Course: **INGE 4001 Sec. 040, 080**

Title: Engineering Materials

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Final Grades

Final Grade Range	Final Letter Grade
90 - 100	A
80 - 89.9	B
70 - 79.9	C
60 - 69.9	D
0 - 59.9	F

Please refer to the Professor's Data Sheet in the "syllabus" section of the Web Page

Grades

- Quizzes: 15 pts.
- 1st Mid-term *Oct. 20, 7pm*: 25 pts.
- 2nd Mid-term *Nov. 19, 7pm*: 25 pts.
- Final Exam: 20 pts.
- Team Assignments: 15 pts.

NO make-up exams, NO exams "replaced".

Accept own responsibility for lack of time/energy/motivation etc. to study.

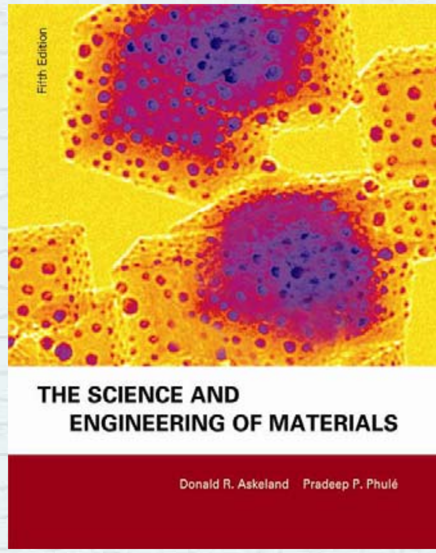
Textbook

The Science and Engineering of Materials

by

Donald R. Askeland and Pradeep P. Phulé

5th Edition



Setting-up Teams

- Team up with one or two friends.
- Select another couple to form a group with no more than 5.
- Name your group with the name of a chemical element.
- Share **all** contact information necessary among your group mates.

Working in Groups

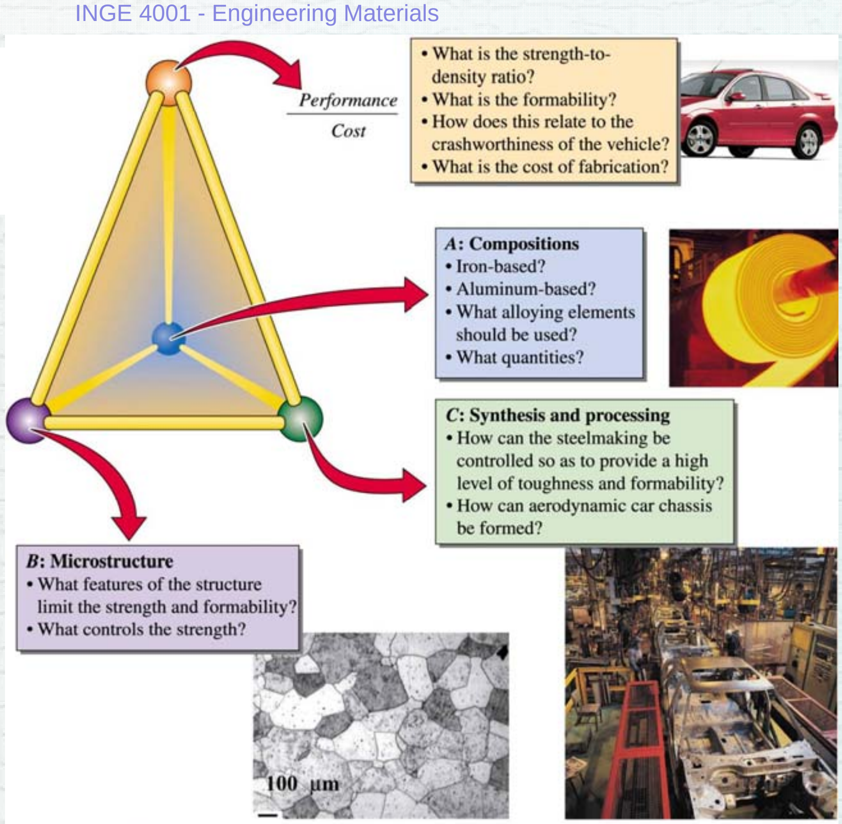
- Leadership responsibility should change for each team assignment.
- Living away from each other will be NO excuse for not completing an assignment in time.
- EVERYONE in each group is required to work on ALL assignments.
- **DO NOT** include in your report the names of those who did not participate!!

MATERIALS

- A definition?
- Types of materials based on constitution and properties:
  - Ceramics
  - Metallic
  - Polymeric
  - Composites
- New materials

Each part of an engineered product is made of a material with specific (by design) properties!!

