

Materials Science Data

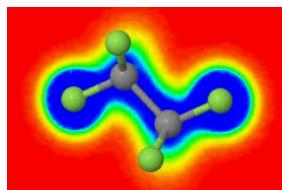
July 30, 2017

- What is materials science ---- the challenge of spanning length scales
- Where do we start --- the periodic table
- Categories of material properties --- what are the relevant descriptors
- How do we measure these properties
- Why are these properties important

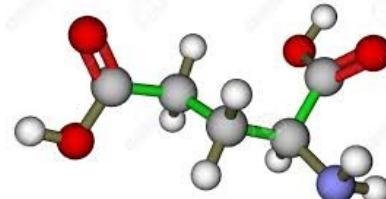
- Materials Science : describes how characteristics at different length scales
- From picometer (1 / 1,000,000,000 meters) to larger than meters
- Relate to properties..... We will discuss some of these relevant properties here
- Includes materials as diverse as electronics, ceramics, metals, rubbers, etc.)

Length Scales

Electron

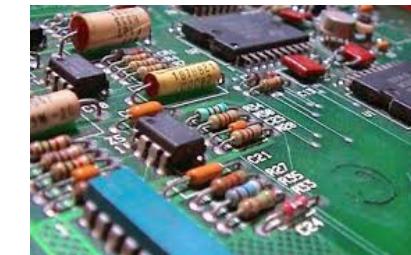
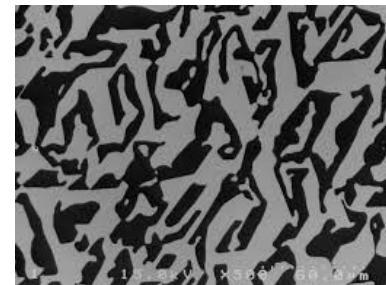
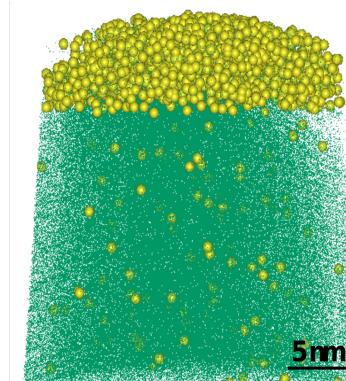


Atom



Molecule

Microstructu
re



Device



Structure



The question materials science asks is : how does a change at the electronic or atomic level impact the property of the final material ?

Where to Begin

Periodic Table of the Elements																		
1 H Hydrogen 1.008																	18 He Helium 4.003	
3 Li Lithium 6.941	4 Be Beryllium 9.012																	
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3	4	5	6	7	8	9	10	11	12	13 B Boron 10.811	14 C Carbon 12.011	15 N Nitrogen 14.007	16 O Oxygen 15.999	17 F Fluorine 18.998	10 Ne Neon 20.180	
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.966	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948	
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Paladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018	
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [263]	107 Bh Bohrium [264]	108 Hs Hassium [265]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown	
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Alkali Metal Alkaline Earth Transition Metal Basic Metal Semimetal Nonmetal Halogen Noble Gas Lanthanide Actinide																		

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The periodic table defines the number of electrons for each element

The Periodic Table as a Data Table

Symbol	Atomic Number	Atomic Weight	Atomic Radius	Covalent Radius	Valence Electrons	Density	Electronegativity	Melting Point	Boiling Point	Toxic	Heat Capacity	Specific Heat
H	1	1.00794	0.78	0.3	1	8.99E-05	2.2	14.01	20.28	FALSE	28.836	14.304
He	2	4.00260	2	1.28	0.93	0.000179		0.95	4.216	FALSE	20.786	5.193
Li	3	6.941	1.52	1.23	1	0.534	0.98	453.69	1620	FALSE	24.86	3.6
Be	4	9.01218	2	1.13	0.89	2	1.8477	1.57	1551	3243	TRUE	16.443
B	5	10.811	0.83	0.88	3	2.34	2.04	2573	3931	FALSE	11.087	1.02
C	6	12.011		0.77	4	3.513	2.55	3820		FALSE		0.71
N	7	14.0067	4	0.71	0.75	0.001251		63.29	77.4	FALSE	29.124	1.04
O	8	15.9994		0.66	6	0.001429	3.44	54.8	90.188	FALSE	29.378	0.92
F	9	18.9984	0.709	0.58	7	0.001696	3.98	53.53	85.01	FALSE	31.304	0.82
Ne	10	20.1797		0.71	8	0.0009		24.48	27.1	FALSE	20.786	0.904
Na	11	22.9897	7	1.54	1.54	1	0.971	0.93	370.96	1156.1	FALSE	28.23
Mg	12	24.305	1.6	1.36	2	1.738	1.31	922	1363	FALSE	24.869	1.02
Al	13	26.9815	4	1.43	1.25	3	2.698	1.61	933.52	2740	FALSE	24.2
Si	14	28.0855	1.17	1.11	4	2.329	1.9	1683	2628	FALSE	19.789	0.71
P	15	30.9737	5	1.04	5	0.000153	2.58	307.3	553.8	FALSE	23.824	0.77
S	16	32.066	1.04	1.04	6	1.07	2.58	386.7	717.824	FALSE	22.75	0.71

Combines qualitative (ie True/False) data as well as quantitative data, with a wide range of values and scales.

Assessing the Properties of the Elements

	Average Value	Standard Deviation
Atomic Number	56.00	32.19
Atomic Weight	136.80	83.59
Atomic Radius	1.58	0.38
Covalent Radius	1.37	0.35
Valence Electrons	4.99	2.90
Density	8.09	6.93
Electronegativity	1.72	0.63
Melting Point	1280.91	907.94
Boiling Point	2518.12	1629.34
Heat Capacity	26.03	3.77
Specific Heat	0.60	1.59
Heat of Fusion	12582.36	10731.84
Heat of Vaporization	258257.38	213142.15
Thermal Conductivity	0.62	1.19
Electrical Conductivity	0.09	0.12
First Ionization Potential	7.94	3.35
Bulk Modulus	91.93	108.84
Shear Modulus	0.52	0.71
Price	60387.95	447439.30

Some data is on the scale of 10^{-2} while other data is on the scale of 10^5

Considering range of standard deviations

--- For heat capacity, the standard deviation is only 14% of the average value
- small fluctuation in value across the periodic table.

--- For price, the standard deviation is 700% the average

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Alkali Metal Alkaline Earth Transition Metal Basic Metal Semimetal Nonmetal Halogen Noble Gas Lanthanide Actinide

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Increasing
number
of
electron
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The periodic table defines the number of electrons for each element

