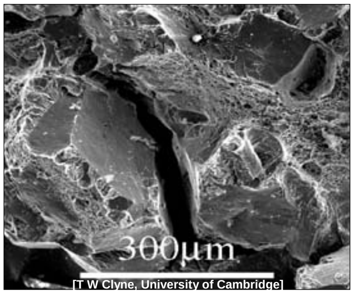
Class 7: Magnetic Hysteresis Loops



[T W Clyne, University of Cambridge]

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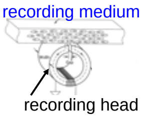
Reading and writing is done using a solenoid and a paramagnetic material.

A head flies over the hard disc. The head has separate, small read and write sensors on it.

Hard drive courtesy Martin Chen from International Business Machines Corporation.

Writing to the disc is done by magnetizing a recording head using a *solenoid*. The *paramagnetic material* inside sets up a field across the gap.



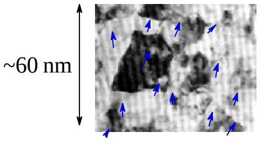
In reading, a field across the gap sets up a current in the solenoid.

Adapted from Fig. 20.18, *Callister 6e.* (Fig. 20.18 from J.U. Lemke, *MRS Bulletin*, Vol. XV, No. 3, p. 31, 1990.)

Magnetic data is stored on domains of ferromagnets

The magnetic field across the gap causes *ferromagnetic domains* in the disc to align.

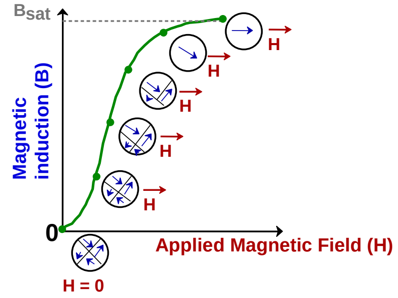
These domains are permanent magnets. They remained magnetized when the writing field is removed.



--Thin film: CoPtCr or CoCrTa alloy. Domains are ~ 10-30nm! (hard drive)

Adapted from Fig. 20.20(a), *Callister 6e*. (Fig. 20.20(a) from M.R. Kim, S. Guruswamy, and K.E. Johnson, *J. Appl. Phys.*, Vol. 74 (7), p. 4646, 1993.)

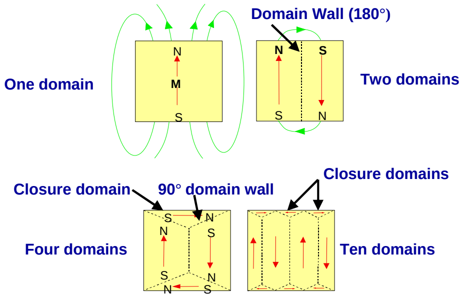
As H increases in ferro- and ferrimagnetic materials, the magnetic moment aligns with H and the induction increases



Domains with aligned magnetic moments grow at the expense of poorly aligned ones

[Callister, Fig. 20.13]

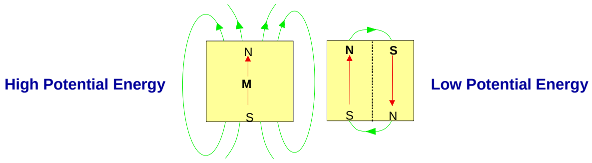
Magnetic domains are regions within the material where all the magnetic dipoles are aligned



[Electronic materials and Devices, S.O. Kasap]

Domains form to cancel out magnetic field lines in the surroundings, decreasing the potential energy

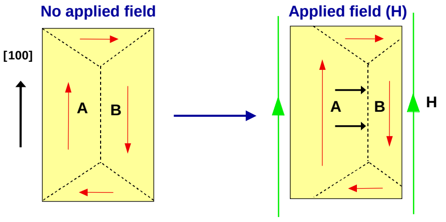
Field lines surrounding a magnetic material, just like an electric field, represent a potential energy (magnetostatic energy)



It is easier for the atoms to align in certain directions

For Fe [100] is an easy direction ,[111] is a hard one

Domains aligned with an applied field grow while domains not aligned with the applied field shrink



Domains A and B are the same size

Domain A, aligned with H, grows and domain B shrinks

The result of the applied field is a net magnetization

[Electronic materials and Devices, S.O. Kasap]

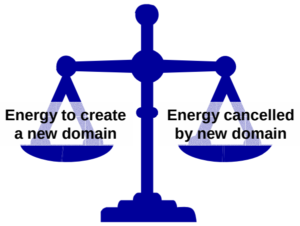
The energy needed to create a new domain is balanced by the energy that would be cancelled out