This is the fundamental concept



The triangular base is needed in order to optimize the material performance in service

Materials Science and Engineering

Basic Knowledge of Materials → Applied Knowledge of Materials → Materials in Service

Science | Engineering

Table I. Median Annual Salaries for Engineers by Discipline (in Dollars)

Discipline	0	5	9–10	13–16	21–25	35+
	Number of Years after B.S.					
Aerospace Engineers	—	—	80,456	94,171	110,179	115,475
Computer Engineers	—	76,760	88,719	99,140	115,330	115,085
Chemical Engineers	—	—	65,802	84,531	96,366	106,749
Civil Engineers	51,827	59,674	67,457	75,920	83,737	90,963
Electrical Engineers	57,200	69,648	80,093	89,298	97,949	102,138
Environmental Engineers	—	—	77,981	82,456	97,433	103,641
General Engineers	—	72,978	88,576	91,982	92,566	95,151
Industrial Engineers	—	69,417	81,052	85,513	98,416	99,767
Materials Engineers	—	—	80,399	91,774	109,567	128,005
Mechanical Engineers	56,208	69,500	81,180	97,210	106,523	115,521
Nuclear Engineers	—	—	—	90,866	95,682	138,532

Salary survey (source *JOM*, Dec. 2008 p. 15)

Chemistry

Mathematics, Computer Sciences Biology

Materials Science and Engineering

Physics

Biomaterials
Nanotechnology
Smart Materials
Superconductors
Photonic materials, etc.

Some Interesting Links

- The best online Periodic Table: webelements.com
- The impact of Materials Engineering on Humankind http://materialmoments.org/
- Materials-related professional societies:
  - MRS www.mrs.org
  - ASM International www.asminternational.org
  - TMS www.tms.org
  - ACerS www.ceramics.org
  - AIST www.aist.org
  - ASTM www.astm.org
  - SAMPE www.sampe.org
  - And dozens more…

MATERIAL ADVANTAGE™ The Student Program for Materials Science and Engineering

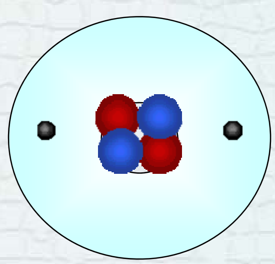
Material Advantage
www.materialadvantage.org
First student chapter in PR

MRS Materials Research Society
The Materials Gateway

First university chapter in PR formalized in Dec. 2008

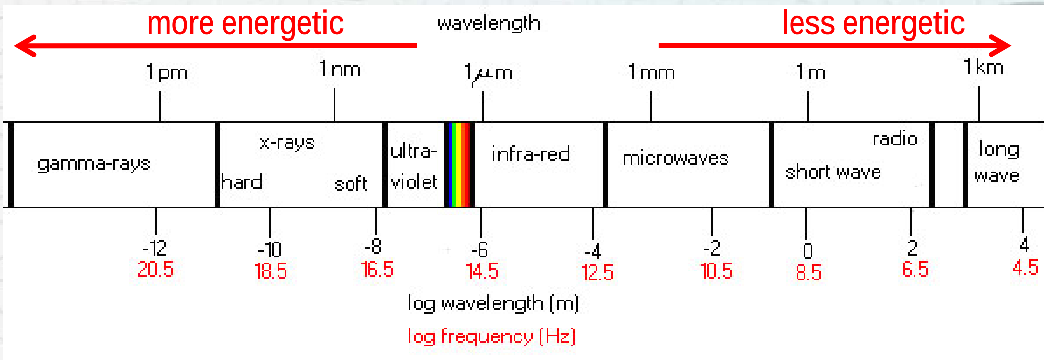
Chapter 2

Atom Structure and Bonds



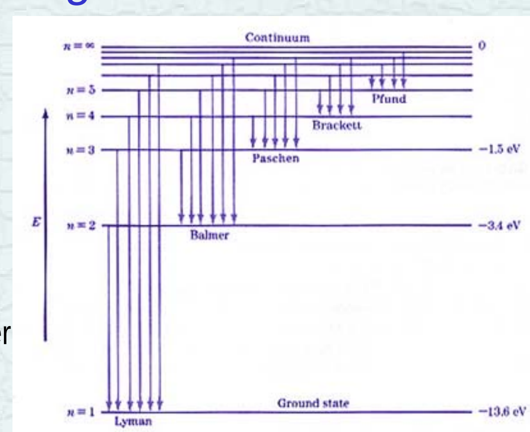
Before we start review basic Chemistry concepts

- atomic number, atomic (molecular) weight, gram-mol, moles
- Avogadro's number N_A
- electrons: as waves and particles
- Planck's Equation: $\Delta E = h\nu = h\, c/\lambda$
- the electromagnetic spectrum



Electrons in an atom are distributed according to the *Energy Level Diagram*

Note how the energy increases with the energy level. Also note how the energy differences between two consecutive levels vary.