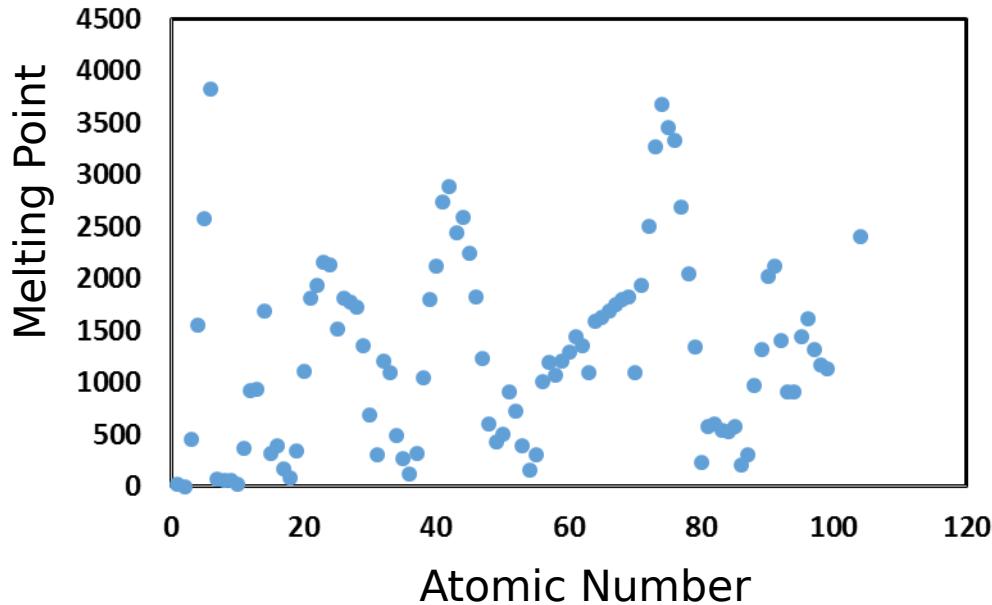
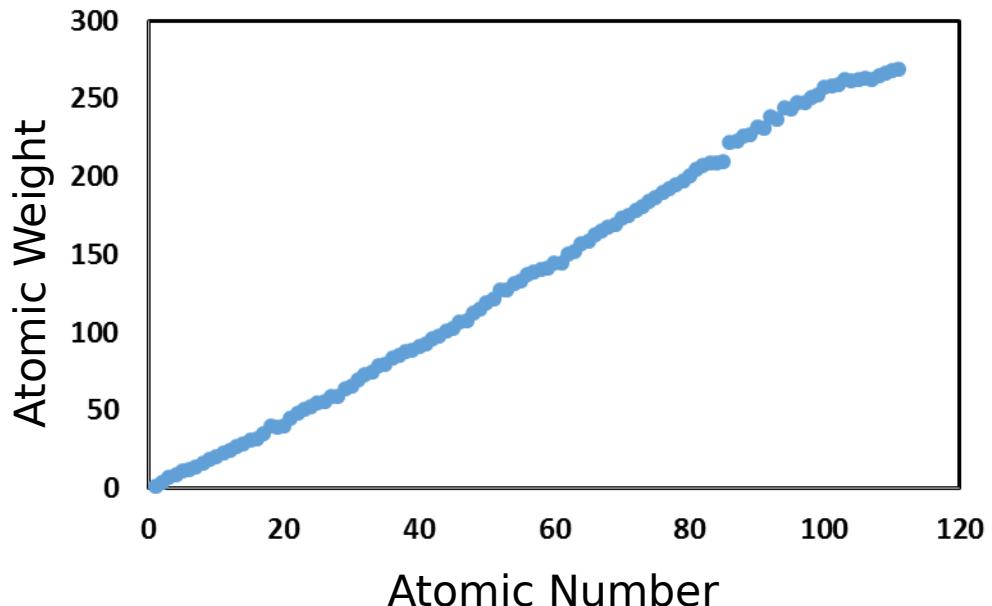
The Periodic Table -- toxicity

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How to use the periodic table for design : Binary description of elements :

- This figure : is the element toxic : yes / no --- blue boxes are for yes
- **no obvious pattern**

The Periodic Table



The Periodic Table of the Elements, showing the arrangement of elements based on atomic number. The table includes element names, atomic numbers, and atomic weights. The elements are color-coded into groups:

- Alkaline Metal:** Li, Na, K, Rb, Cs, Fr
- Alkaline Earth:** Be, Mg, Ca, Sr, Ba, Ra
- Transition Metal:** Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr, Hg, Tl, Pb, Bi, Po, At, Uut, Uup, Uuo
- Basic Metal:** Be, Mg, Al, Si, P, S, Cl, Ar, At, Uuo
- Semimetal:** Ge, As, Sb, Te, Po
- Nonmetal:** N, O, F, Ne, Cl, Br, Kr, At, Uuo
- Halogen:** F, Cl, Br, I, At
- Noble Gas:** He, Ne, Ar, Kr, Xe, Rn, Uuo
- Lanthanide:** La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu
- Actinide:** Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr

In some cases, the trends reflected in the periodic table are clear ; other times they are not obvious

-- atomic weight increases as we move along the table ; the temperature at which the element melts does not follow a clear pattern

Example Properties / Categories from the Periodic Table

Thermal Properties	Size Properties	Electronic Properties	Engineering Property	Environmental Property
Boiling Point	Atomic Weight	Valence Electrons	Bulk Modulus	Toxic
Heat Capacity	Atomic Radius	Density	Shear Modulus	Radioactive
Melting Point	Covalent Radius	Electronegativity		Price
Specific Heat		First Ionization Potential		
Heat of Fusion		Metal Classification		
Heat of Vaporization		Electrical Conductivity		
Thermal Conductivity				

- While properties address specific aspects, they can also be broken up into larger categories, as shown for example here :
 - Thermal properties : how does the element behave as temperature changes
 - Size properties : how do we describe the change in size
 - Electronic properties : what does the electron impact on the element
 - Engineering properties : mechanical description, eg. Strength, toughness, etc.
 - Environmental property : health and availability

Importance of Remembering Units

“NASA lost a \$125 million Mars orbiter because a Lockheed Martin engineering team used English units of measurement while the agency's team used the more conventional metric system for a key spacecraft operation, according to a review finding released Thursday.

“The units mismatch prevented navigation information from transferring between the Mars Climate Orbiter spacecraft team in at Lockheed Martin in Denver and the flight team at NASA's Jet Propulsion Laboratory in Pasadena, California.”

.....

“That probably stopped the engine from completing its burn, so Climate Orbiter likely plowed through the atmosphere, continued out beyond Mars and now could be orbiting the sun.”

From CNN: September 30, 1999

Example Units

Temperature (eg. Melting point, boiling point) often reported in units of degrees Kelvin (defined so that the lowest possible temperature = 0 K). As opposed to Celsius which is defined so that water freezes at 0 and boils at 100, and Fahrenheit where 0 and 100 are based on salt water mixtures

$$\text{Kelvin} = 273 + \text{Celsius} = 241 + 1.8 * \text{Fahrenheit}$$

Size / Length vary in reported unit depending on the length scale. Atoms measured in angstroms (10^{-10} m) ; Electronic circuits often measured in microns (10^{-6} m) ; Objects measured in meters (m)

$$\text{nm} = 10^{-9} \text{ m} ; \text{um} = 10^{-6} \text{ m} ; \text{mm} = 10^{-3} \text{ m} ; \text{cm} = 10^{-2} \text{ m}$$

Going From the Element to the Material

The complexity of the material is greater than just summing the elemental properties :

e.g. melting point of material AB does not likely scale with melting point of A + melting point of B

Multiple issues to consider : for example bonding and charge

Types of bonds (example materials):

Metallic (metals),

Ionic (salt),

Covalent (diamond),

Molecular (wax)

Obviously, this plays a major role in the properties of the material

Going From the Element to the Material

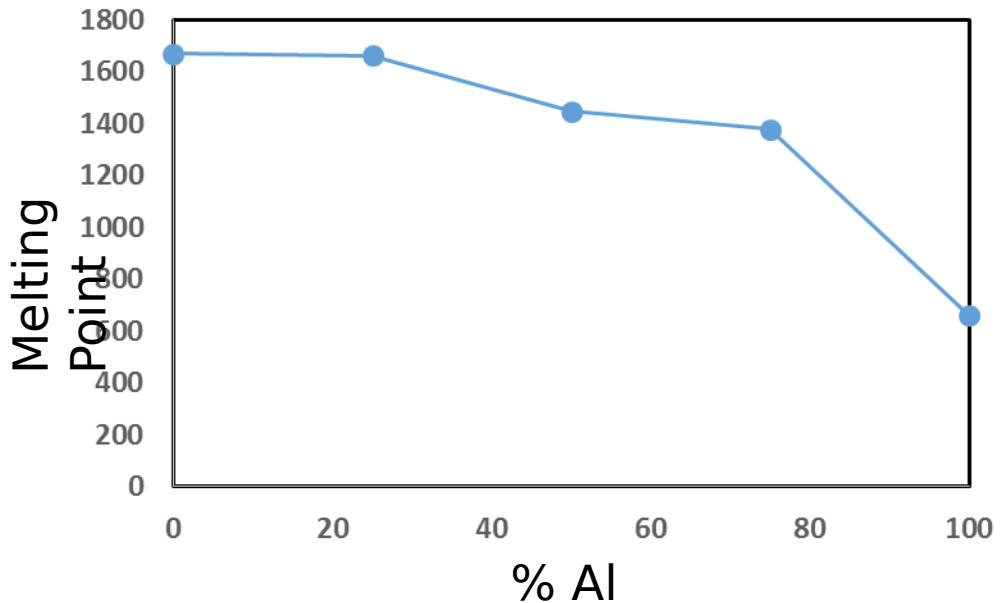
100% Ti Melting point (MP) = 1670 °C

100% Al MP= 660 °C

25% Al - 75% Ti MP = 1663 °C

50% Al - 50% Ti MP = 1447 °C

75% Al - 25% Ti MP = 1378 °C



Complexity of materials prevents us from just averaging the values of elemental properties.

