Energy Devices – Introduction and Motors (Lecture 1)

Eric R. Switzer
(http://kicp.uchicago.edu/∼switzer/)

Oct. 3, 2009

Lecture outline:

- Consumption energy scales.
- The program of education in physics, current research, and outline of the series.
- Moving charges in a magnetic field feel a force, the Lorentz force.
- Translating the Lorentz force to the force on currents in magnetic fields.
- The force on currents in a magnetic field can be used to make a DC motor!
- From Oersted and Ampère: Currents produce magnetic fields; the electromagnet.
- The magnetic field of permanent magnets is due to quantum-mechanical effects which spontaneously align microscopic spins.
- Domains and magnetization.
- We now know how to make a simple motor!

Table 1: Energy scales from the global to microscopic.

Object	Energy scale (J)
Tsar Bomba (50 MT):	2×10^{17}
Mount St. Helens (24 MT):	1×10^{17}
Worldwide energy use in 1 hour:	6×10^{16}
US energy use in 1 hour:	1×10^{16}
Coal power station (1000 MW electrical) in 1 hr:	4×10^{12}
A barrel of oil (bboe):	6×10^{9}
Car on the highway (55 mph, 30 mpg, gasoline) for 1 hour:	2×10^{8}
1 gallon of gasoline:	1×10^{8}
A ten pound log:	9×10^{7}
2000 kcal Consumed:	8×10^{6}
A kilowatt for one hour:	4×10^{6}
1 horsepower for an hour:	3×10^{6}
1 hr of human exertion (800 W):	3×10^{6}
1 candle (77 W) for an hour:	3×10^{5}
60 W bulb for one hour:	2×10^{5}
1 g of carbohydrates/protein:	2×10^{4}
Heat 1 lb water one degree F (BTU)	1×10^{3}
Heat 1 g water one degree C (cal)	4
Lifting an apple one meter:	1
Particle at the LHC in CERN (7 TeV):	1×10^{-6}
A single uranium fission reaction (200 MeV):	3×10^{-11}
A single deuterium-tritium reaction (18 MeV):	3×10^{-12}
Ionizing hydrogen (13.6 eV):	2×10^{-18}
Complete methane (one molecule) burning (10 eV):	2×10^{-18}
A typical solar photon (2.44 eV):	4×10^{-19}
A molecule in the room (0.04 eV):	6×10^{-21}

Image sources:	
Fig. 1 (left), 2 (right)	Hand derived from `http://en.wikipedia.org/wiki/File:Right_hand_rule_cross_product.svg`.
Fig. 2 (left)	Motor shape suggested by `http://sol.sci.uop.edu/~jfalward/physics17/chapter9/chapter9.html`.
Fig. 3	Defect added to domains suggested in *Solid State Physics* by Ashcroft and Mermin.

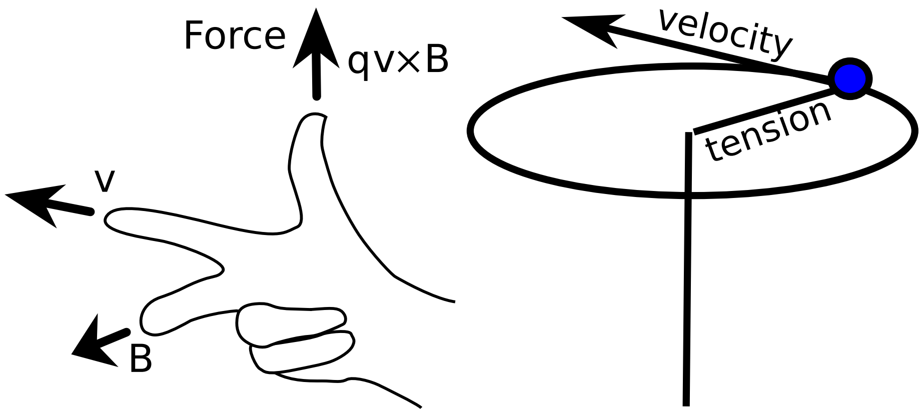

Figure 1: Finding the direction of the force (F) from a magnetic field (B) on a charge with velocity v. When an object moving at constant velocity experiences constant acceleration that is perpendicular to the velocity, it moves in a circle.