This defines the quantum numbers:

n: principal quantum number

l : subsidiary (angular momentum) quantum number

m_l: magnetic quantum number

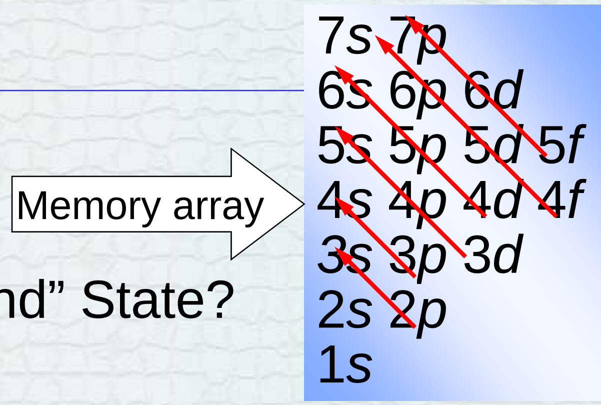
m_s: spin quantum number

Homework: Definition of each quantum number

- *n*: 1, 2, 3, 4, 5, 6…
- *l*: 0, 1, 2, 3, …*n*-1 labeled as: *s*, *p*, *d*, *f*
- m_l: 2*l* + 1 varies from -*l* through +*l*
- m_s: -½ and ½

General "filling" sequence of electron orbitals

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6 7s^2 5f^{14} 6d^{10} 7p^6$

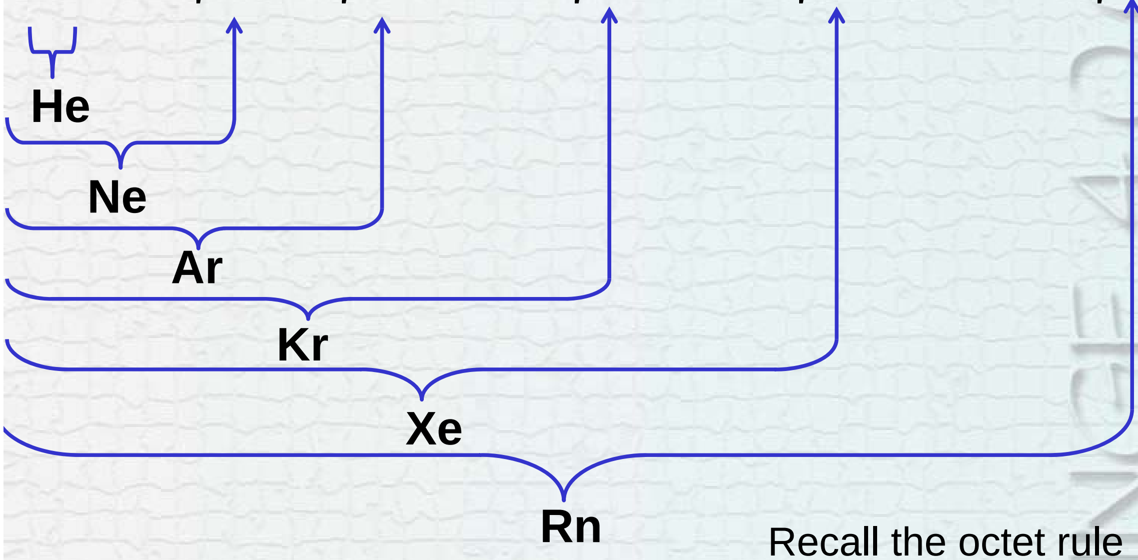


Meaning of "Ground" State?