Correlations / trends clearly exist, but this defines the difficulty in design.

Desired Properties of Materials

Metals : want strong and tough metals for structural applications : eg. Cars, buildings, etc. Want them to be lighter - use less gas

Nanoparticles : Want them to have good properties for the application, but do not want them to be toxic

Batteries : want to provide large amounts of current and for long time periods

Magnets : Want high magnetization values, while also being able to operate them at high temperature (eg. Hard disk drives)

While the exact design specifications for each material depends on specific applications, some characteristics are common :

Want it to be cheap, want it to have elements which are available, and want it to not be toxic or environmentally harmful

Data challenges

- ❖ Small dataset
- ❖ High dimensional dataset
- ❖ Multicollinearity

Data of Metals

Metals : want strong and tough metals for structural applications : eg. Cars, buildings, etc. Want them to be lighter – use less gas

Popular metal currently is titanium-aluminum alloys (alloy is a metal containing multiple elements)

What is studied is how does the material change when another element X is added :
 Ti-Al-X

For example, for $X = \text{Ag}$, strength is worse but toughness is better than for $X = \text{Au}$.

X	Alloy Strength	Alloy Toughness	Alloy Density
Ag	114.63	1.91	3.66
Au	118.89	1.89	3.67
Cd	111.94	1.81	3.73
Co	112.83	1.94	3.45
Cr	119.18	1.79	3.39
Cu	115.92	1.96	3.45
Fe	114.02	1.8	3.38
Hf	113.03	1.74	3.86
Hg	115.12	1.78	3.97
Ir	125.63	2.03	3.59

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19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	18		
Rb Rubidium 84.468	Sr Strontium 87.62	Y Yttrium 88.906	Zr Zirconium 91.224	41	42	43	44	45	46	47	48	In Indium 112.414	Sn Tin 114.818	51	52	53	54	Ar Argon 39.949	
37	38	39	40	41	42	43	44	45	46	47	48	Sb Antimony 112.760	Tl Thallium 204.363	51	52	53	54	Br Bromine 79.904	
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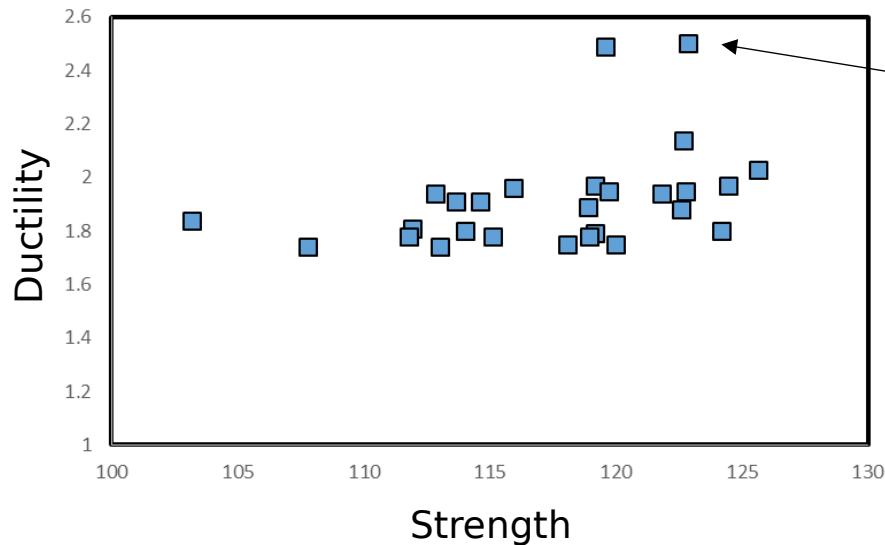
Strength is a measure of how well a material can resist being deformed from its original shape

Toughness is the ability of a material to absorb energy and plastically deform without fracturing

Density is the mass / volume. Therefore, assuming a uniform volume, density is correlated to the mass. Can be measured by weighing the material and measuring the volume.

In general, we want a material which is strong, tough, and has low density --- ie. you can hit the material with a large force without damage and the material is light

