Properties of Metals Used in the Vibration Unit

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Introduction

A smartphone's vibration unit is a brushless direct current (BLDC) motor that capitalizes on varying rigidity, density, malleability, conductivity, and ferromagnetic properties of its many alloys. This unit functions by using shifting electromagnetic poles generated in copper coils mounted in a fixed stator to oppose a swiveling rotor's permanent magnet. This forces the rotor, which is attached to an uneven metal weight, to spin resulting in vibration. Below is a partial explanation on how and why this motor functions, with special emphasis on properties of metals. Magnetism is the main driving force of the motor along with the wiring used to transfer current.

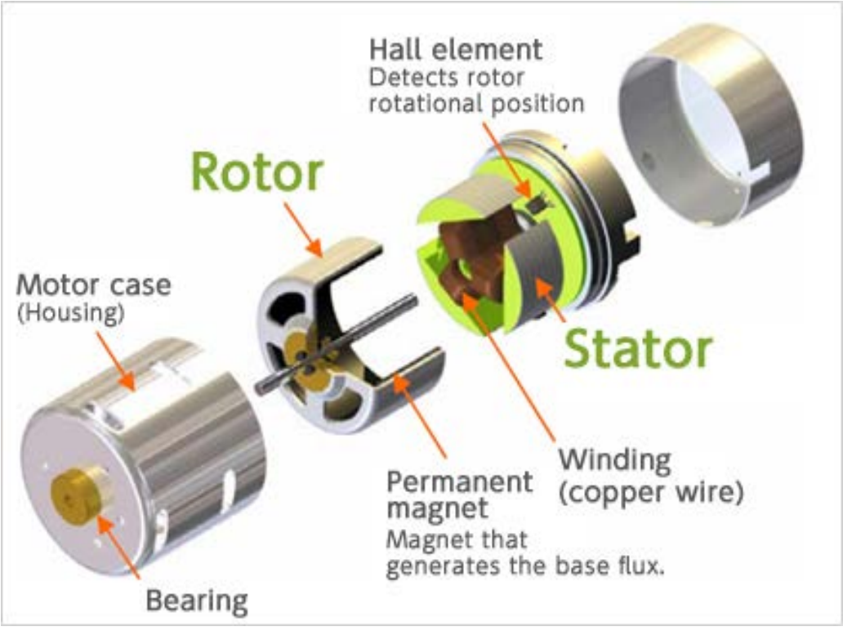


Figure 1. A brushless DC motor disassembled

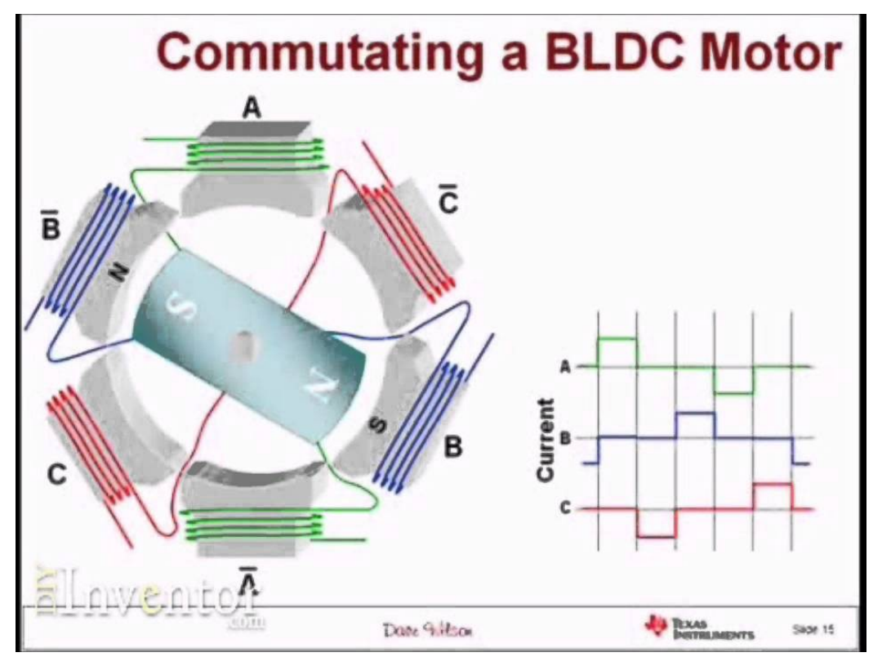


Figure 2. BLDC motor's magnet with conductive wiring

Essence of Conductivity

- Large groups of discrete unoccupied energy levels of similar energy from 'bands' in which electrons can move
- Easily shifted electrons can 'bump' into other electrons, causing rapid propagation
- Electron movement results in a current that has directionality and in turn generates a magnetic field
- Conductors have low resistance to electron movement due to a small energy gap between bands

