Utilizing the Magneto-Coulomb Effect

1. Introduction

The Magneto-Coulomb Effect (MCE) is a recent discovery to explain certain characteristics in single electron spin-valve devices. All the literature on the subject concerns nano-systems, there appears to be no recent evidence of the effect being observed or used in macro systems. However, the basic MCE could also apply to larger devices, and it seems to be a ready answer to the paradoxical features of the Unruh/Coler devices. For that reason it is worth studying the MCE as it applies to large scale, which is the objective of this paper.

The MCE concerns ferromagnets within an external magnetic field, where the applied field changes the energies of the spin-polarized conduction electrons within the magnet. The following explanation is taken from [1], which initially considers the case where the external applied field is parallel to the internal magnetization of the ferromagnet (assumed to be constant). The energies of the spin up (↑) and spin down (↓) electrons shift by the Zeeman energy, in opposite directions. However, for a ferromagnet, the density of states of both spin species differs ($N_{\uparrow} > N_{\downarrow}$), with more spin-up electrons gaining the Zeeman energy than spin-down electrons lose. Hence the overall energy of the electrons increase and a shift in the chemical potential $\Delta\mu$ needs to take place to keep the number of electrons constant. In practice, the ferromagnet will be attached to a non-magnetic lead. This demands equal chemical potentials in both metals. Hence, the energy shift in the ferromagnet translates to a change in the contact potential between the ferromagnet and the normal metal, $\Delta\phi$, according to, $-e\Delta\phi = -\Delta\mu$. Equivalently, one could say that the work function of the ferromagnet changes by $\Delta W = -\Delta\mu$. Note that the parallel orientation of the external field creates this negative work function, causing the ferromagnet to try to shed electrons into the contacting metal, whereas the opposite is the case for an anti-parallel applied field. If the applied field alternates at some frequency then the ferromagnet pumps alternating current into the contact. In large systems the ferromagnet can be considered to be almost an infinite source of electrons, hence the single electron coulomb-blockade seen in nano-systems does not occur.

An electrically isolated ferromagnet within a RF magnetic field would exhibit alternating surface charge, as depicted in figures 1 for the parallel case and figure 2 for the anti-parallel case. This could be the basis for an experiment to verify the effect.