Example:

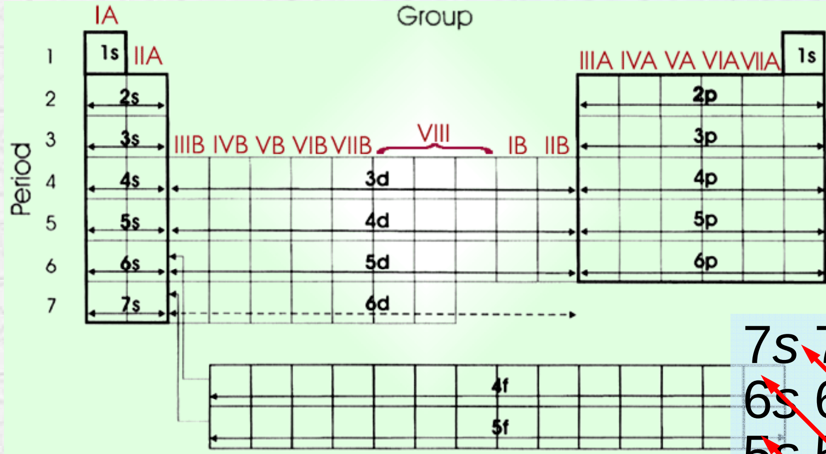
Fr (Z = 87)

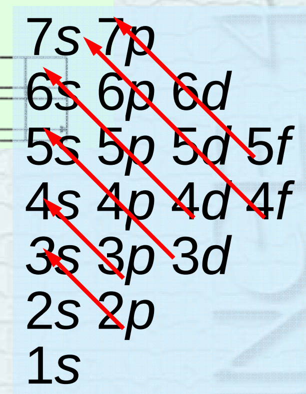
$1s^2\ 2s^2 2p^6\ 3s^2 3p^6\ 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6 7s$



Recall the octet rule

Valence (Outer Electron) Structure in the Periodic Table



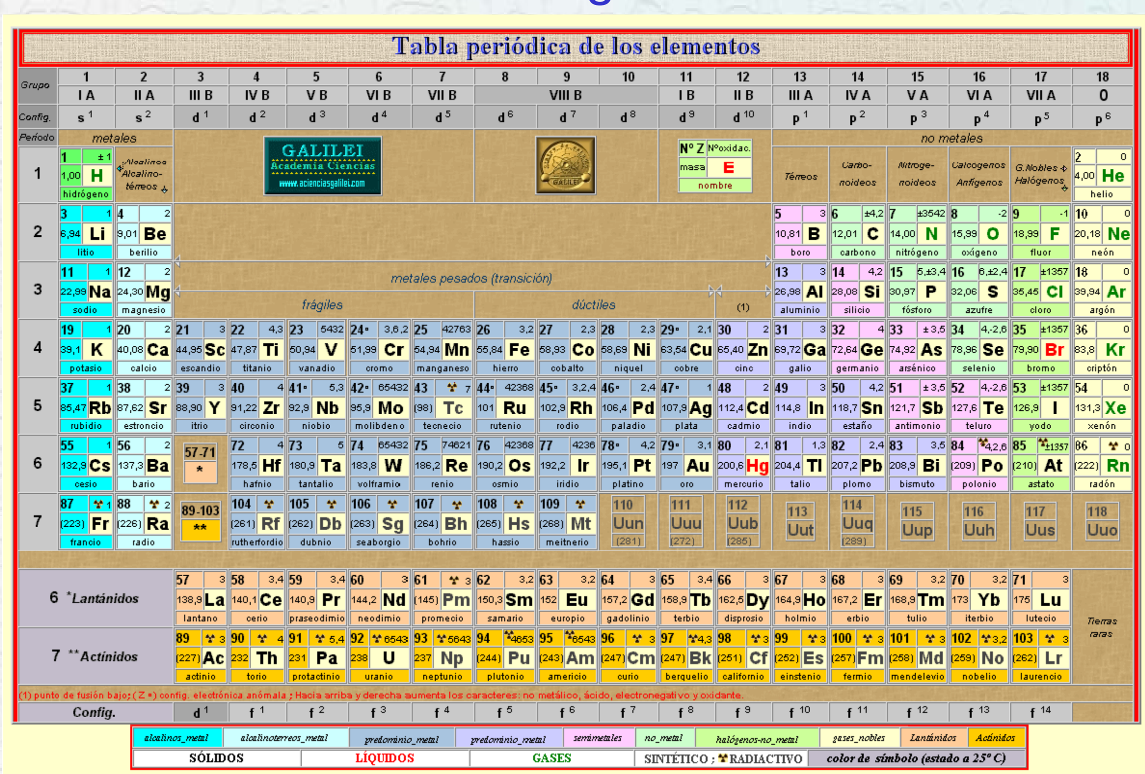


Example Ge (Z=32) in IVA group:

$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ $4s^2 4p^2$

Core electrons — Valence electrons

A more interesting Periodic Table



Electronic Configurations of the Elements

What's the problem with Cr?

