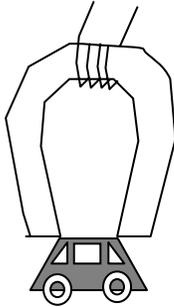


3.15 Electrical, Optical and Magnetic Materials and Devices
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Fall 2006

Problem Set 7: out 29 November
Due Weds. 6 December

1. We want to build an electromagnet that can pick up a car in a scrapyard.



Assume a car has a mass of 2000 kg of which 25% is made of steel ($B_s = 1$ T, density 2.5 g/cm^3). Assume that the maximum force on a magnetic material of moment M and volume V in a field H is given by $\mu_0 MHV$. Suppose the core has a length of 5 m and the gap length is 1 m and there are 10,000 turns of wire around the core. Choose a core material from the list below and assess the feasibility of building an electromagnet strong enough to do the job.

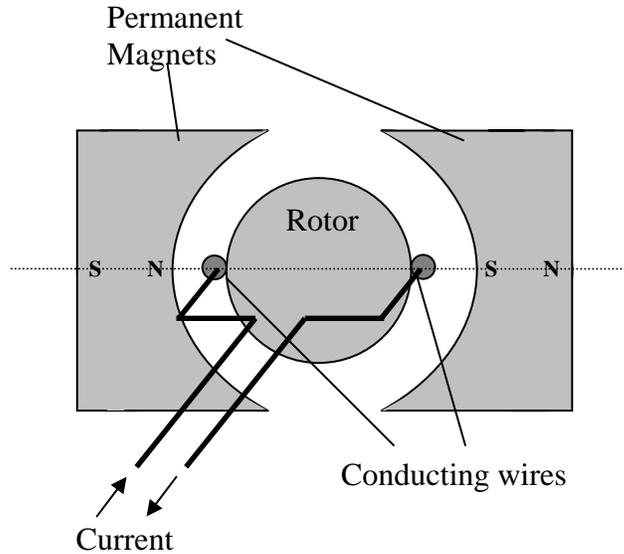
Hint: Start by calculating how much field you would need to pick up the car.

Magnetic materials

	T_c/K	B_s/T	$H_c / A/m$	μ_r
Fe	1043	2.2	4	200,000
Fe-3%Si	1030	2.1	12	40,000
a-FeBSi	630	1.6	1	100,000
Alnico-5	1160	1.4	64,000	1000
BaO.(Fe ₂ O ₃) ₆	720	0.4	264,000	2000
SmCo ₅	1000	0.85	600,000	1000
Nd ₂ Fe ₁₄ B	620	1.1	890,000	2000

2.

Electric motors are used in a broad range of applications, from household appliances to electricity-powered cars. A schematic of a simple DC motor is given below:



A sliding electrical contact reverses the polarity of the applied current when the rotor has reached 90 degrees from the position shown above.

- Explain how passing a DC current produces torque on the rotor. What is the relation between force applied at the edge of the rotor to current flow and magnetic field? Why is the sliding electrical contact necessary?
- Redraw the above diagram *and* a diagram in the plane denoted by the dashed line, indicating the directions of magnetic field, electrical current, and rotor motion.
- At what angles of rotation is the torque on the rotor maximum and minimum in the above design? What change could you make that would give a more uniform torque?
- Why would you want to use a magnetic material in constructing the rotor? What is the desired level of coercivity of this material? What other properties are desirable?
- A certain hybrid-electric car uses the same electric motor that propels the car to generate electrical power as the car is braking. Explain how this is possible.

3.

A magnetic tape consists of elongated needle-shaped particles of maghemite (cubic iron oxide, Fe_2O_3) sprinkled onto a plastic backing strip and stuck down using an epoxy. The particles are typically $\sim 250\text{nm}$ long and 25 nm wide.



- a) What factors control the coercivity of these particles, and which of these factors do you think is the most important? What sort of magnetic domain structure do you expect the particles to have (draw a sketch)?
- b) Recording of data bits onto tape is similar to what happens on a hard disk, except that the bits are larger. Draw how a '1' and '0' would be represented on the tape. Explain what limits the maximum data density that can be recorded onto tape, compared with the maximum data density that can be recorded onto a hard disk.
- c) There is another similar oxide of iron called magnetite, Fe_3O_4 . It has a structure based on cubic spinel (i.e. its formula can be written AB_2O_4 , where the A sites are occupied by Fe^{3+} and the B sites by equal numbers of Fe^{3+} and Fe^{2+}). The A ions are all magnetized along the +x direction, while the B ions are all magnetized along the -x direction in the crystal.

What kind of magnetic material is magnetite?

What is the electronic structure and magnetic moment of an Fe^{3+} ion and an Fe^{2+} ion?

What is the net magnetic moment of a molecule of Fe_3O_4 ?

If a the unit cell of Fe_3O_4 has a lattice parameter of 0.8 nm, and contains 8 molecules of Fe_3O_4 , what is the saturation magnetization of the material?