Data of Metals : Design Loop



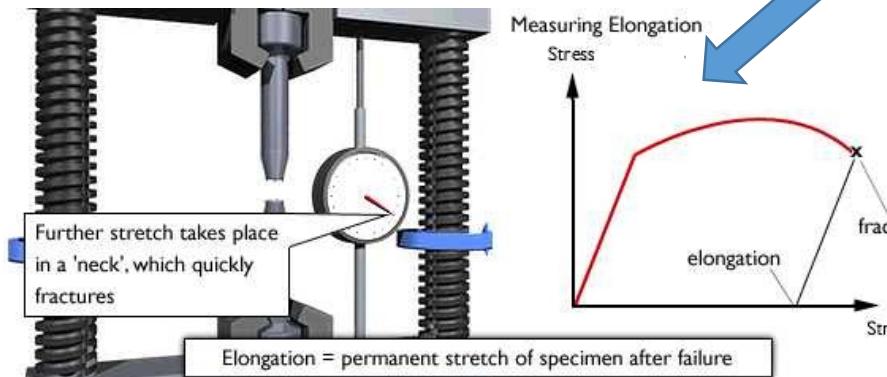
Expensive

Application : How does it operate under service conditions



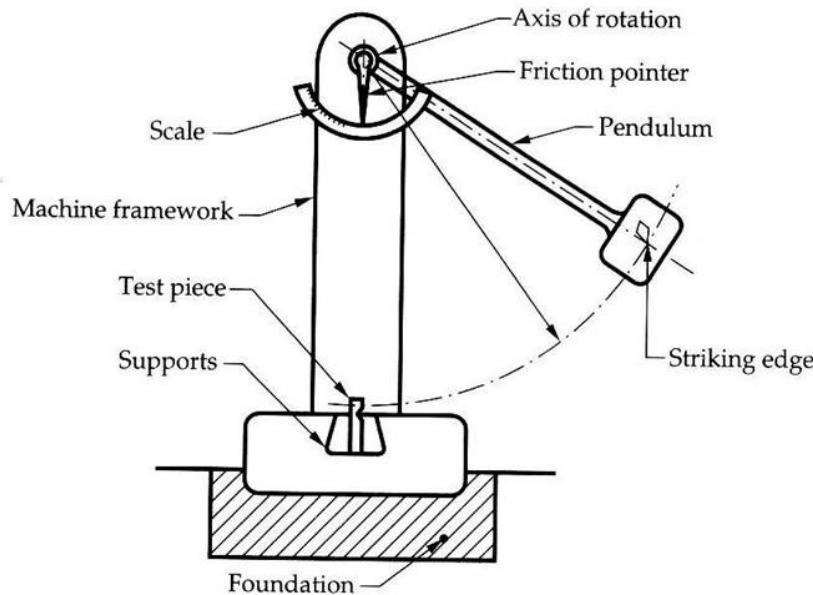
Strength

Testing : Measuring strength and ductility to add another data point



Iterate the process

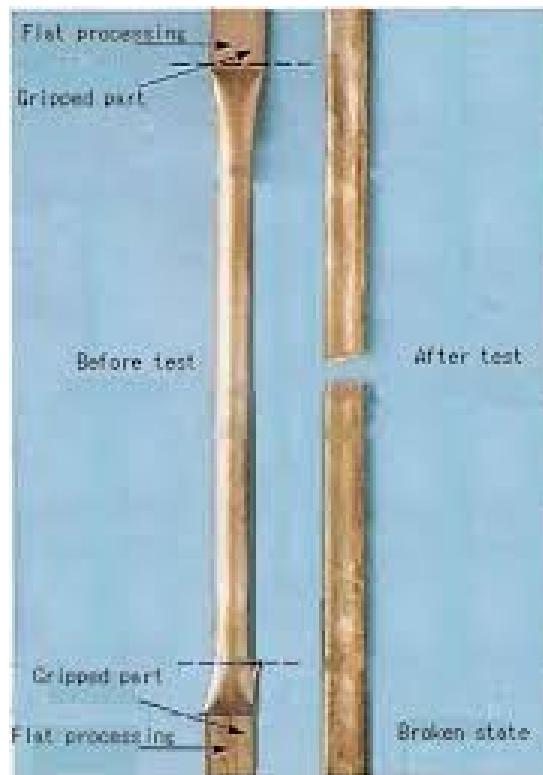
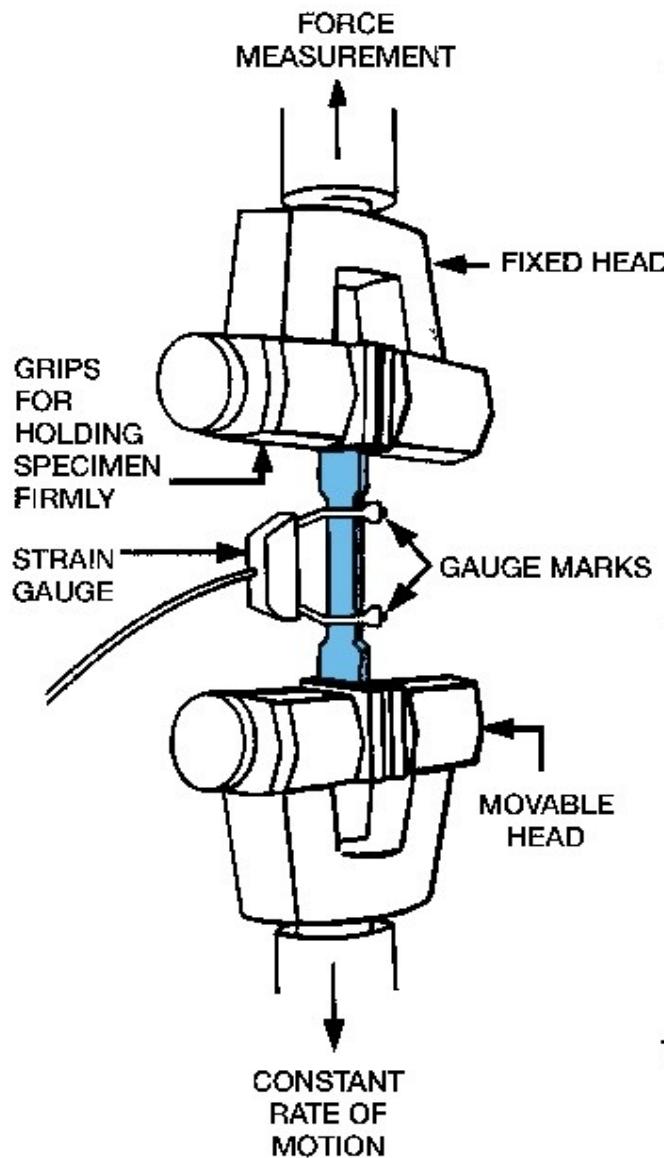
Measuring Strength



Multiple ways to measure strength: one example is an 'impact test', where the material is hit with a hammer. The more force of the hammer (or alternatively the greater resistance of the material to a given force) required to break the sample corresponds with higher strength.

Strength typically in units of GPa = Force / area --- thus the force of the hammer for a

Measuring Toughness



A common approach to measure toughness (ductility) is to pull on the material and measure how far it stretches before it deforms.

If a material can stretch a large amount before it breaks, then that indicates that the material is tough ; if it breaks without stretching much, than it is brittle.

Toughness reported in % elongation = length at fracture / original

Desired Properties of Materials

Metals : want strong and tough metals for structural applications : eg. Cars, buildings, etc. Want them to be lighter – use less gas

Nanoparticles : Want them to have good properties for the application, but do not want them to be toxic

Batteries : want to provide large amounts of current and for long time periods

Magnets : Want high magnetization values, while also being able to operate them at high temperature (eg. Hard disk drives)

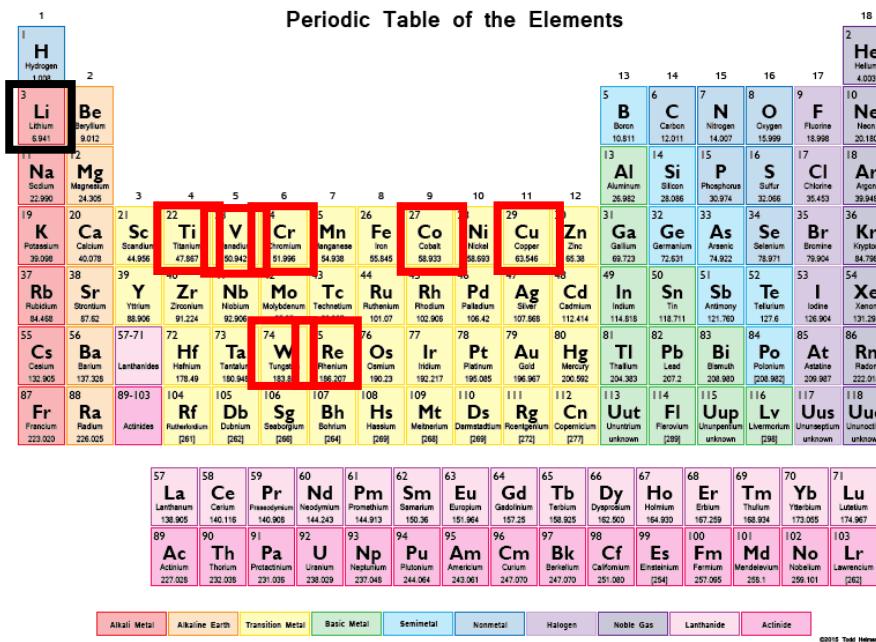
Battery Data

A	B	Average Output Voltage	Capacity
Ca	Co	3.25	242
Ca	Mo	2.44	97
Ca	Ti	1.93	149
Ca	V	2.68	260
Ca	W	1.5	59
Li	Co	3.76	274
Li	Gr	4.01	295
Li	Cu	3.91	262
Li	Mo	2.45	199
Li	Re	1.55	216
Li	Ti	1.78	309
Li	V	2.91	298
Li	W	1.7	120
Mg	Co	3.05	138
Mg	Mo	2.32	191
Mg	Ti	1.21	291
Mg	V	2.54	282
Mg	W	0.78	60
Y	Cu	3.11	436
Y	V	1.84	316
Zn	Mo	1.04	167
Zn	Ti	-0.17	238
Zn	V	1.18	232
Zn	W	-0.86	58

- Average output voltage measures the maximum amount of voltage which can be output
- Capacity describes the amount of current that can be output over a period of time - in units of Milliamp-hours (mAh). A larger capacity means that it will take longer to discharge the battery
- We want to maximize the output voltage possible, while also making it take longer to discharge the battery.

Battery Data

Battery types of AB – for example, first row is a CaCo battery



If we look for example at the elements that could be combined with Li, no clear trend is seen between periodic table and properties

A	B	Average Output Voltage	Capacity
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In the last year, the Samsung cell phones have been in the news due to causing fires --- resulting from Li-ion batteries

The reason behind the fires is due to incorrect selection of battery size --- results in trying to pull more voltage from the battery than the output allows.

Therefore, an increase in output voltage is required to get same

Battery Considerations

Similar issues have resulted recently in the Boeing Dreamliner airplane, as well as for hoverboards.

Lithium-ion batteries, unlike other rechargeable batteries, have a potentially hazardous pressurized flammable liquid electrolyte.

In the case of the Dreamliner, the overheated or overcharged cell resulted in failure after 52,000 hours, as opposed to the 10 million flight hours predicted.

