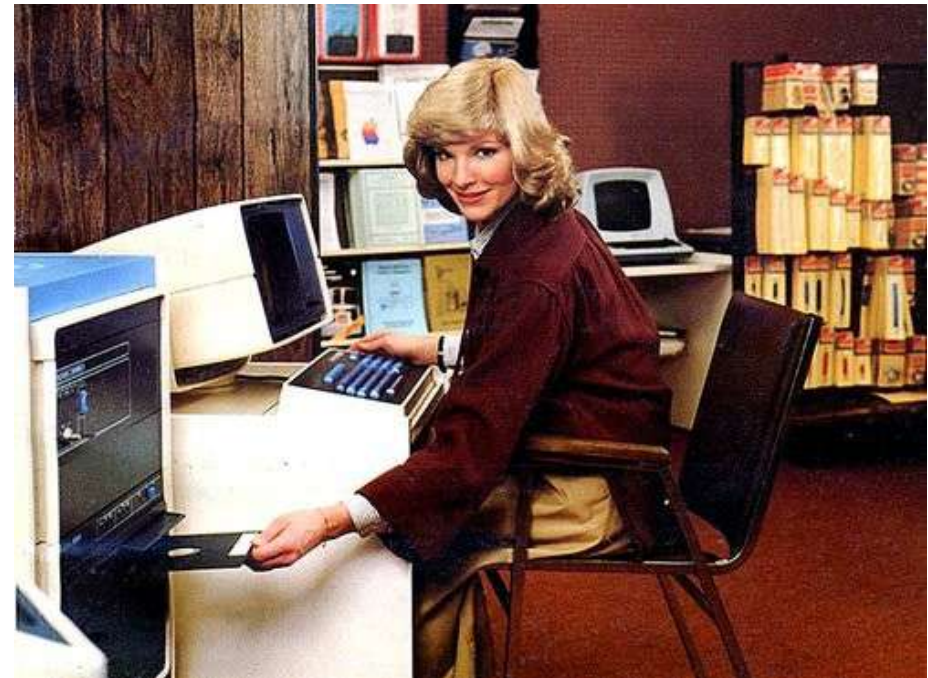
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5¼-inch Floppy disk (1983) 1200 KB