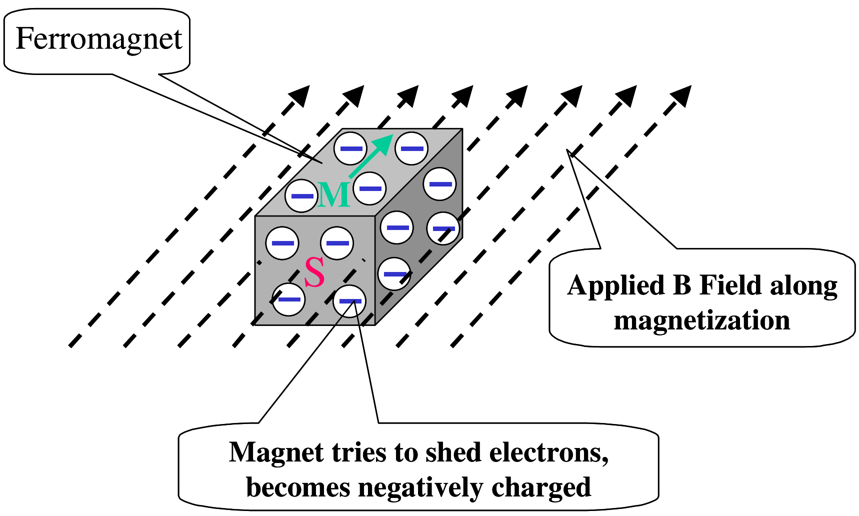


Figure 1. Surface charge induced by parallel applied field

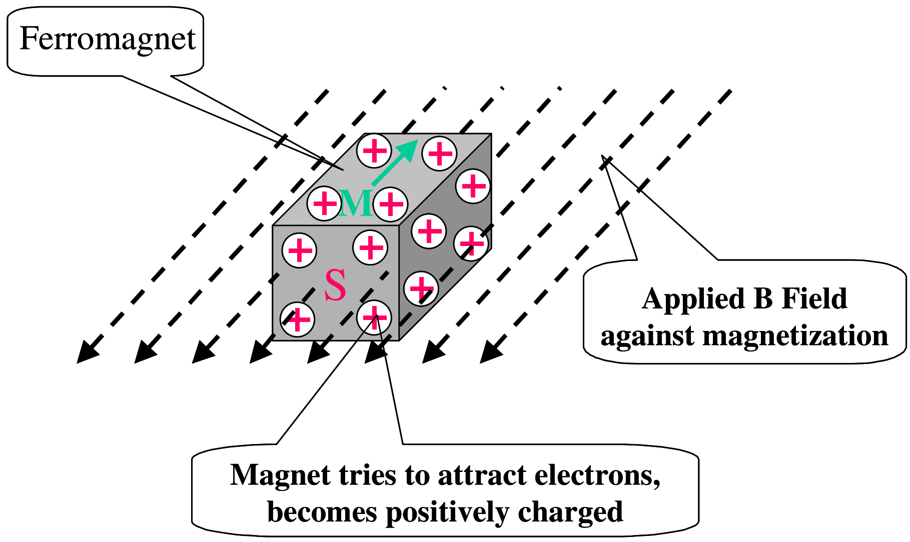


Figure 2. Surface charge induced by anti-parallel applied field

2. Magnitude of MCE

From [1] the contact potential $\Delta\phi$ is given by

$$\Delta\phi = -\frac{1}{2} P g \frac{\mu_B}{e} B \qquad (1)$$

where g is stated in [1] as the electron gyromagnetic ratio (actually the dimensionless electron g-factor which is close to 2 in value), μ_B the Bohr magneton, e the electron charge, B the applied field and P the thermodynamic spin-polarization given by

$$P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} \qquad (2)$$

Equation (1) can also be derived for the effective potential when a magnetic field gradient is considered. A magnetic dipole μ that is aligned with the B field along x will endure a magnetic force given by

$$F_x = \mu \frac{dB_x}{dx} \qquad (3)$$

With an electron as that dipole the force can be considered to be due to an effective E_x field

$$E_x = -\frac{\mu}{e} \frac{dB_x}{dx} \qquad (4)$$

Since $E_x = \frac{d\phi}{dx}$ the effective chemical potential ϕ is

$$\phi = -\frac{\mu}{e} B_x \qquad (5)$$

Taking account of the spin polarization P and the actual dipole moment μ of the electron as $g\mu_B$ leads to (1)

Whereas (1) assumes the polarization P to be a fixed value, in the Coler stromerzeuger the ferromagnet is a Fe core within a coil carrying a DC magnetizing current placed within a larger flat coil carrying RF current. Thus the polarization has a static value plus an alternating value. Taking $P = \frac{M}{M_{SAT}}$, where M_{SAT} is the saturation magnetization, and since

$M = \chi H$ where χ is the magnetic susceptibility, and with g cancelled by the factor 2, we can recast (1) as

$$\Delta\phi = -\frac{\chi H^2}{M_{SAT}}\frac{\mu_B\mu_0}{e} \tag{6}$$

where we have also replaced B by $\mu_0 H$. Saturation flux density B_{SAT} is a more widely recognized material characteristic than M_{SAT} and is given by $B_{SAT} = \mu_0 M_{SAT}$ hence (6) can be written as

$$\Delta\phi = -\frac{\chi H^2}{B_{SAT}}\frac{\mu_B{\mu_0}^2}{e} \tag{7}$$

Here H has two components, H_{DC} from the magnetizing coil current and H_{RF} from the RF coil. Expanding H^2 and since $H_{DC} >> H_{RF}$ we obtain

$$\Delta\phi \approx -\frac{\chi\left({H_{DC}}^2 + 2H_{DC}H_{RF}\right)}{B_{SAT}}\frac{\mu_B{\mu_0}^2}{e} \tag{8}$$

Ignoring the static component of $\Delta\phi$ leaves us with the RF component

$$\Delta\phi \approx -\frac{2\chi H_{DC}H_{RF}}{B_{SAT}}\frac{\mu_B{\mu_0}^2}{e} \tag{9}$$

In terms of the applied RF B field (9) becomes

$$\Delta\phi \approx -\frac{2\chi H_{DC}B_{RF}}{B_{SAT}}\frac{\mu_B\mu_0}{e} \tag{10}$$

