XII:Magnetic Materials

1:Atomic magnets:Electron Spin

- Atoms are made up from :
  - Electrons
  - Protons
  - Neutrons
- They all have mass and spin.
- Spin is a quantum property:
  - up(1/2) and down(-1/2), the magnets directions
  - Spins tend to pair:1/2 & -1/2,but the unpaired electron produced the magnetism.
  - Effective spin, S, is the sum.

2: Beyond a single atom - magnetic ordering

- All atoms with order numbers of electrons must have unpaired spins(even can too).
- The unpaired spins in neighboring atoms interact and the type of interaction caused the magnetic order.
- In some transition metals spins line up to form simple permanent magnets.

3:Beyond a single atom-Ferromagnetic ordering

- Each of the atoms can be thought as a bar magnet.
- The combination of these magnets which all pointing in the same way is called Ferromagnetic ordering.

4:Magnetic domains

- Atoms in solid are spaced by ~$\mathrm{\mathring{A}}$
- Over μ m's, magnetic materials in domains.
- Domains are randomly orientated.
- An external magnetic field line them up.
- When turn off, we have a permanent magnet.
- Real domains:Cobolt(Co)

5:Magnetic hysteresis

- At "0":
  - Domains are randomly aligned.
  - No net magnetic flux from the materials.
- 0-b:
  - Domains aligned gradually
- b-c:
  - All domains aligned
  - Further increase in flux is linear and reversible
  - No further magnetization
  - Saturation
- Reduction the external fields:
  - Some domains remain aligned.
  - d is termed remnant flux.(we made a permanent magnet).

- We can continuously cycle the external field, switching the direction of alignment of the domain periodically.
- Switch the domains cost the energy.
- The energy is proportional to the area of the hysteresis loop.
- This energy heats the metal.
- This contributes to inductive heating to anneal steel.

6: Hard and soft ferromagnetic materials

- Th bigger the hysteresis, the costlier it is to change polarity.
- For hard materials:
  - Large coercive force.
  - High hysteretic loss.
  - Good for permanent magnets.
  - Applied for permanent magnets and inductive heating
- For soft materials:
  - Small coercive force
  - Low loss
  - Not for permanent magnets

7: Ordered magnetism

- In addition to ferromagnetism, there are other ordered arrangements.
- The atomic magnets can alternate in alignment
  - Antiferromagnetism
- The strengths of the atomic magnets may differ.

8: Disordered magnetism

- The second law of thermodynamics tells the nature of disorder.
- In many materials(Paramagnets) the electron spins may be:
  - Far away
  - Weakly interacted
- These magnets are weakly attracted by external field.
- These show no hysteresis.
- Some may repel the field: Diamagnets

9: Temperature

- Heating up magnets
  - As the temperature is raised , thermal agitation introduced disorder.
  - Above a critical temperature, it may lost the order and become paramagnetism.
  - For ferro- & ferrimagnets this is called the Curie temperature.
  - And for antiferromagnets the Neel temperature.
- Cooling down metals
  - There is zero electrical resistance
  - This magnet is a perfect diamagnet.
  - These are superconductors.
  - This is fundamentally a quantum magnetic phenomenon, not an electrical one.
  - Superconductors exhibit the Meisner Effect.