Cooperative magnetism

The **magnetization** describes the magnetic state of matter which was brought into a magnetic field. The magnetization of matter is based on the orientation of permanent magnetic moments. A spontaneous magnetization denotes the parallel orientation of the magnetic moments within Weiss regions without the influence of a magnetic field (**ferro- and ferrimagnetization**)
An electron which is circling around an atomic nucleolus has an orbital magnetic moment (exception: s-electrons) and because of the electrons spins it has a spin magnetic moment. Often the orbital magnetic moment is in the first approximation suppressed ➔spin-only magnetism (e.g. ions of the first transition row).
In a homogenous magnetic field with magnetic flux B, matter may influence the magnetic field in two different ways:
a) diamagnetic ➔the density of the field lines decreases.
b) paramagnetic ➔the density of the field lines increases.

As a result the original magnetic flux $B_{external}$ changes: $B_{internal} = B_{external} + B'$. The diamagnetic effect occurs in all substances. The *paramagnetic* effect exists, when the individual magnetic moments of electrons are not compensated, so that the atoms, ions or molecules have a permanent external magnetic moment and behave as molecule magnets which *point randomly in all directions* because of thermal motion (e.g: for most transition element ions or for all molecules with an odd number of electrons).

The dimensionless constant χ_v (**magnetic susceptibility)** describes the change of the magnetic flux: $B' = \chi_v \times B_{external}$
The diamagnetic component χ_{dia} is independent of temperature, while the paramagnetic susceptibility χ_{para} is dependent of temperature, because the thermal motion of the molecules works against the alignment of the molecular magnets in an external magnetic field (Curie's Law: "The paramagnetic susceptibility is inverse proportional to the absolute temperature").
The **Curie–Weiss Law** $\chi_{para} = C/(T-\Theta)$ considers that magnetic dipoles affect the orientation of their neighbours in the external magnetic field.
C stands for the Curie constant and is related to the μ_{mag} of the matter.

Below a certain temperature, the magnetic moments of individual paramagnetic particles interact **➔cooperative/collective magnetism**. This particles are either directly adjacent to each other (direct magnetic interactions) or they are bound via diamagnetic particles (superexchange). There exist three different types of the cooperative magnetism:
-In a **ferromagnetic** substance all magnetic spin moments from adjacent atoms align spontaneously *parallel* below the Curie –Temperature T_C. But the sample remains unmagnified because the alignment without previous exposure to a magnetic field is restricted to Weiss regions. (e.g.:Fe T_C=766°C, Co, Ni Gd, EuO). Above T_C ferromagnetic materials are paramagnetic.
-In **antiferromagnetic** substances, the magnetic spin moments of the paramagnetic centres (*same magnitude*) spontaneously orient themselves *antiparallel* below the Neel-Temperature T_N. Above the T_N → paramagnetism.
Examples: Cr (475K), Mn (95K), MnO, CoO, NiO
-**Ferrimagnetism** is comparable to antiferromagnetism but *the magnetic moments have different magnitudes.* Examples: Ferrite (Fe_3O_4), Garnet

Temperature dependence of the susceptibility χ:
paramagnetic: χ increases with decreasing temperature;
ferro/ferrimagnetic: χ increases at first low with decreasing temperature, below Curie-temperature χ increases strong (complex behaviour);
antiferromagnetic: χ increases with decreasing temperature, above and below T_N χ decreases, max.(χ)= T_N

Questions:

1.) Explain the terms susceptibility, Curie Law and cooperative magnetism. Sketch the temperature dependence for para- dia- and antiferro-magnetic materials.

2.) Describe and sketch (use arrows for the magnetic moments) the differences between para-, ferro-, ferri- and antiferromagnetism.