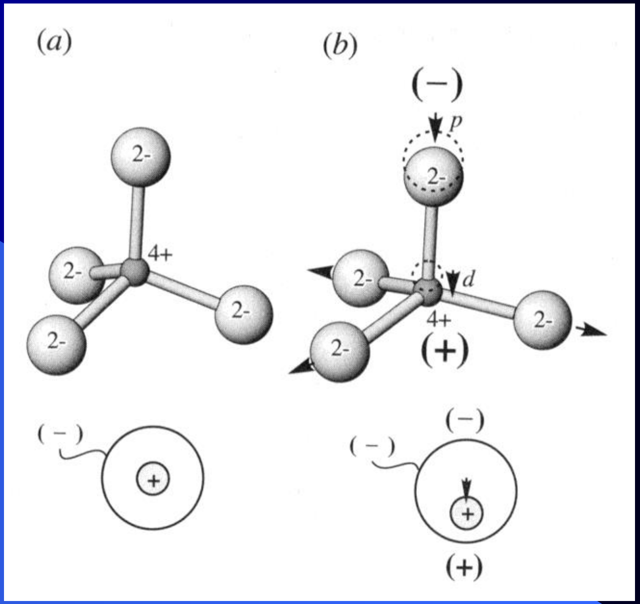
Earth Materials I – Piezoelectricity, Density, and Magnetic Susceptibility

Piezolectricity

Figure 6.14 Piezoelectricity. (*a*) A silicon tetrahedron consists of a Si^{4+} centered within four O^{2-}. The positive charge is centered within the negative charge as is shown schematically with the two circles below. (*b*) If deformed by pressing downward at *p*, an O^{2-} and the Si^{4+} are moved downward distance *d* and the three O^{2-} on the base are spread outward. Because only one O^{2-} moves down, the center of the positive charge on the Si^{4+} is moved downward relative to the center of mass of the negative charge on the four O^{2-}. This charge displacement produces a voltage, that is positive on the bottom and negative on top.



The crystal CANNOT have a center of symmetry. Common piezoelectric minerals are quartz, topaz, and tourmaline

Density and Specific Gravity

The specific gravity ($G = \rho/\rho_{H2O}$) of a mineral is a function of how tightly the ions/atoms are packed (the packing index) and the chemical composition. The packing index is

$$PI = \frac{V_I}{V_C} \text{ x } 100$$

where PI is the packing index, V_I = the total volume of the ions in the unit cell based on their ionic radii, and V_C = the volume of the unit cell.

Note that for Density and Specific Gravity have the same numerical value. However specific gravity is unitless. Density is reported either as g/cm^3 (cgs units) or kg/m^3 (SI units).

The specific gravity of a mineral can be determined by using a pychnometer

Magnetism in minerals

- A spinning electron produces a magnetic field (Bohr magnetic moment).
- Bohr magnetic moment can be cancelled if there are two electrons in an orbital.
- In order for a mineral to be magnetic it must have orbitals with unpaired electrons.
- The most important elements are the transition metals (Fe, Mn, Ti, and Cr) that have only partially filled 3d orbitals.
- The strength of the magnetic moment depends on the number of unpaired electrons.
- Fe^{3+} and Mn^{2+} have 5 unpaired 3d electrons and thus the largest magnetic moment.
- The nature of the magnetic behavior of a mineral that contains these transition metals depends on how the magnetic moments of the atoms/ions are oriented within the crystal structure.

Diamagnetism – all orbitals of the atoms/ions contain paired electrons. No magnetic behavior. When placed in a magnetic field diamagnetic minerals will be slightly repelled.

Magnetic behavior

- Paramagnetism – magnetic moments of constituent atoms/ions are not aligned. The net magnetic moment is zero. Applying a magnetic field leads to a slight alignment of the magnetic moments. Magnetic susceptibility is a measure of the strength of the magnetic moment. This depends on chemical composition and crystal structure.
- Ferromagnetism – magnetic moments of the constituent atoms/ions become aligned forming magnetic domains. Application of an external magnetic field leads to the alignment of the magnetic domains and permanent magnetism.
- Ferrimagnetism – there are some unpaired electrons that can form magnetic domains that can be aligned when placed in a magnetic field. Currie T and remnant magnetism.
- Antiferrimagnetism – minerals in which antiparallel spins completely cancel to yield zero net magnetic moments.