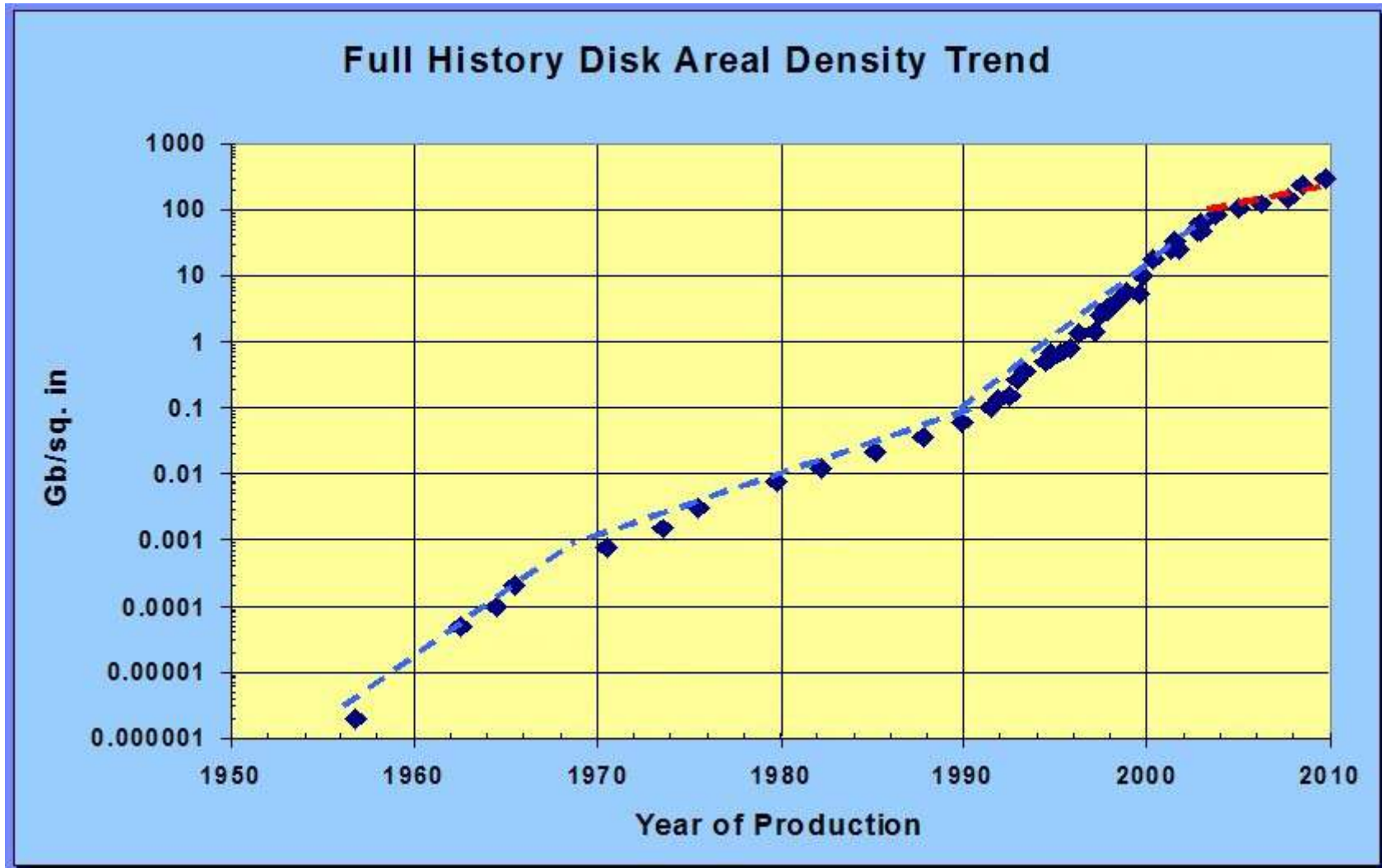
Magnetic data storage

3½-inch Floppy disk (1989) **1.44 MB**

Hard disk drive (2010) **2 TB**



Storage over the years



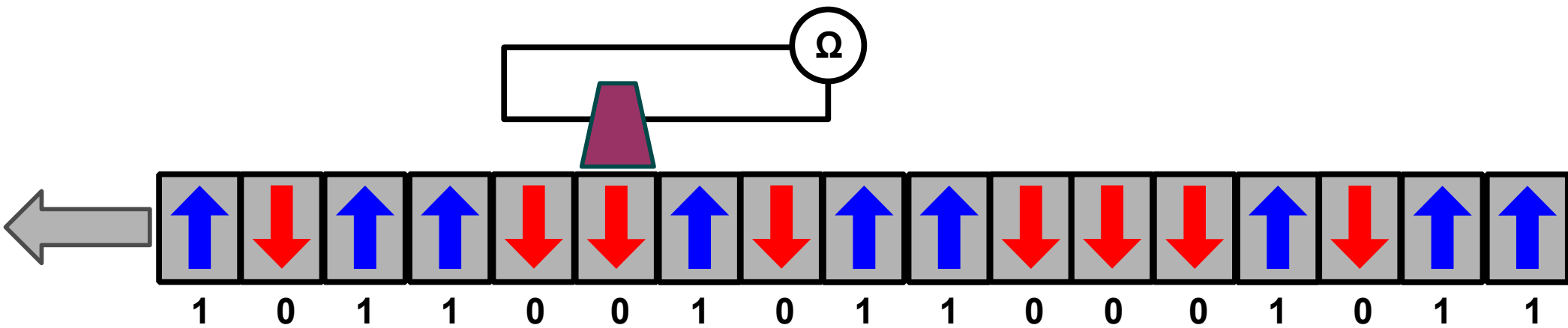
Giant-magnetoresistance (1988)