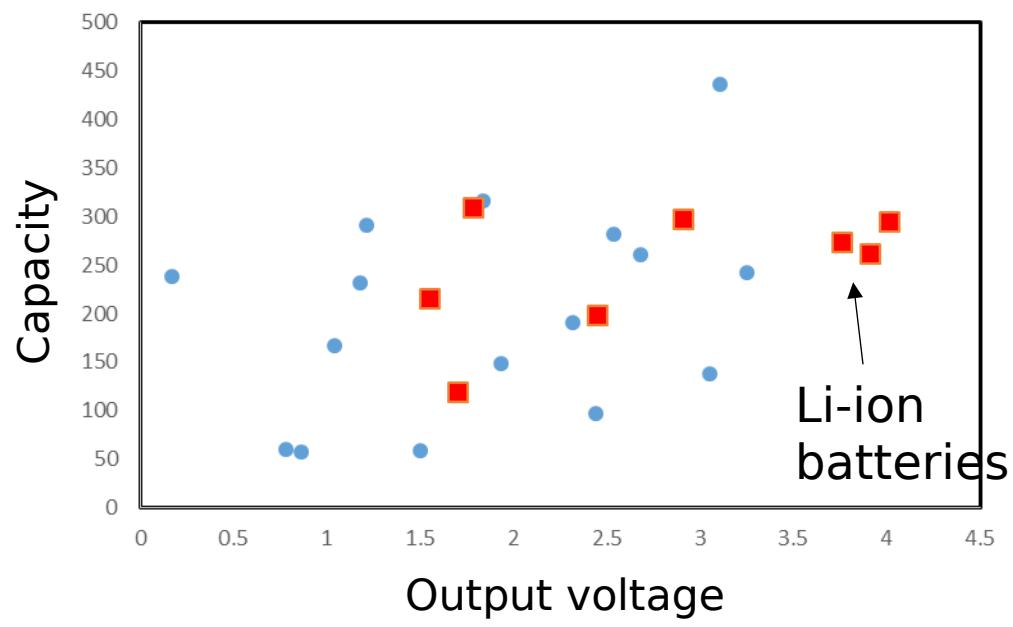
In the case of the hoverboards, the batteries were overcharged due to using charger not certified for the batteries.



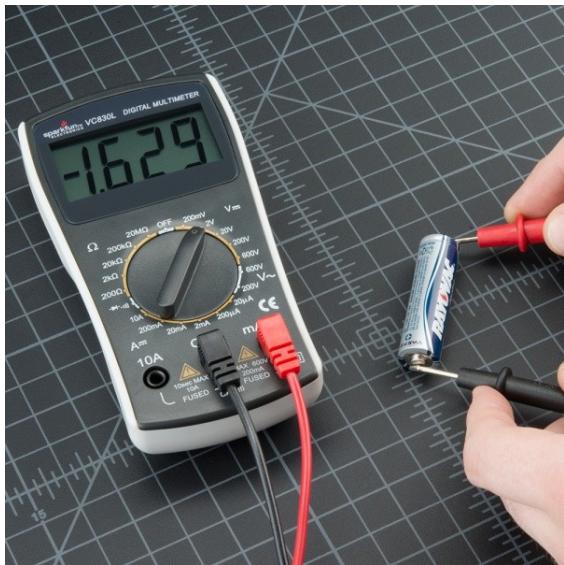
Battery Considerations

- Lithium-ion cells are very susceptible to damage outside the allowed voltage range that is typically within (2.5 to 3.65) V
- Exceeding this voltage range results in premature aging of the cells and, furthermore, results in safety risks due to the reactive components in the cells
- So why are we still using Li-ion batteries even with these problems.
- Because, as shown in the graph, they tend to perform better than batteries that use less flammable materials.

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Measuring Battery Properties

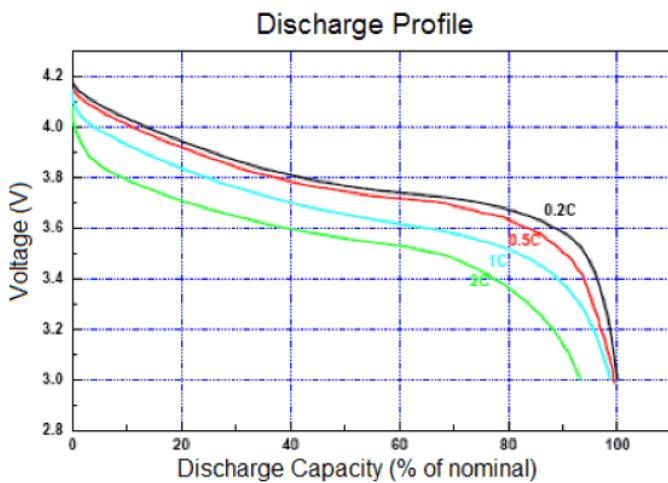


Capacity is determined by the equation :

$Q = I * t$, where Q is charge, I is current, and t is time.

Capacity is related to Q, ie. the usable charge

At constant current, can run battery cell until it reaches minimum voltage. From the time (t) and constant current (I), the capacity is estimated.



Taking the area underneath the curve of I versus t gives an exact value of capacitance, as current is unlikely to remain constant.

Desired Properties of Materials

Metals : want strong and tough metals for structural applications : eg. Cars, buildings, etc. Want them to be lighter - use less gas

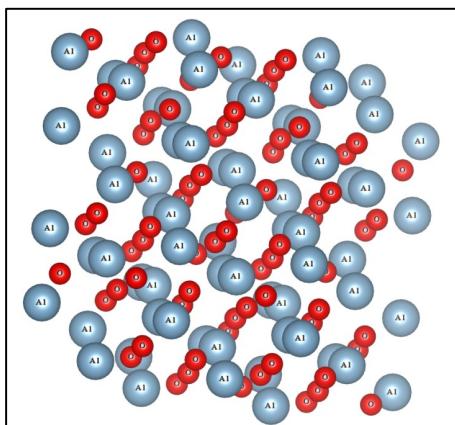
Nanoparticles : Want them to have good properties for the application, but do not want them to be toxic

Batteries : want to provide large amounts of current and for long time periods

Magnets : Want high magnetization values, while also being able to operate them at high temperature (eg. Hard disk drives)

Toxicity Data

Oxide nanoparticle	Toxicity	is.toxic
TiO ₂	1.74	FALSE
SnO ₂	2.01	FALSE
ZrO ₂	2.15	FALSE
SiO ₂	2.2	FALSE
Fe ₂ O ₃	2.29	TRUE
Al ₂ O ₃	2.49	TRUE
Cr ₂ O ₃	2.51	FALSE
CeO ₂	2.602	FALSE
Sb ₂ O ₃	2.64	TRUE
In ₂ O ₃	2.81	TRUE
Bi ₂ O ₃	2.82	TRUE
La ₂ O ₃	2.87	TRUE
Y ₂ O ₃	2.87	TRUE
V ₂ O ₃	3.14	TRUE
CuO	3.2	TRUE
NiO	3.45	TRUE
ZnO	3.45	TRUE
CoO	3.51	TRUE