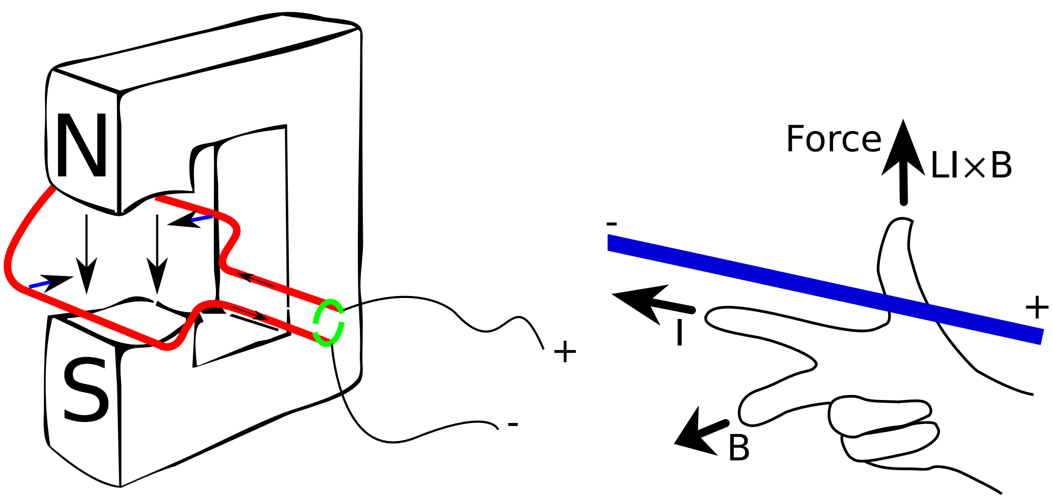

Figure 2: A simple motor described in this lecture. The right hand rule tells us that the force on a length of wire (direction of thumb) is perpendicular to the direction of the current flow and the magnetic field. The net force drives the loop counter-clockwise.

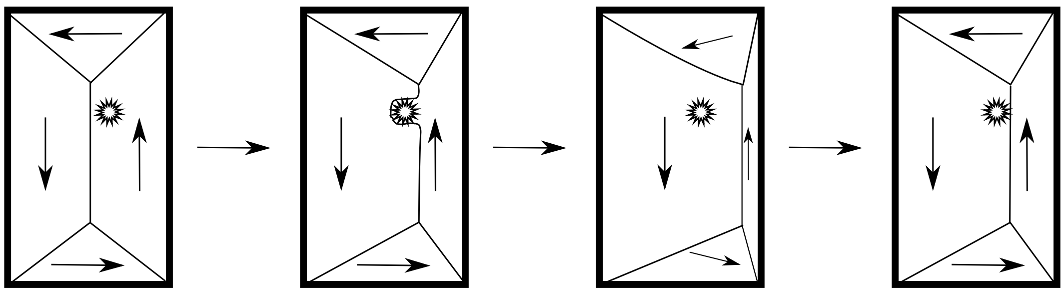

Figure 3: Making a magnet. Ferromagnetic materials comprise many smaller magnets. In a piece of standard iron, there is no net magnetic field. This is represented by the leftmost box above. As we turn up an external magnetic field, the domains grow (second from left), and as we continue to turn up the field, the domains grow and their magnetic moments rotate. In the final box, we have turned the field off again. In real magnetic materials, imperfections (here a blob) will hinder the motion of the domain – while a strong field can make the domain snap across the imperfection, it is unable to snap back across it when there is no external field. (Incidentally, you can build a device to hear this domain motion and the resulting sound is called Barkhausen noise.) In general, this inability to return to zero magnetization is “hysteresis”. Because the down-pointing domain is larger in the end, this material will act like a little magnet. This is the principle of how magnets are made – raw materials are compressed together and magnetized in the presence of a field.