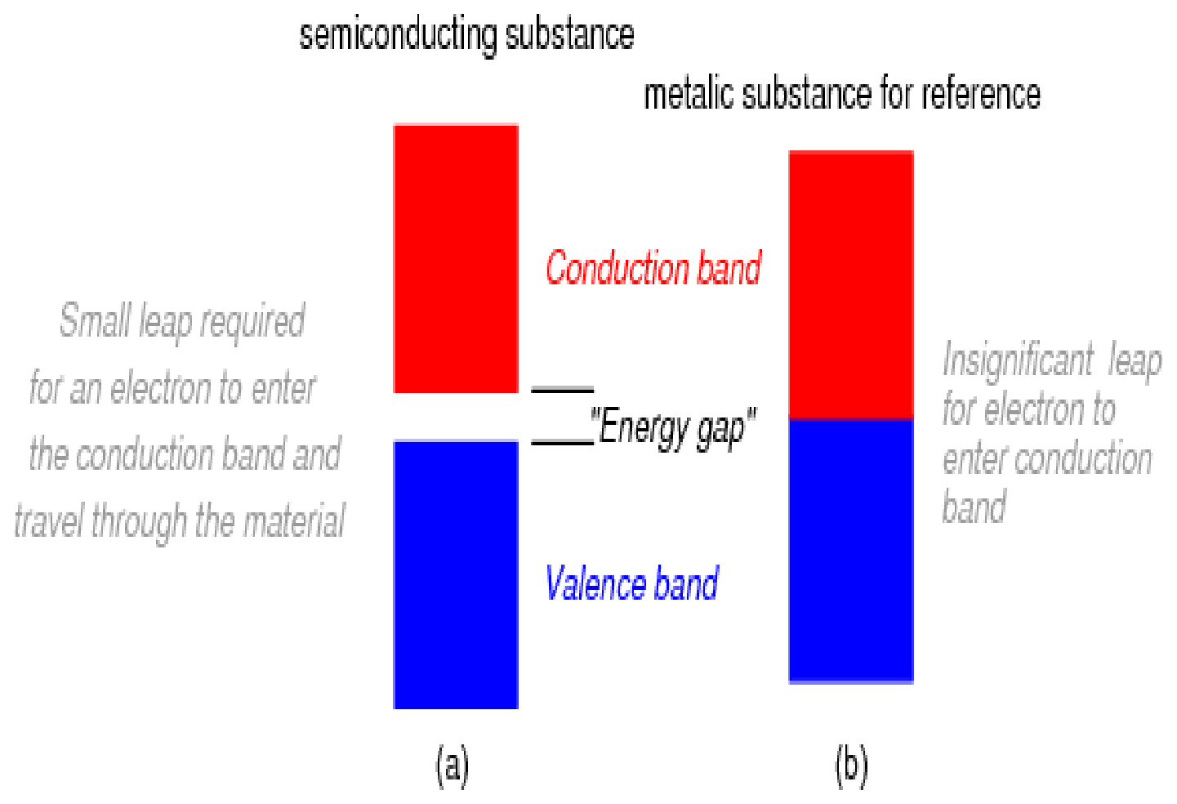


Figure 3. Band theory of semi-conductors and conductors

Sea: The Metallic Bond

- Metallic bonds are formed by a diffuse "sea" of valence electrons that are not tightly held to an individual atom
- Positively charged atom cores are largely indistinguishable from each other, even in alloys
- Freedom of movement allowed accounts for most properties associated with metals such as conductivity, malleability, and ductility