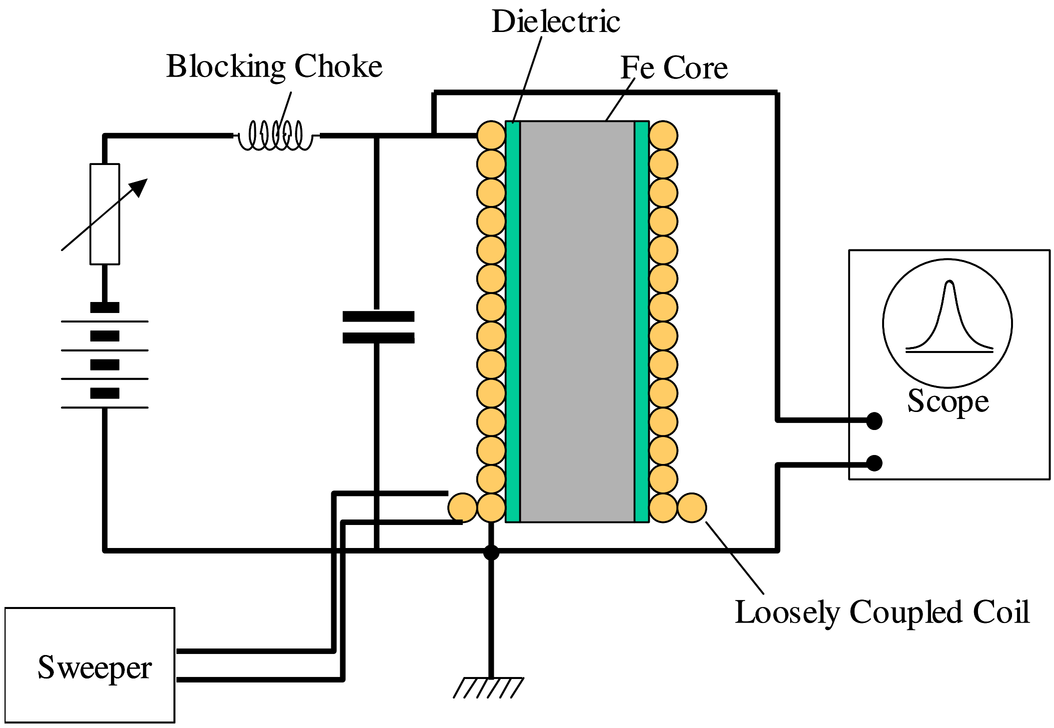
Using 100 turns over 0.1 meter as a typical experimental coil placed around the core and carrying current i we obtain $H_{DC} = 10^3 i$. Susceptibility χ is not well controlled in Fe depending on purity, annealing and magnetic history, which is perhaps why Coler had difficulty in getting the adjustments right. For pure Fe χ can be as high as 10^5 but 10^4 is more likely. Then since the constants $\frac{\mu_B\mu_0}{e}$ yield a value 7.274E-11 we obtain a RF contact potential of about 700 µV per (RF) Tesla per (DC) ampere of coil current, possibly rising to 7 mV if the higher susceptibility is achieved.

This voltage appears at the surface of an electrically isolated Fe core and this poses a dilemma in how to usefully connect to this. At first sight it would seem that the self-capacitance of the core should play its part, but that approach does not take account of the enormous store of charge within the core volume. It is posited here that the core behaves as though it were electrically connected to earth, whence it is capable of transferring any amount of charge via capacitive connection limited only by (a) the contact potential $\Delta\phi$ and (b) the value of the capacitive connection. If this is true then Coler's machine wastes much of the RF current through the stray capacity between the core and the magnetization winding, leaving only a small portion to appear via the capacitor plates. In the next section this problem is addressed by using the close wound coil for both the DC and the RF currents then the stray capacitance to the core becomes integral to the RF circuit. Alternatively permanent magnets are used to magnetize the core. Note that if the core is itself a permanent magnet then the equations derived here do not apply and the advantage gained by the high susceptibility is lost.

3. Suggested Experiments with Fe Cores

Figure 3 shows an experiment where the core surface is covered by a thin dielectric, then the coil is tightly wound over that. This maximises the capacitance between coil and core, which could be in the order of 500pF. *The core has no other electrical connection to it.* From the perspective of the shunt capacitance now seen by the coil, this will be quite low being the value given by that 500pF in series with the self-capacitance of the core, which is in the region of 10pF. However for the injection of charge from the core via the MCE it is the 500pF value that determines this. This contradiction goes against all good engineers' circuit intuition, but we are dealing with an effect that has only recently been discovered and therefore has no pedigree on which we can rely. At the nano level the MCE is subject to Coulomb blockade, which is the loss of electrons in the tiny source volume significantly affecting the number density there. In our case the source volume contains such a large quantity of electrons that it can be considered an infinite source, hence the apparent (but invisible) electrical connection to infinity that resolves the above conundrum.

With 100 turns on the core the inductance is about 1mH requiring 625pF to resonate at about 200KHz. With 1 A of DC magnetization current the contact potential yields a value of about 300 μV per amp of RF current that relates to an effective resistance value of 300 μΩ. With the correct direction of the applied field that resistance can be negative and if it has a magnitude greater than the series losses in the RF circuit self-oscillation could occur. In the experiment a sweep generator is loosely coupled to the circuit and the tuned circuit response is displayed. The magnetization current is then adjusted and if the MCE is present a change of Q will be noticed. By noting the response both with and without MCE the MCE can be



quantified.

Figure 3. Experimental Scheme

Figure 4 shows a similar arrangement except here the magnetization is supplied by permanent magnets. Adjusting the separation of the two magnets has the same effect as varying the magnetizing current in the first scheme.