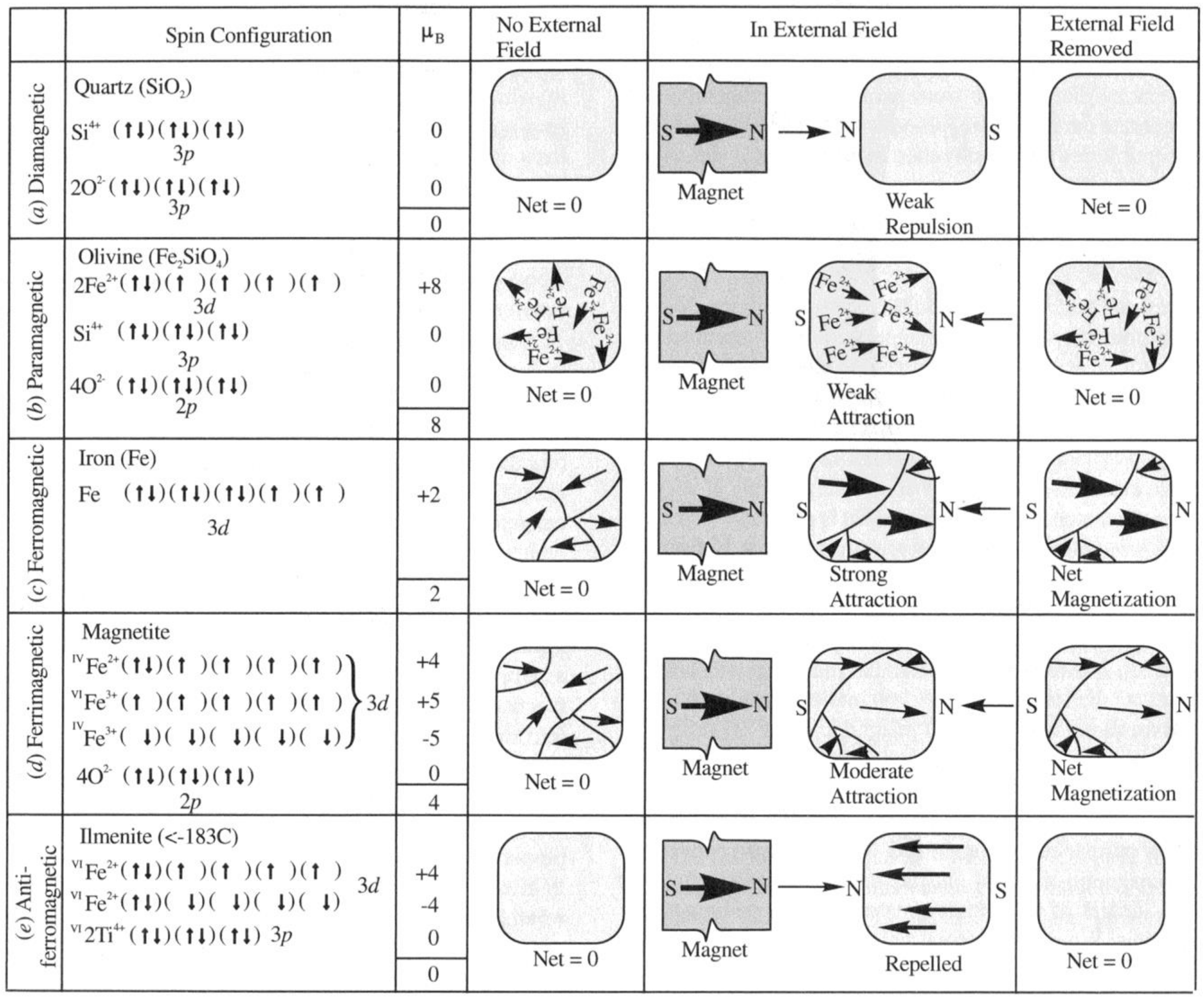


Figure 6.13 Magnetism. See text for discussion. (*a*) Diamagnetism in quartz. Neither Si^{4+} nor O^{2-} has unpaired electrons so neither has a Bohr magnetic moment μ_B. (*b*) Paramagnetism in olivine. The Fe^{2+} has a net Bohr magnetic moment, but in the absence of an external magnetic field, the orientations are random. (*c*) Ferromagnetism in native iron. Each iron atom has two unpaired electrons and a Bohr magnetic moment of 2. Domains within the mineral have uniform magnetic orientation. (*d*) Ferrimagnetism in magnetite. The $^{IV}Fe^{3+}$ and $^{VI}Fe^{3+}$ each has five unpaired electrons but with opposite spins so their net magnetic moments cancel. The $^{IV}Fe^{2+}$ has a net magnetic moment and causes the magnetite to have ferromagnetic properties. (*e*) Antiferromagnetism in ilmenite below −183°C. Fe^{2+} in adjacent sites has antiparallel spins. Net magnetic moments cancel. Antiferromagnetic materials are repelled by a magnet.

Magnetic Susceptibility

Magnetic susceptibility characterizes the ability of a substance to be magnetized when exposed to external magnetic field. In magnetically isotropic substances, it is defined as follows

$M = \mathrm{k}\, H$,

where *M* represents the vector of the induced magnetization (in SI of units in A/m), *H* is the vector of the intensity of magnetic field (also in A/m) and k is the magnetic susceptibility (dimensionless scalar entity). In some substances, the susceptibility is constant, while in the others it is a complex function of the field intensity.