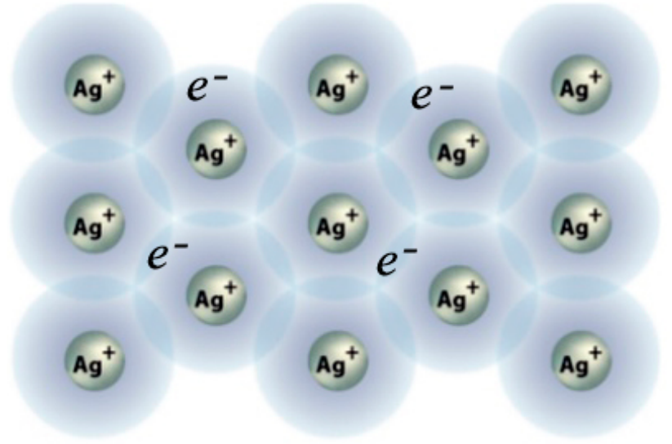


Figure 4. Representation of "sea" of electrons in silver ions

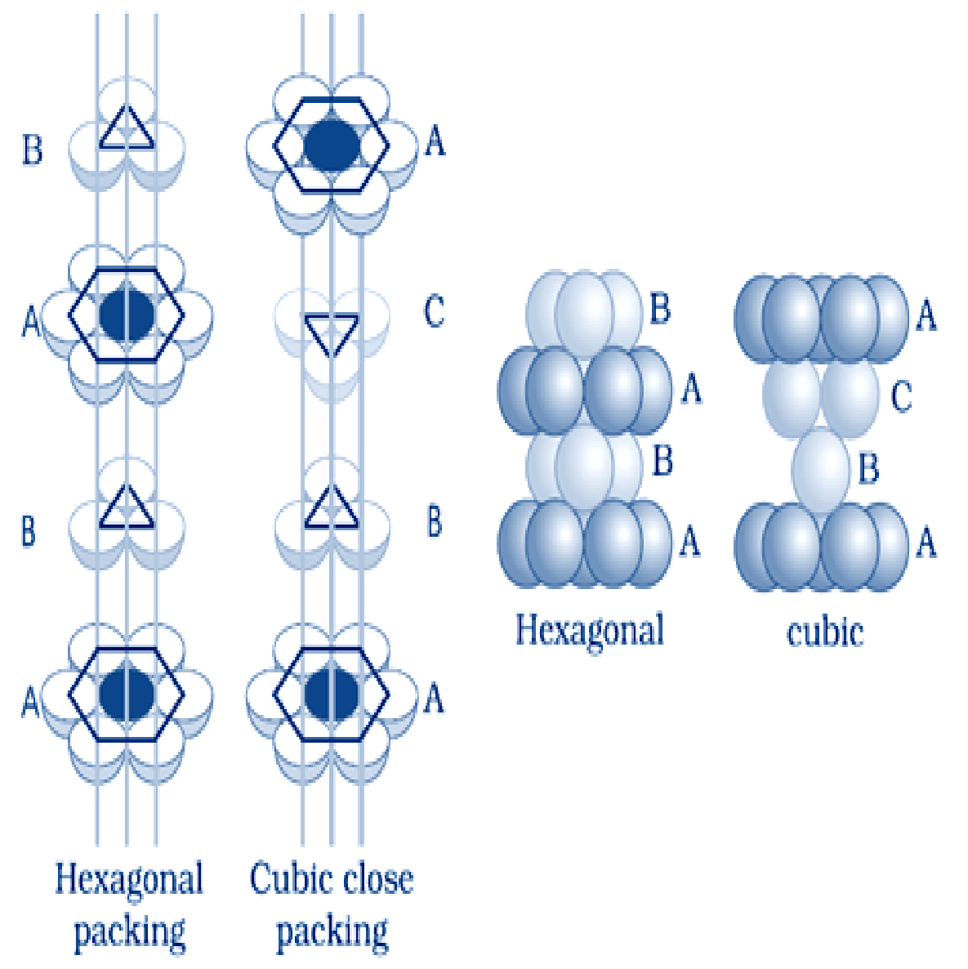


Figure 5. Typical packing structure for metallically bonded atoms

Magnetism and Photons

- State changes, including those electrons undergo, require energy transmission
- Photons mediate electron spin interactions and give rise to magnetic force
- These protons are "virtual", existing only briefly between being (re)absorbed and (re)emitted between electrons
- Electrons only have two spin directions – magnets don't have a specific direction
- Magnetic fields are a result of electron spin interactions on a large scale