Albert Fert Peter Grünberg



Magnetic data storage



Magnetoresistance

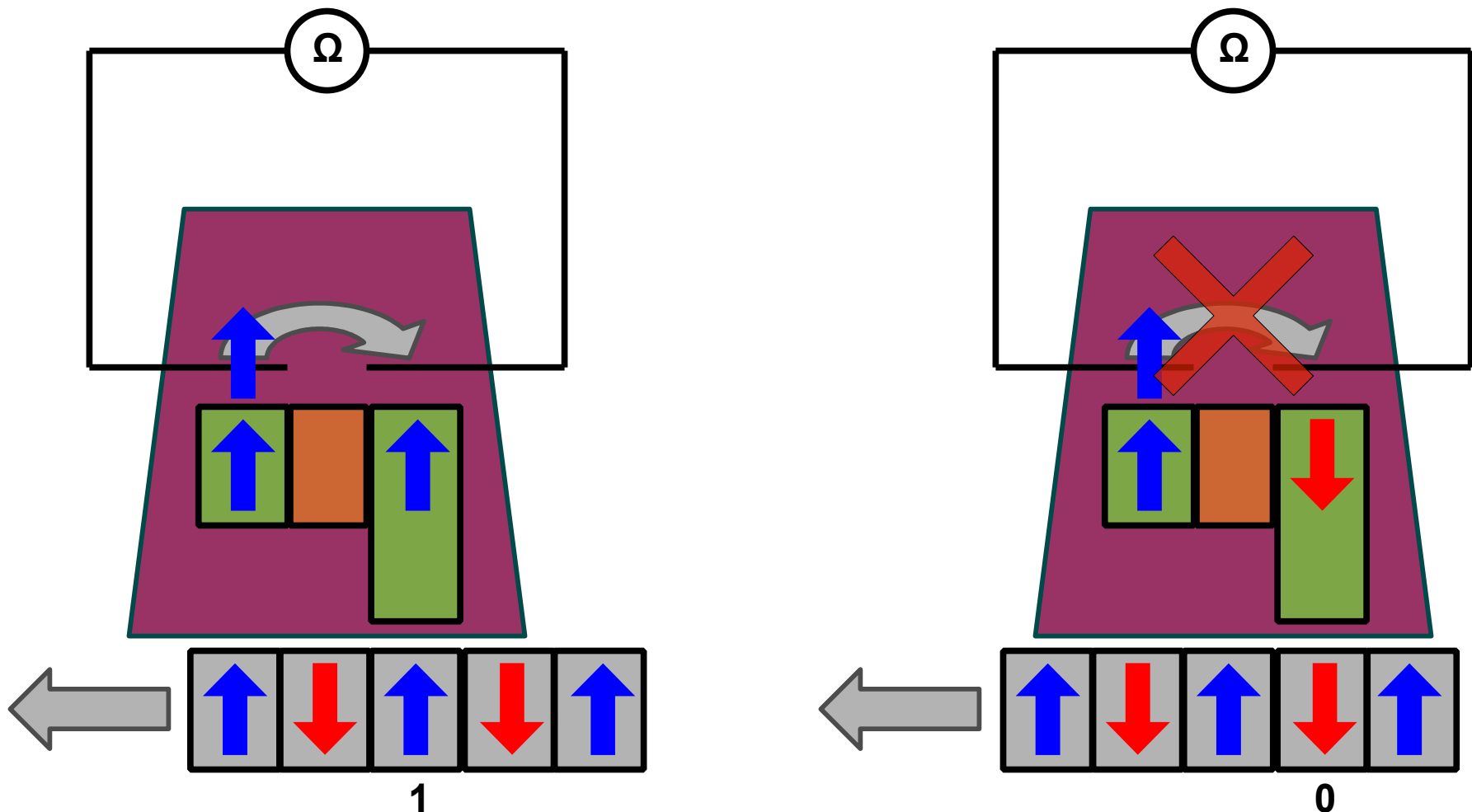
Carrier velocity due to fields

$$\mathbf{v} = M (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \qquad \mathbf{v} = \frac{M}{1 + (M B)^2} (\mathbf{E} + \mathbf{E} \times \mathbf{B})$$

which is reduced by 5% in typical metals so need large magnetic domains → low data density

Giant & colossal magnetoresistance

Change in resistance is up to 100000% so can have very small magnetic domains and high data storage density



Summary: *more is different*

- Particles obeying well understood microscopic physics display important collective motion – *more is different*
- Many-body interactions coupled with quantum mechanics leads to new counterintuitive phenomena
- Real-life applications:
 - Electronics
 - Material science
 - Chemistry