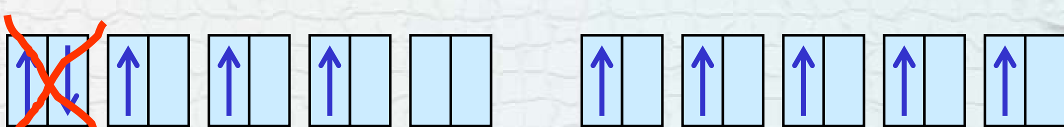
Electron Configurations of the Elements

Z	Element	Electron configuration	Z	Element	Electron configuration
1	H	$1s$	53	I	[Kr]$4d^{10}5s^25p^5$
2	He	$1s^2$	54	Xe	[Kr]$4d^{10}5s^25p^6$
3	Li	[He]$2s$	55	Cs	[Xe]$6s$
4	Be	[He]$2s^2$	56	Ba	[Xe]$6s^2$
5	B	[He]$2s^22p$	57	La	[Xe]$5d6s^2$
6	C	[He]$2s^22p^2$	58	Ce	[Xe]$4f5d6s^2$
7	N	[He]$2s^22p^3$	59	Pr	[Xe]$4f^26s^2$
8	O	[He]$2s^22p^4$	60	Nd	[Xe]$4f^46s^2$
9	F	[He]$2s^22p^5$	61	Pm	[Xe]$4f^56s^2$
10	Ne	[He]$2s^22p^6$	62	Sm	[Xe]$4f^66s^2$
11	Na	[Ne]$3s$	63	Eu	[Xe]$4f^76s^2$
12	Mg	[Ne]$3s^2$	64	Gd	[Xe]$4f^75d6s^2$
13	Al	[Ne]$3s^23p$	65	Tb	[Xe]$4f^96s^2$
14	Si	[Ne]$3s^23p^2$	66	Dy	[Xe]$4f^{10}6s^2$
15	P	[Ne]$3s^23p^3$	67	Ho	[Xe]$4f^{11}6s^2$
16	S	[Ne]$3s^23p^4$	68	Er	[Xe]$4f^{12}6s^2$
17	Cl	[Ne]$3s^23p^5$	69	Tm	[Xe]$4f^{13}6s^2$
18	Ar	[Ne]$3s^23p^6$	70	Yb	[Xe]$4f^{14}6s^2$
19	K	[Ar]$4s$	71	Lu	[Xe]$4f^{14}5d6s^2$
20	Ca	[Ar]$4s^2$	72	Hf	[Xe]$4f^{14}5d^26s^2$
21	Sc	[Ar]$3d4s^2$	73	Ta	[Xe]$4f^{14}5d^36s^2$
22	Ti	[Ar]$3d^24s^2$	74	W	[Xe]$4f^{14}5d^46s^2$
23	V	[Ar]$3d^34s^2$	75	Re	[Xe]$4f^{14}5d^56s^2$
24	Cr	[Ar]$3d^54s$	76	Os	[Xe]$4f^{14}5d^66s^2$
25	Mn	[Ar]$3d^54s^2$	77	Ir	[Xe]$4f^{14}5d^76s^2$
26	Fe	[Ar]$3d^64s^2$	78	Pt	[Xe]$4f^{14}5d^96s$
27	Co	[Ar]$3d^74s^2$	79	Au	[Xe]$4f^{14}5d^{10}6s$
28	Ni	[Ar]$3d^84s^2$	80	Hg	[Xe]$4f^{14}5d^{10}6s^2$
29	Cu	[Ar]$3d^{10}4s$	81	Tl	[Xe]$4f^{14}5d^{10}6s^26p$
30	Zn	[Ar]$3d^{10}4s^2$	82	Pb	[Xe]$4f^{14}5d^{10}6s^26p^2$
31	Ga	[Ar]$3d^{10}4s^24p$	83	Bi	[Xe]$4f^{14}5d^{10}6s^26p^3$
32	Ge	[Ar]$3d1^{10}4s^24p^2$	84	Po	[Xe]$4f1^{14}5d^{10}6s^26p^4$
33	As	[Ar]$3d^{10}4s^24p^3$	85	At	[Xe]$4f^{14}5d^{10}6s^26p^5$
34	Se	[Ar]$3d^{10}4s^24p^4$	86	Rn	[Xe]$4f^{14}5d^{10}6s^26p^6$
35	Br	[Ar]$3d^{10}4s^24p^5$	87	Fr	[Rn]$7s$
36	Kr	[Ar]$3d^{10}4s^24p^6$	88	Ra	[Rn]$7s^2$
37	Rb	[Kr]$5s$	89	Ac	[Rn]$6d7s^2$
38	Sr	[Kr]$5s^2$	90	Th	[Rn]$6d^27s^2$
39	Y	[Kr]$4d5s^2$	91	Pa	[Rn]$5f^26d7s^2$
40	Zr	[Kr]$4d^25s^2$	92	U	[Rn]$5f^36d7s^2$
41	Nb	[Kr]$4d^45s$	93	Np	[Rn]$5f^46d7s^2$
42	Mo	[Kr]$4d^55s$	94	Pu	[Rn]$5f^67s^2$
43	Tc	[Kr]$4d^55s^2$	95	Am	[Rn]$5f^77s^2$
44	Ru	[Kr]$4d^75s$	96	Cm	[Rn]$5f^76d7s^2$
45	Rh	[Kr]$4d^85s$	97	Bk	[Rn]$5f^97s^2$
46	Pd	[Kr]$4d^{10}$	98	Cf	[Rn]$5f^{10}7s^2$
47	Ag	[Kr]$4d^{10}5s$	99	Es	[Rn]$5f^{11}7s^2$
48	Cd	[Kr]$4d^{10}5s^2$	100	Fm	[Rn]$5f^{12}7s^2$
49	In	[Kr]$4d^{10}5s^25p$	101	Md	[Rn]$5f^{13}7s^2$
50	Sn	[Kr]$4d^{10}5s^25p^2$	102	No	[Rn]$5f^{14}7s^2$
51	Sb	[Kr]$4d^{10}5s^25p^3$	103	Lr	[Rn]$5f^{14}6d7s^2$
52	Te	[Kr]$4d^{10}5s^25p^4$			