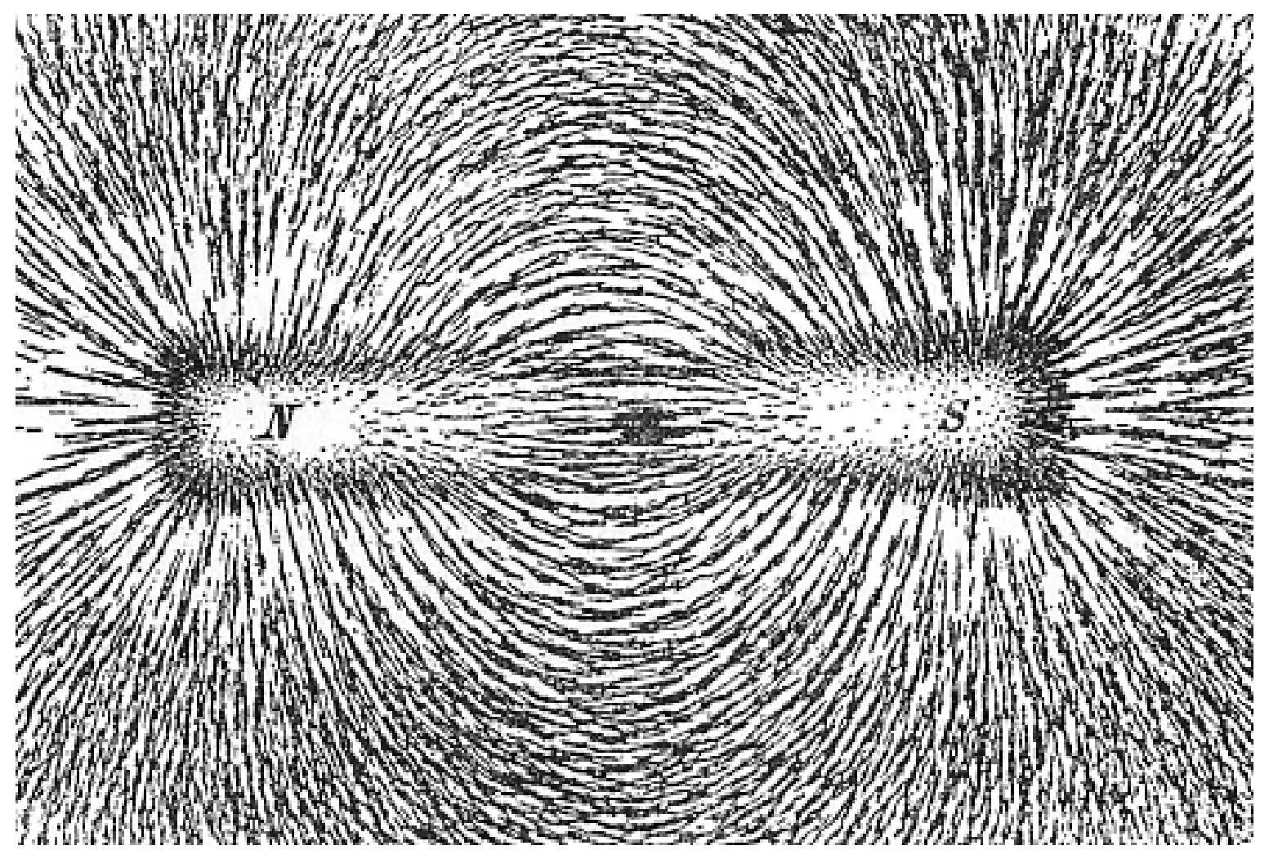
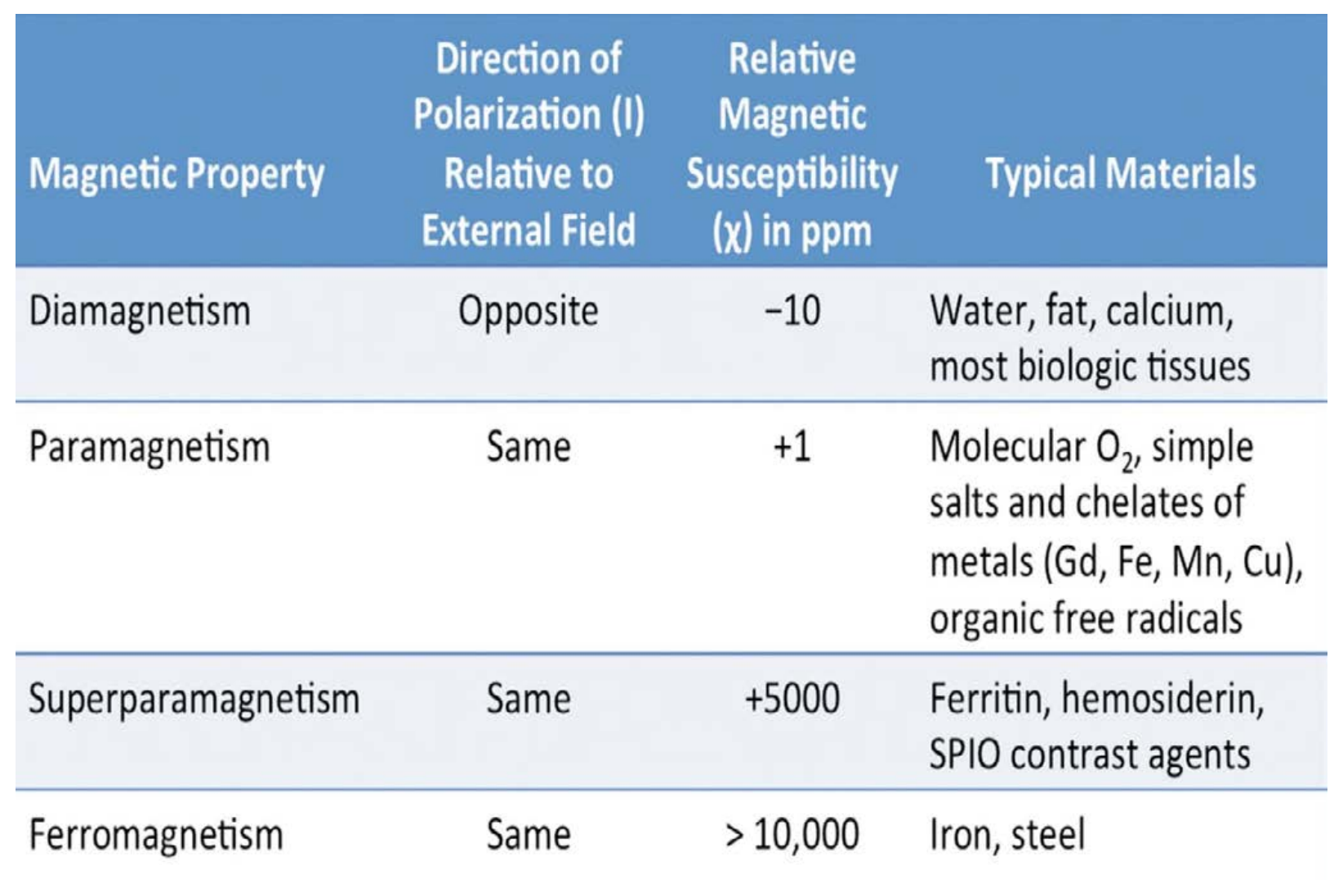