- Toxicity is reported as $\log(1/\text{EC}_{50})$

EC_{50} has units of mol/L

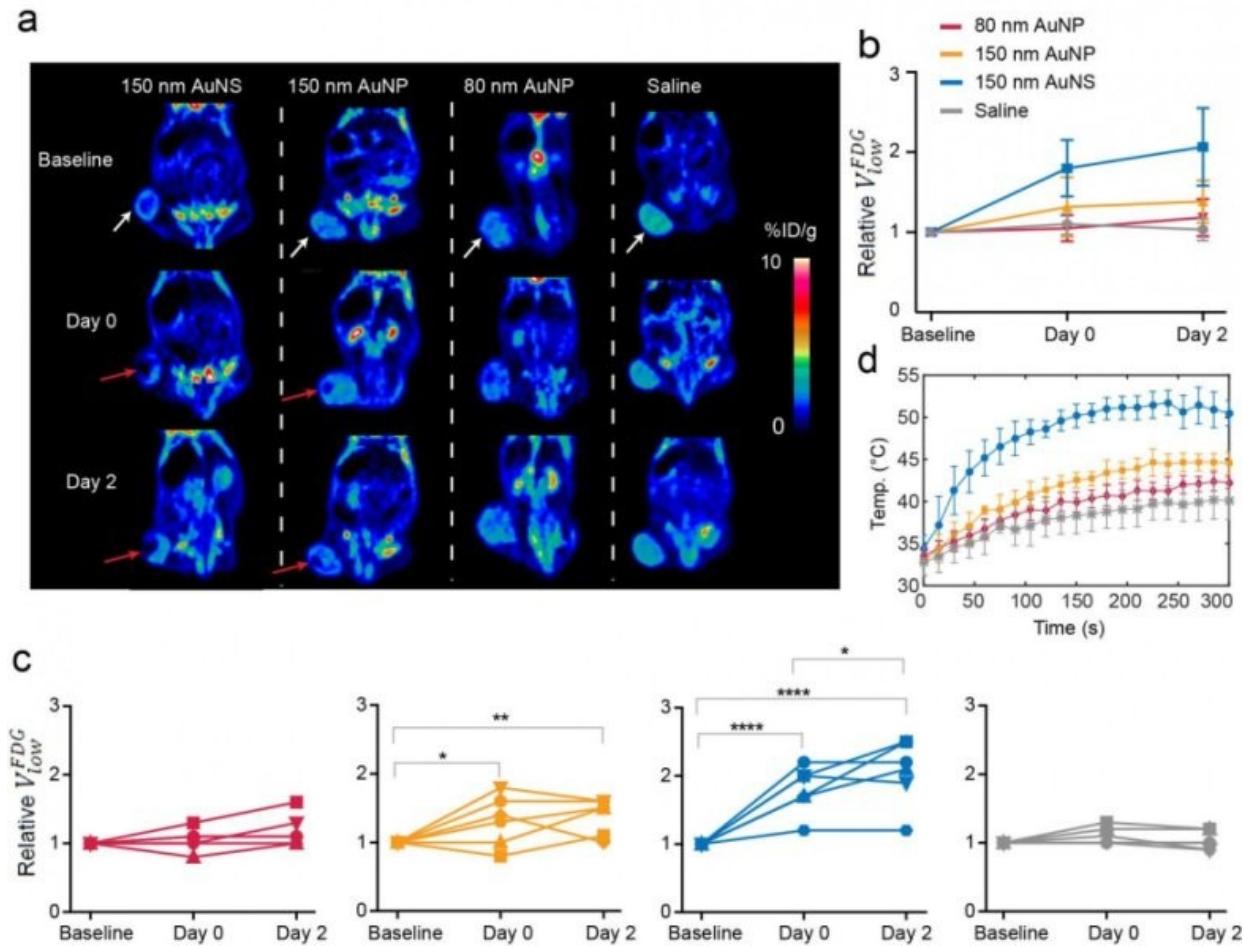
Mol : measure of quantity
L : measure of volume

- Mol/L is therefore a density. This measures what density of nanoparticles is required to alter half of the cells. So large EC_{50} means that lots of nanoparticles are needed to affect the cells - thus less toxic.

- Therefore, this would correspond to smaller $1/\text{EC}_{50}$
--- ie. larger $1/\text{EC}_{50}$

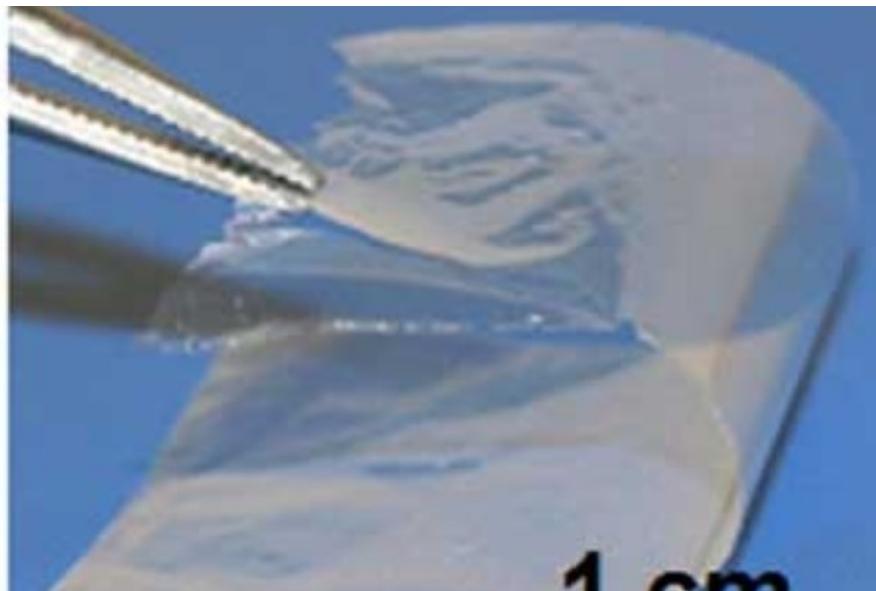
Uses of Nanoparticles

The images show PET scans of a mouse with a large tumor (by the white arrow). The tumor is treated with nanoparticles, which are injected directly into the tumor and are then flashed with near infrared laser light. The laser light heats the nanoparticles, thus damaging or killing the cancer cells (red



Uses of Nanoparticles

Fabrics are being engineered to contain nanosilver – any of a collection of nanoparticles made from silver – are used to kill odor causing bacteria in socks and sports clothing.



Could a seemingly simple clear plastic bag—the kind that you load your fruits and vegetables into at the supermarket—actually be as strong as steel? It could be if it is made from a new composite plastic that blends the strength of nanoparticles with the pliancy of a water-soluble polymer.

Toxicity in Nanoparticles

“Currently, more than 600 consumer products containing nanomaterials are already on the market, used in sporting goods, tires, stain-resistant clothing, sunscreens, cosmetics, and electronics and increasingly utilized in biomedicine for purposes of diagnosis, imaging, and drug delivery.

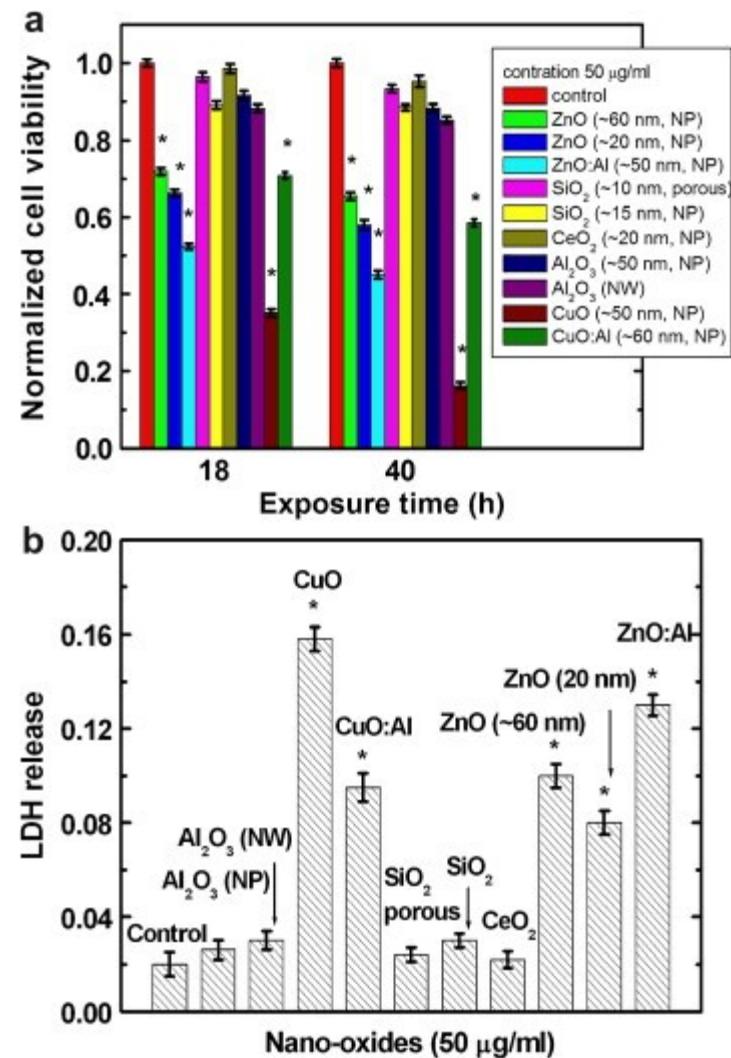
“[T]he increased presence of nanomaterials in commercial products raises concerns about adverse effects on environment, health, and society (NanoEHS). The key to the long-term growth and sustainability of nanomaterials is to establish end-user confidence that the engineered nanomaterials are safe. Increasing numbers of investigations show that many types of nanomaterials, including carbon nanotubes, fullerenes, quantum dots such as CdS, oxide nanoparticles such as ZnO and TiO₂, have a toxic effect on biological systems.”
Environmental Materials, 31, p. 8022-8031

Measuring EC₅₀ Data

In toxicology measurements, dose descriptor is the term used to identify the relationship between a specific effect of a chemical substance and the dose at which it takes place. The dose descriptors are used to derive the no-effect threshold levels for human and environmental health and safety.