One more word on orbitals and electronic configuration

Remember: The first three quantum numbers define an orbital. The fourth quantum number m_s defines the suborbital where an electron is located.

Suborbitals are "filled" as follows:



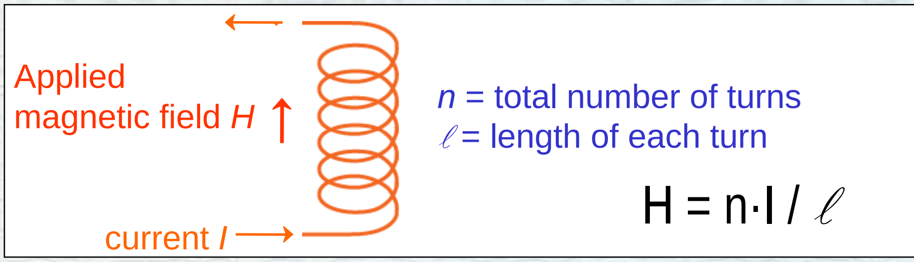
Incorrect arrangement of electrons in *d*-orbitals

Correct arrangement of electrons in *d*-orbitals

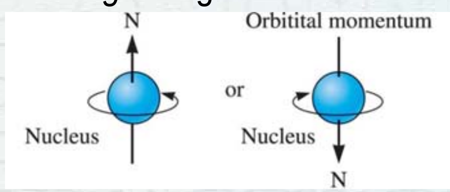
Hunds rule: Before an orbital will have two electrons, all orbitals of that energy level will have one electron. The second electron will have spin that is opposite of the first.

Let's have a brief introduction to magnetism and magnetic materials. Pages 726-737

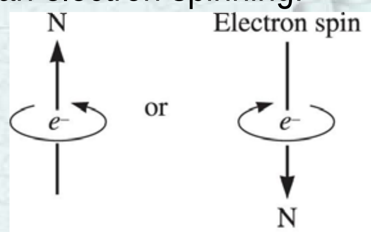
Basic: Magnetic fields are formed as a result of moving electrical charges.



The simplest *circulating* charge is the electron around the nucleus in a hydrogen atom



or an electron spinning:



Both contribute to one atom's magnetic moment

The arrangement of (anti)spins imposed by the electronic configuration, Pauli's exclusion principle and Hind's rule govern the magnetic properties of elements

- Inspect the Periodic Table: transition metals, lanthanides, and actinides
- Partially filled *nd and nf* orbitals!
- How those spins interact in a crystal (with zillion atoms) defines the observed magnetic behavior when an external field *H* is applied

TABLE 20-1 *The electron spins in the 3d energy level in transition metals, with arrows indicating the direction of spin*

Metal	3d					4s
Sc	↑					↑↓
Ti	↑	↑				↑↓
V	↑	↑	↑			↑↓
Cr	↑	↑	↑	↑	↑	↑
Mn	↑	↑	↑	↑	↑	↑↓
Fe	↑↓	↑	↑	↑	↑	↑↓
Co	↑↓	↑↓	↑	↑	↑	↑↓
Ni	↑↓	↑↓	↑↓	↑	↑	↑↓
Cu	↑↓	↑↓	↑↓	↑↓	↑↓	↑