Figure 6. Transmission of photons between spinning electrons

Magnetic Susceptibility

- Magnetic susceptibility is a measure of how much a material is attracted into or pushed out of a magnetic field
- Paired electrons have a net magnetic moment of zero and are called diamagnetic
- Unpaired valence electrons have a nonzero net magnetic moment and can be oriented by a magnetic field
- Paramagnetism results from unpaired valence electron magnetic dipoles aligning in an external magnet field but losing the magnetic properties gained after the external magnetic field is removed
- Ferromagnetism occurs when unpaired valence electron magnetic dipoles align in an external magnetic field but magnetic properties gained are kept after the external magnetic field is removed



Magnetic Property	Direction of Polarization (I) Relative to External Field	Relative Magnetic Susceptibility (χ) in ppm	Typical Materials
Diamagnetism	Opposite	−10	Water, fat, calcium, most biologic tissues
Paramagnetism	Same	+1	Molecular O_2, simple salts and chelates of metals (Gd, Fe, Mn, Cu), organic free radicals
Superparamagnetism	Same	+5000	Ferritin, hemosiderin, SPIO contrast agents
Ferromagnetism	Same	> 10,000	Iron, steel

Figure 7. Magnetic susceptibility of different types of magnetism present in compounds

Ferromagnetism

- Ferromagnetism is a magnetic property in which unpaired electrons align in the direction of an external magnetic field
- Removal of the external magnetic field will not demagnetize the material completely
- The direction of magnetization will remain unless the temperature is below the Curie temperature
- The critical temperature at which a metal loses the magnetic properties caused by an external magnetic field is the Curie temperature

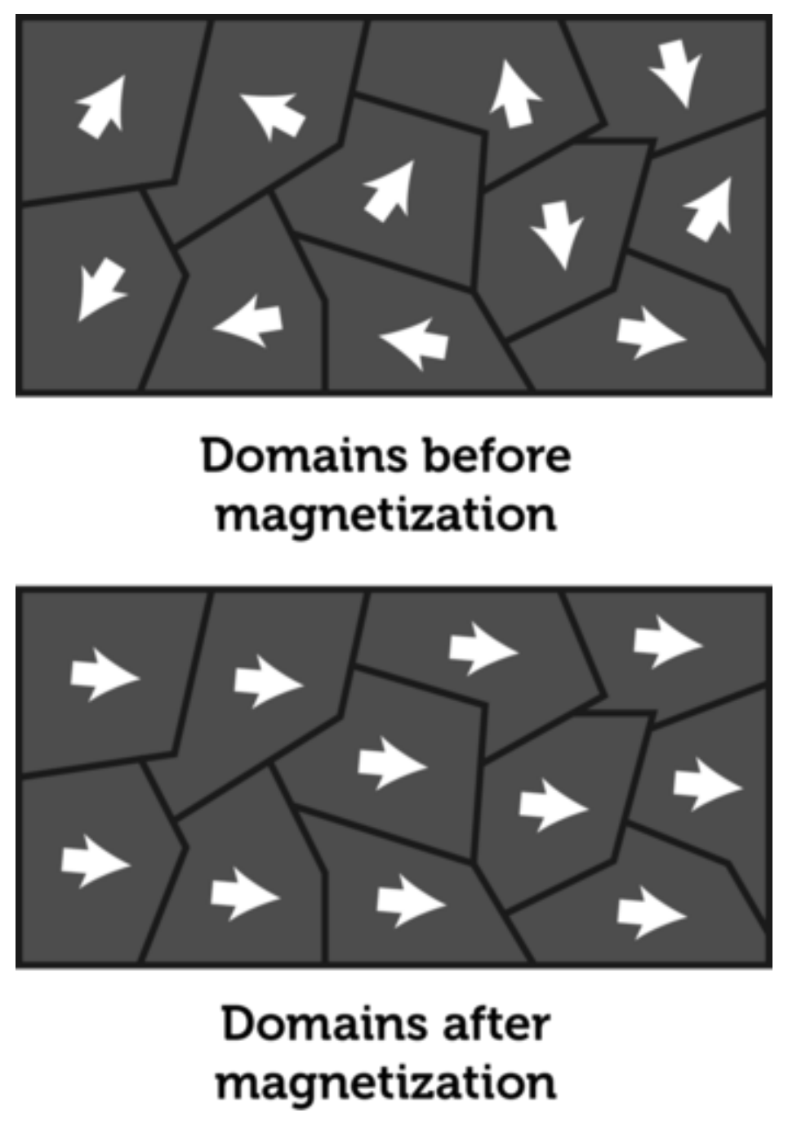


Figure 8. Domains of a ferromagnetic material after external magnetization

Magnetic Anisotropy

- Magnetic anisotropy refers to the dependence of magnetic properties based on a certain direction
- Magnetocrystalline anisotropy is a special case of anisotropy in which the crystal structure determines the preferred direction of magnetization
- The easy axis refers to the direction that is "easy" to magnetize the crystal along
- The hard axis is the opposite, more external magnetic field is necessary to magnetize the domains of the crystal in the "hard" direction