New domains reduce the potential energy of the magnetic field

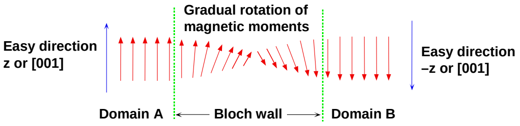
But energy is needed to create a new domain because domain walls are high energy states

Domain walls are high energy states because they do not align with the rest of the domains

When the energies are balanced, domain formation stops



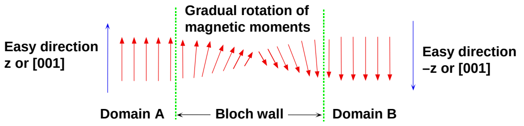
Atoms must misalign at the domain walls creating a high energy state



It may take several hundred atom spaces for the magnetic moments to gradually rotate 180° at the domain wall

[Electronic materials and Devices, S.O. Kasap]

The boundaries are many atoms wide and change gradually, reducing the high energy of domain walls



By rotating slowly, the exchange force between the atoms is minimized

But this rotation requires the atoms to be aligned along less than easy directions

Balance between these two competing forces determines the wall thickness and energy

When the energy increase of a new domain and the energy reduction of the magnetic field are balanced, formation of new domains stops

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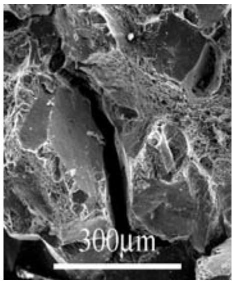
The atoms systematically align with the field but not necessarily in a smooth process



A dislocation in steel that could pin a domain wall

Domains in the direction of the field grow at the expense of other domains

The domain walls move through the material

Defects, dislocations, and impurities can temporarily pin domain walls

The magnetization (M) for an applied field depends on how easy it is to align the domains in that direction for that particular material

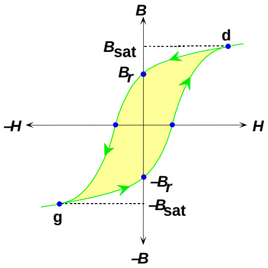
[T W Clyne, University of Cambridge]

Energy is lost in the magnetization of polycrystalline material causing hysteresis

An applied field aligns the domains inside the many grains of a polycrystalline material, just as in a single crystal material

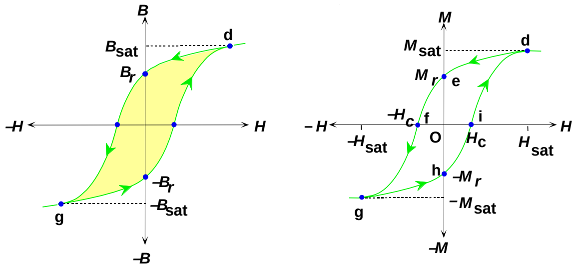
As the domain walls move through the lattice, energy is irreversibly lost

The lost energy of the process is called hysteresis



B vs. H
Hysteresis loop

Hysteresis loops can be plotted for *B* (applied magnetic field) or for *M* (magnetic field vector)



B* vs. *H

M* vs. *H

The area inside the hysteresis loop shows the energy loss per unit volume per cycle

[Electronic materials and Devices, S.O. Kasap]

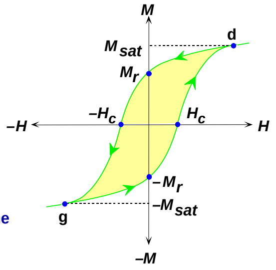
Hysteresis loops show the cycle of magnetization and demagnetization and the lost energy

Atoms align to an applied magnetic field, increasing the magnetization

The magnetization reaches a saturation point, M_{sat}

When the applied field is removed, a remnant magnetization, M_r, still remains

H_c (coercive field) is the magnetic field in the opposite direction required to remove this magnetization

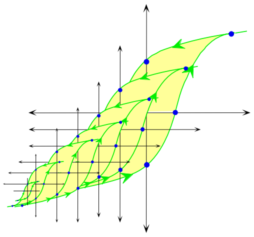


Hysteresis loops show the cycle of magnetization and demagnetization and the lost energy

Simply applying the coercive field (H_c), however, will not completely demagnetize the material

When the coercive field is removed, the magnetization goes to some non-zero value

To demagnetize, keep cycling through smaller and smaller hysteresis cycles



In conclusion, there is a permanent energy loss associated with magnetization called hysteresis

Depending on their alignment, domains grow and shrink in an applied field

When energy needed to create a new domain balances the magnetic field energy that would be cancelled out, domain formation stops

The movement of the domain walls through the lattice and through defects results in a energy loss called hysteresis