Parallel spins don't necessary indicate "collaborative" magnetic moments, e. g. Cr (an *antiferromagnetic* element)

Externally Applied Field and Material Response

B magnetic inductance (flux density) *induced* by *H* in vacuum is:

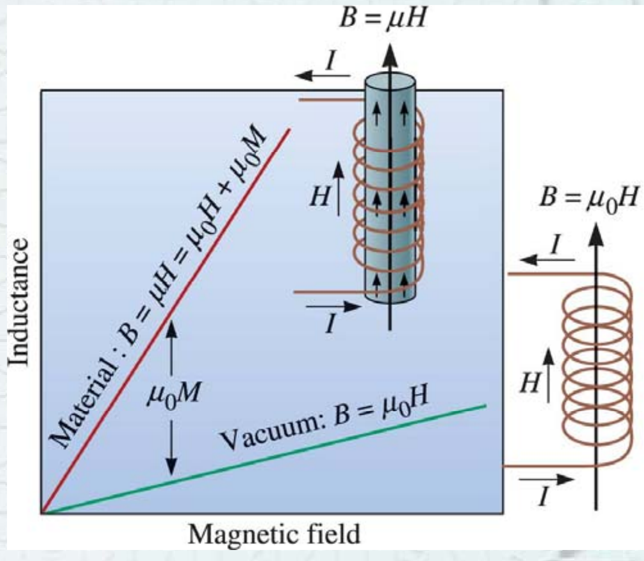
$B_0 = \mu_0 H$

In a material: $B = \mu H$

The magnification (or not) of the field induced is calculated as:

$B = \mu_0 H + \mu_0 M = \mu H$

How permeability μ relates to μ_0 defines the type of material



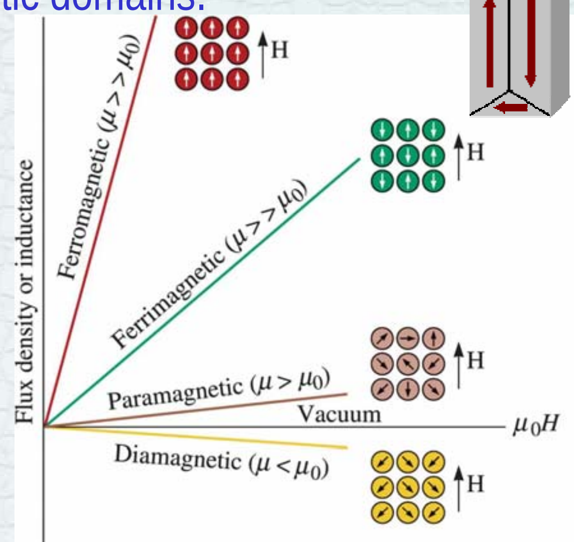
Classification of materials in terms of their magnetic response (behavior) and the effect of magnetic domains.

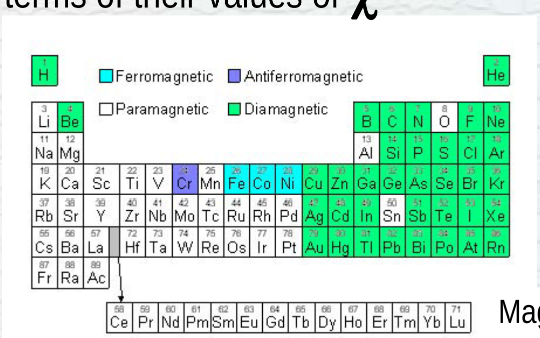
Note the orientation of the magnetic moments in each material