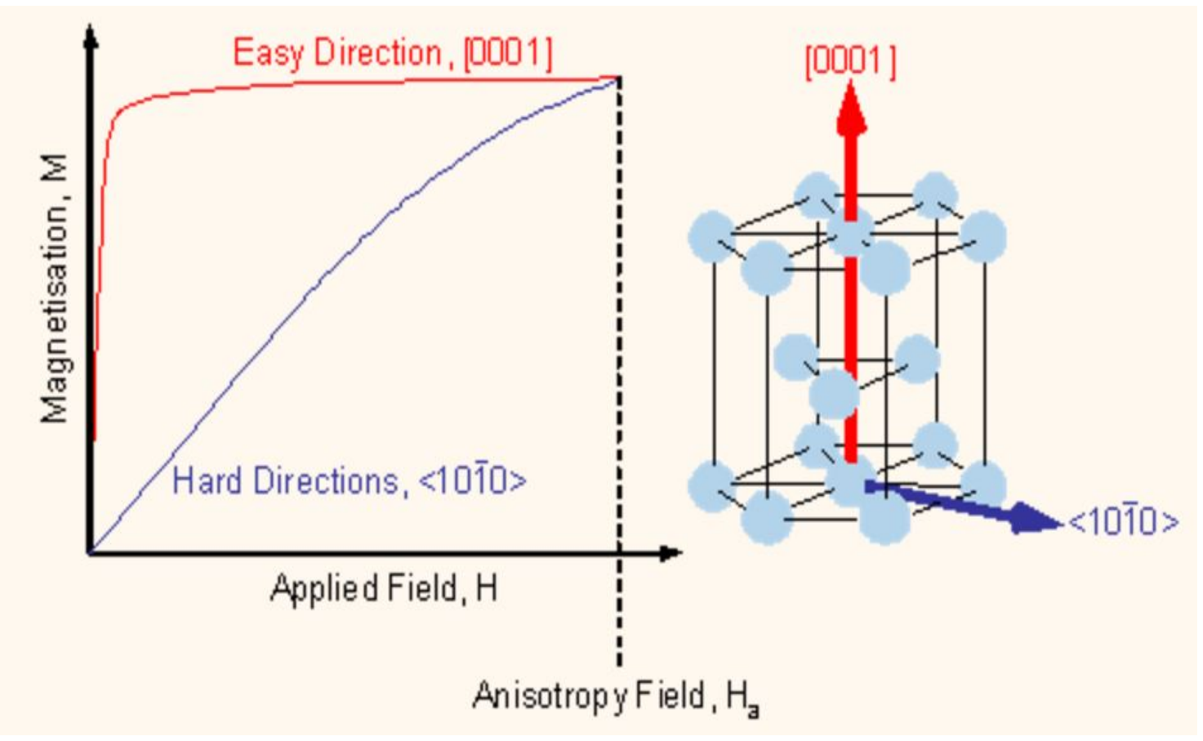


Figure 9. Magnetocrystalline anisotropy of cobalt

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Magnetocrystalline Anisotropy of $Nd_2Fe_{14}B$

- The crystal structure of $Nd_2Fe_{14}B$ is tetragonal
- The easy axis is uniaxial and along the c-axis of the crystal
- A uniaxial easy axis infers that magnetization will be primarily along the c-axis only
- Due to the high magnetocrystalline ansisotropy of the crystal structure, $Nd_2Fe_{14}B$ has a high coercivity