Dose descriptors are determined in the toxicological studies on the hazards of the substance and are usually expressed as LC50, LD50, NOAEL, NOAEC, T25, BMD, EC50, NOEC, DT50, etc. They are used for hazard classification and risk assessment.

LC50 is a statistically-derived dose at which 50% of the animals will be expected to die. For inhaled toxicity, air concentrations are used for exposure and LC50 is measured in $\mu\text{g}/\text{ml}$.



Desired Properties of Materials

Metals : want strong and tough metals for structural applications : eg. Cars, buildings, etc. Want them to be lighter – use less gas

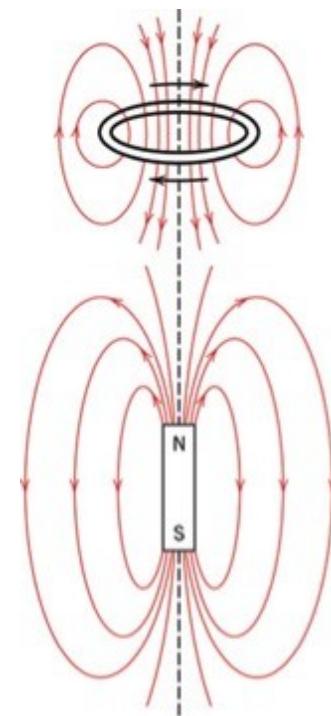
Nanoparticles : Want them to have good properties for the application, but do not want them to be toxic

Batteries : want to provide large amounts of current and for long time periods

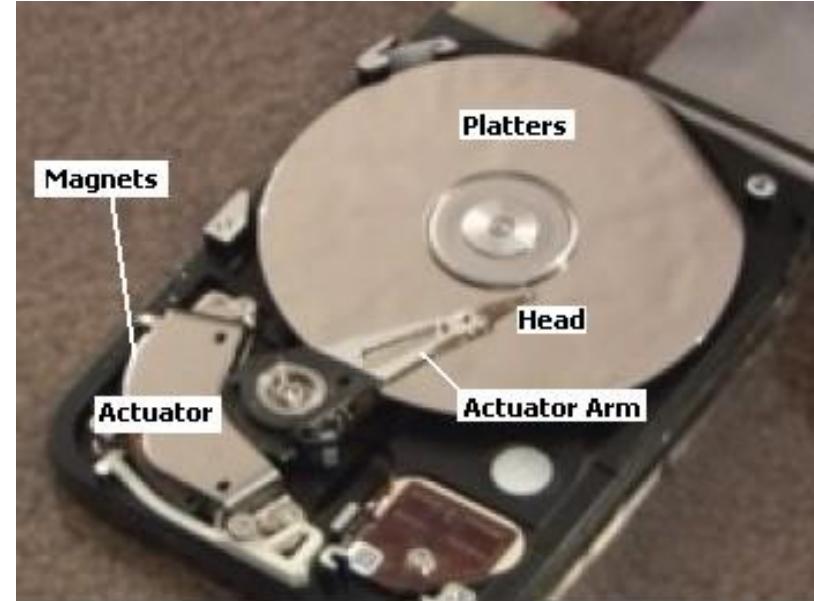
Magnets : Want high magnetization values, while also being able to operate them at high temperature (eg. Hard disk drives)

Magnetic Data

A	B	Maximum Temperature	Saturation Magnetization	Contain RE	Contains Toxic
Ce	Fe	-38	2.5	TRUE	FALSE
Co	Ga	316	0.53	FALSE	TRUE
Co	Pt	567	1.01	FALSE	TRUE
Co	Si	237	0.24	FALSE	TRUE
Co	Sn	366	0.76	FALSE	TRUE
Cr	O	123	0.49	FALSE	FALSE
Dy	Fe	362	5.8	TRUE	FALSE
Er	Fe	314	4.9	TRUE	FALSE
Eu	O	-204	2.36	TRUE	FALSE
Fe	Ni	570	1.04	FALSE	FALSE
Fe	Pd	476	1.38	FALSE	FALSE
Fe	Pt	477	1.43	FALSE	FALSE
Gd	Co	741	0.29	TRUE	TRUE
Gd	Fe	523	3.6	TRUE	FALSE
Ho	Fe	335	5.5	TRUE	FALSE
Mn	Al	377	0.75	FALSE	FALSE
Mn	As	45	0.63	FALSE	TRUE
Mn	Bi	360	0.73	FALSE	FALSE
Ni	Fe	570	1.04	FALSE	FALSE
Ni	Mn	477	1	FALSE	FALSE
Sm	Co	747	0.86	TRUE	TRUE
Sm	Fe	415	2.7	TRUE	FALSE
Tb	Fe	425	0.5	FALSE	FALSE
Tm	Fe	326	2.6	TRUE	FALSE
Y	Co	714	0.85	FALSE	TRUE
Y	Fe	54	0.48	FALSE	FALSE



Magnetic Application --- Computer Hard Disk Drive (HDD)

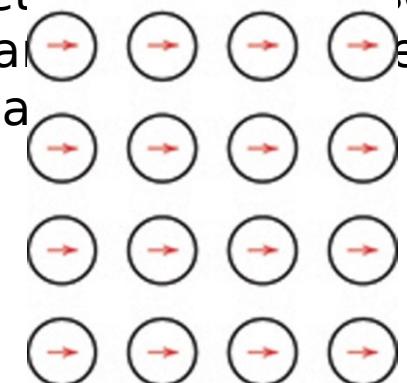


The magnet controls the spin, and leads to the faster reading of data and leads to larger hard drive capacities and better performance.

Magnetic Data

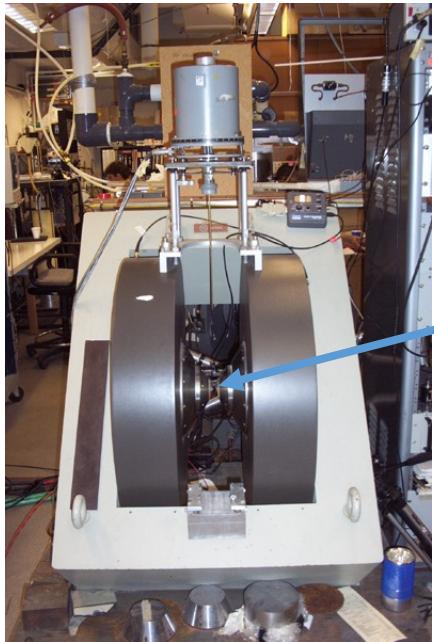
A	B	Maximum Temperature	Saturation Magnetization	Contain RE	Contains Toxic
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Y	Fe	54	0.48	FALSE	FALSE

The maximum possible magnetization, or **magnetic saturation, M_s** of a ferromagnetic material represents the magnetization that results when all the magnetization in a solid piece aligned with an external field $H = 0$.