Magnetic susceptibility is

$$\chi = \frac{\mu}{\mu_0} - 1$$

<u>Homework:</u> Classify the materials in terms of their values of **χ**

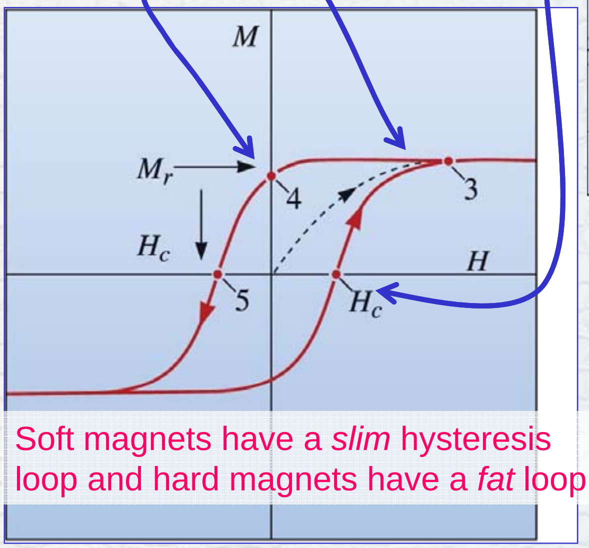




Magnetic behavior of the elements at room temperature

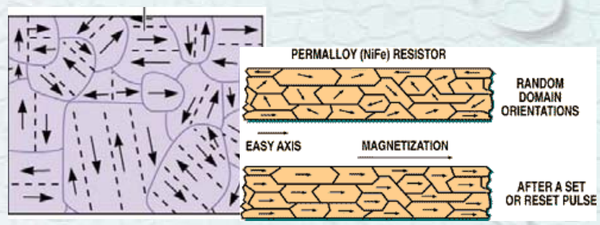
Magnetization behavior

Hysteretical behavior, with a saturation level (M_s), a residual magnetization (remanescence M_r), a coercivity H_c.

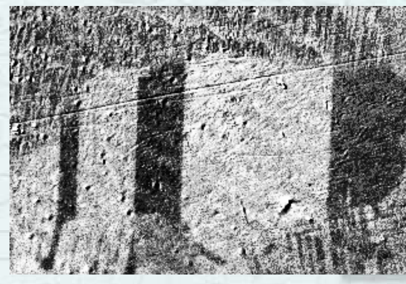


Soft magnets have a *slim* hysteresis loop and hard magnets have a *fat* loop.

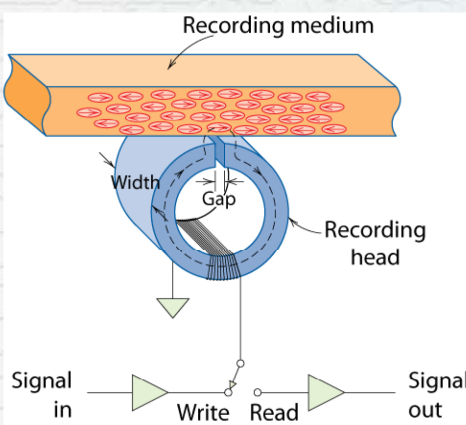
Upon initial magnetization these magnetic domains start aligning (parallel) until saturation



Domains can be imaged. This image shows the magnetization process of a steel grain

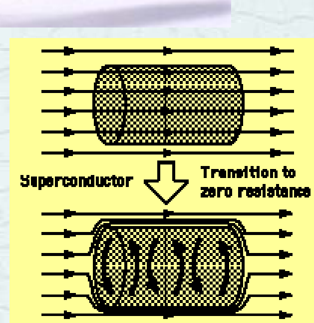


Some uses of materials with specific magnetic properties



Magnetic data storage

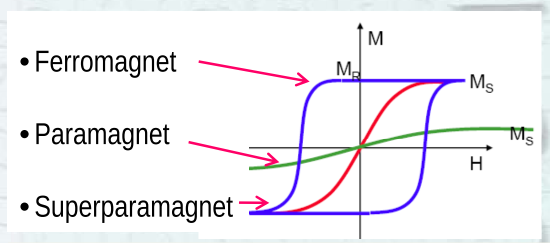
Note that magnetic data recording is longitudinal in nature.

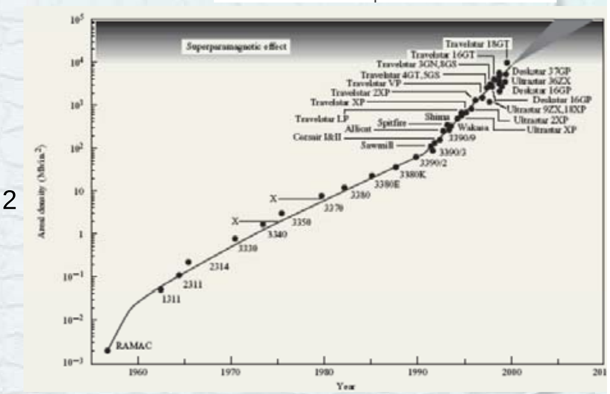


Magnet levitation in superconductors

One word on superparamagnetism

- If domains are too small (nanosized), in ferromagnets or ferrimagnets, they can *flip* their magnetic moments with just thermal oscillations
- Superparamagnets can retain high M_S but with no coercivity.
- There is a limitation on the recording density in current magnetic media: 0.15 $Gbit/mm^2$
- Modern challenge: can we increase it?





- Investigate what the Néel-Arrhenius law is.