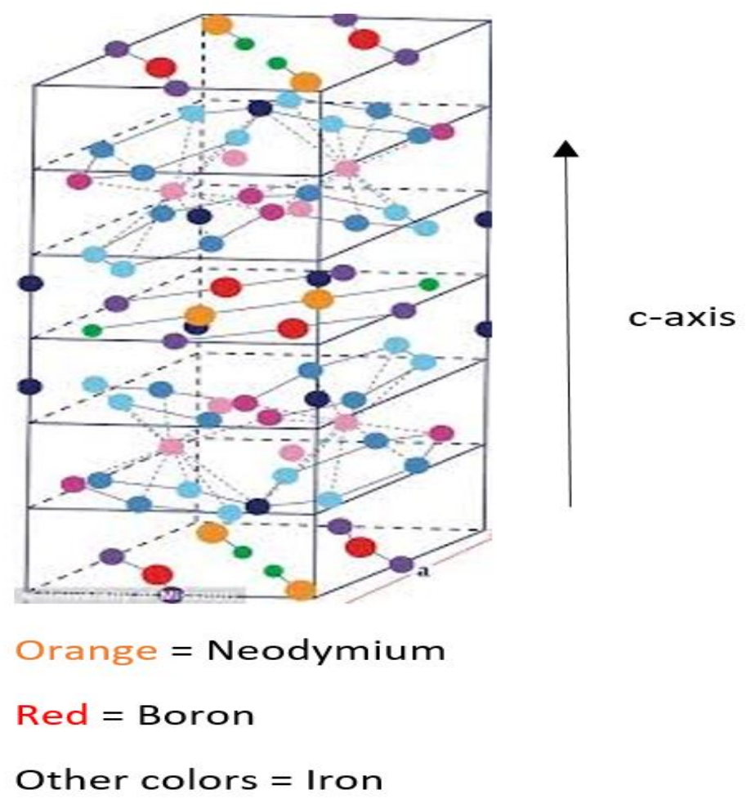


Figure 10. Tetragonal crystal structure of $Nd_2Fe_{14}B$ with easy axis

Neodymium vs. Other Magnets

- BH_{max} refers to the density of the magnetic field measured as J/m^3
- Remanence is a measure of how much magnetization is retained in a material after an external magnetic field is removed
- The resistance to being demagnetized is known as coercivity
- As observed, neodymium magnets offer superior magnetic density, remanence, and coercivity compared to other permanent magnets

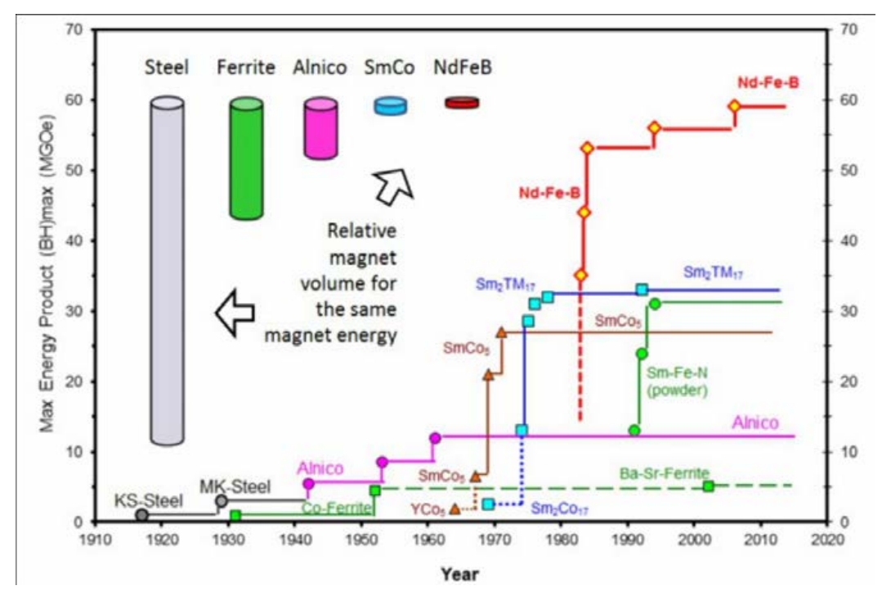


Figure 11. BH_{max} vs Year

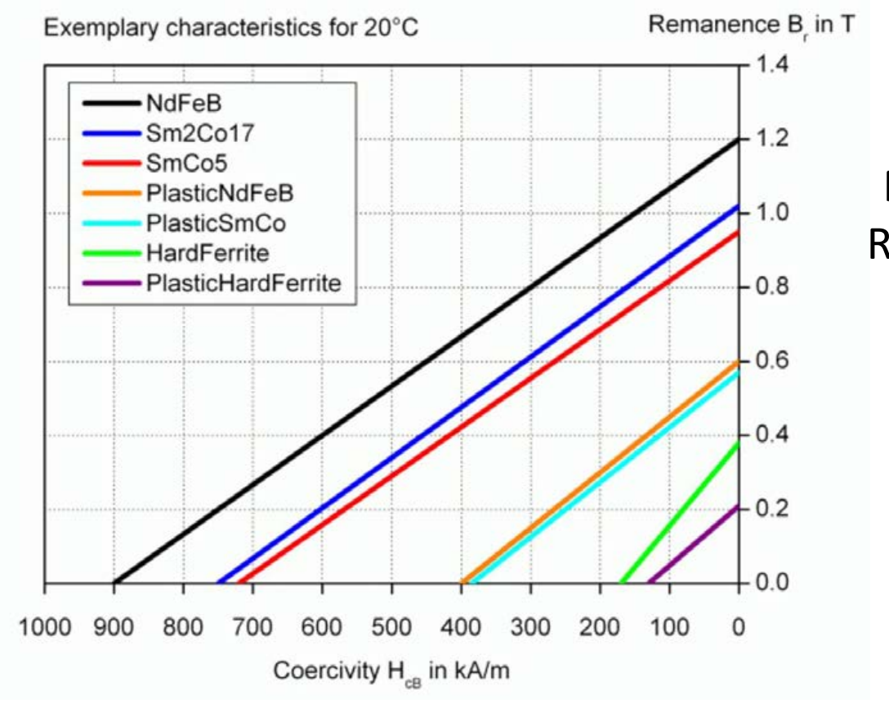


Figure 12. Remanence vs. coercivity

Drawbacks of Neodymium Magnets

- Neodymium magnets are very susceptible to humid environments
- The Nd^{3+} ion is the most common ion of neodymium and reacts with water to form neodymium hydroxide
- Corrosion of neodymium magnets can be slowed by adding a coat of zinc, nickel, tin, or a mixture of the three
- The Curie temperature of neodymium magnets is lower than other strong permanent magnets such as AlNiCo and $SmCo_5$ magnets
- A lower Curie temperature reduces the range of application of neodymium magnets