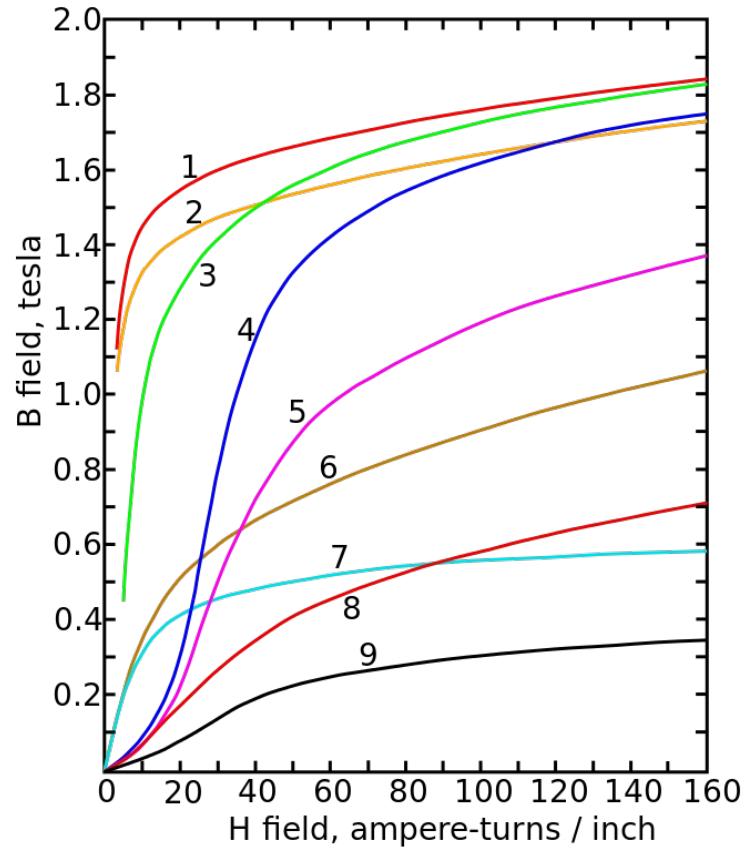
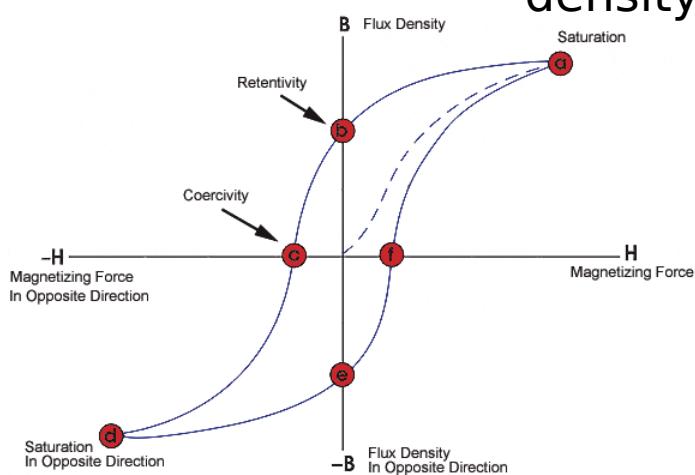


Small domains in materials can be magnetically aligned in one of two orientations, corresponding to a 0 or a 1 in digital storage. This technique is used in hard drives.

Measuring Saturation Magnetization



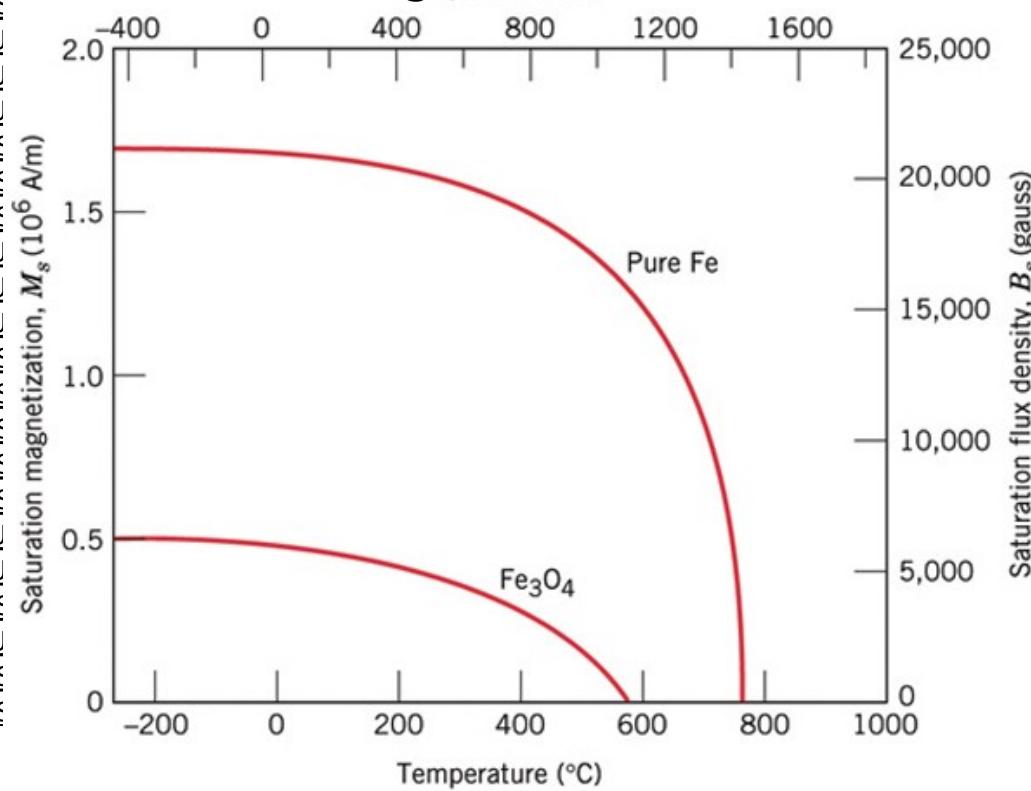
Place
magnet
inside.
Apply
different
magnetic
fields, and
measure
magnetic
flux
density



Magnetic Data

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The saturation falls off with temperature, and there is a maximum temperature above which a material cannot be magnetized.



Magnetic Data

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Magnetization is measured as **A/m** - amps per meter.

The ampere is the unit of electrical current, and 1 amp is the current that flows with a charge of 1 Coulomb per second.

The Coulomb is dimensionless, and is 6.24×10^{18} - so that's the number of electrons that pass a given point in 1 second.

Summary

What is the link between the elements as described in the periodic table and the application properties when elements are combined.

Metals : want strong and tough metals for structural applications : eg. Cars, buildings, etc. Want them to be lighter - use less gas

Nanoparticles : Want them to have good properties for the application, but do not want them to be toxic

Periodic Table of the Elements																																																																						
1 H Hydrogen 1.008	2 He Helium 4.000	3 Li Lithium 6.941	4 Be Beryllium 9.012	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180	11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.986	15 P Phosphorus 30.974	16 S Sulfur 32.074	17 Cl Chlorine 35.453	18 Ar Argon 39.949	19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.966	22 Ti Titanium 47.887	23 V Vanadium 50.942	24 Cr Chromium 51.976	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.822	34 Se Selenium 78.911	35 Br Bromine 80.918	36 Kr Krypton 83.804	37 Rb Rubidium 84.967	38 Sr Strontium 87.621	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Tc Technetium 95.96	43 Ru Ruthenium 101.07	44 Rh Rhodium 102.907	45 Rh Rhodium 102.907	46 Pd Palladium 106.42	47 Ag Silver 107.86	48 Cd Cadmium 112.44	49 In Indium 113.41	50 Sn Tin 118.711	51 Sb Antimony 121.8	52 Te Tellurium 123.94	53 I Iodine 131.264	54 Xe Xenon 131.339	55 Cs Cesium 132.905	56 Ba Barium 138.906	57 La Lanthanum 139.905	58 Ce Cerium 140.908	59 Pr Praseodymium 141.908	60 Nd Neodymium 144.913	61 Pm Promethium 146.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 158.926	65 Tb Terbium 167.25	66 Dy Dysprosium 162.903	67 Ho Holmium 164.930	68 Er Erbium 167.269	69 Tm Thulium 168.934	70 Yb Ytterbium 173.955	71 Lu Lutetium 174.967
89 Ac Actinium 227.029	90 Th Thorium 232.029	91 Pa Protactinium 231.029	92 U Uranium 238.029	93 Pu Plutonium 239.048	94 Am Americium 244.064	95 Bk Berkelium 243.061	96 Cf Californium 247.070	97 Es Curium 247.070	98 Fm Fermium 251.060	99 Dy Dysprosium 257.065	100 Gd Gadolinium 258.1	101 Ho Holmium 261.905	102 Er Erbium 268.105	103 Tm Thulium 273.955	104 Yb Ytterbium 274.967	105 Lu Lutetium 275.967																																																						
<small>Alkal Metal Alkaline Earth Transition Metal Basic Metal Semimetal Nonmetal Halogen Noble Gas Lanthanide Actinide</small>																																																																						
<small>©2010 Tisch University elements.org</small>																																																																						

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