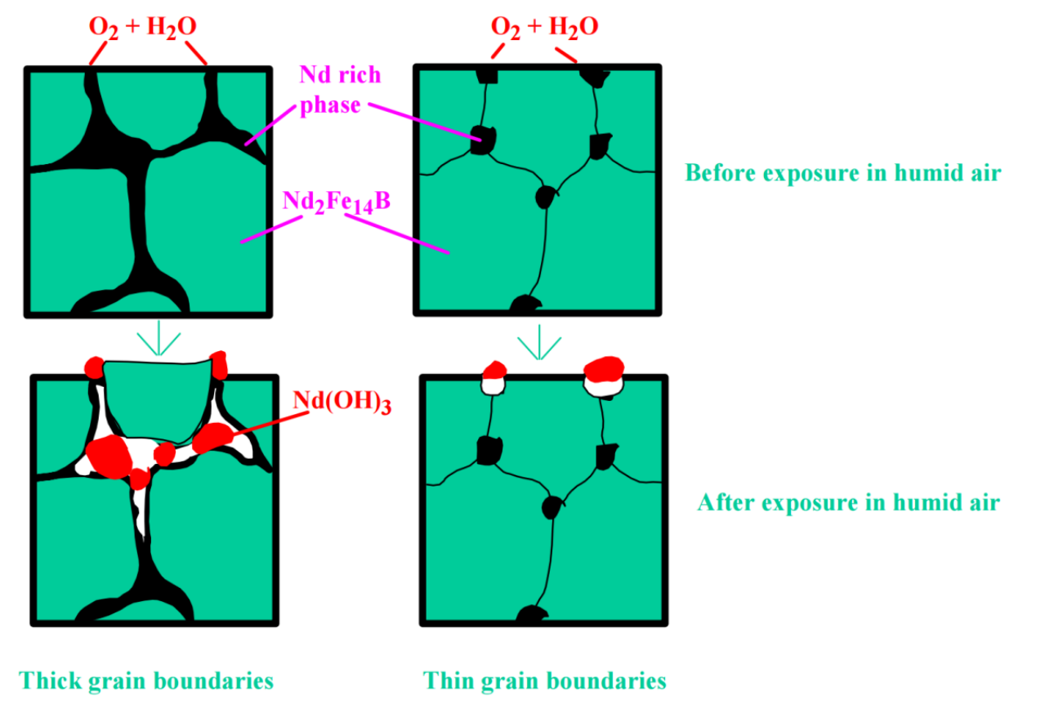
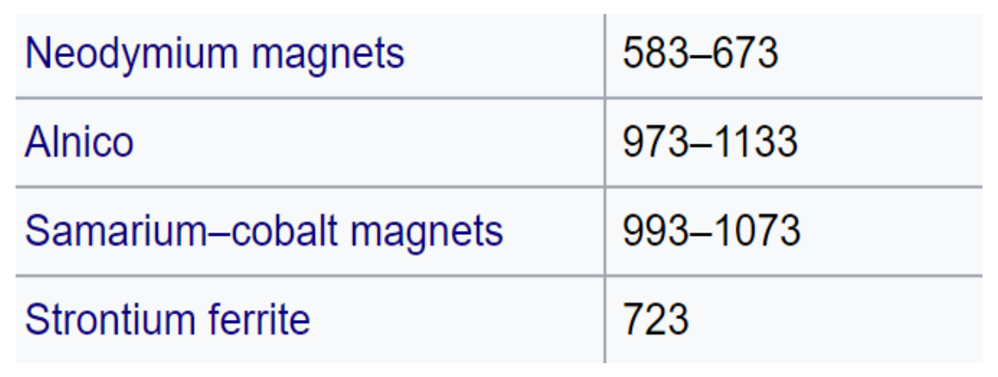


Figure 13. Corrosion of neodymium magnet



Neodymium magnets	583–673
Alnico	973–1133
Samarium–cobalt magnets	993–1073
Strontium ferrite	723

Figure 14. Curie temperature of magnets in K

Conclusions

The crucial piece in the operation of the vibration unit of a cell phone is the magnet. The magnet used must be small yet strong enough to produce torque within the motor. Neodymium magnets are preferred due to high magnetic density and remanence compared to other magnets. The neodymium magnet must be plated with either tin, nickel, zinc, or a mixture. Wiring of the motor is done with copper due to cost while partially sacrificing conductivity. Gold and silver are better conductors, but are more expensive and can be replaced by copper. The wiring must also be coated with a thin, tough polymer film. Stainless steel and plastic are used for the other components due to cost issues.

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