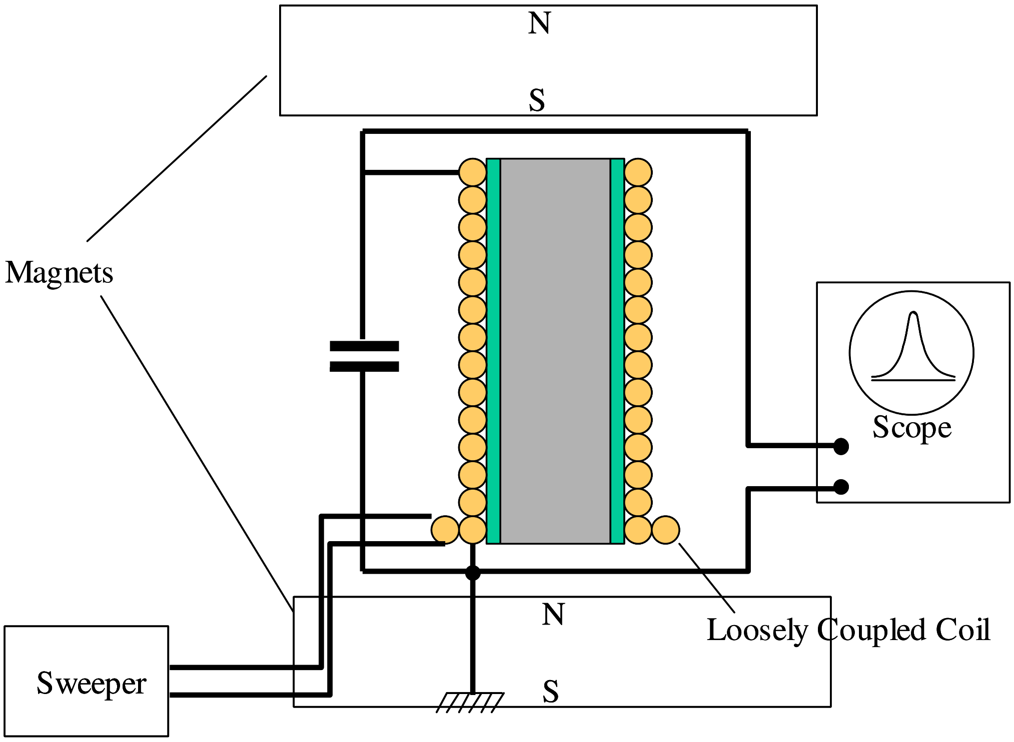


Figure 4. Alternative Scheme

4. Suggested Experiment with Permanent Magnets

The alternating nature of the surface charge depicted in figures 1 and 2 suggests an experiment using two permanent magnets that are arranged side by side with oppositely directed magnetizations and subjected to a RF field. If connected via an appropriate circuit RF current should then flow from one magnet to the other. This is depicted in figure 5 with the magnets connected to a LC circuit tuned to the drive frequency so that the resonant circuit magnifies the low output voltage up to a measurable level. The two magnets hold themselves together against the insulator by magnetic attraction.

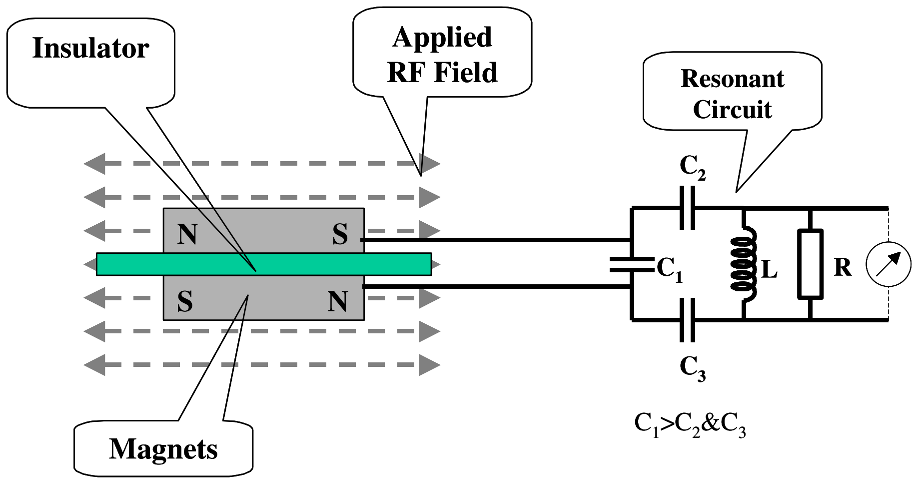


Figure 5. Experiment using Permanent Magnets

Figure 6 shows the complete experiment with drive from a signal generator connected to a coil surrounding the two magnets. Here the LC circuit is shown as a step-up transformer as an alternative method of increasing the voltage.

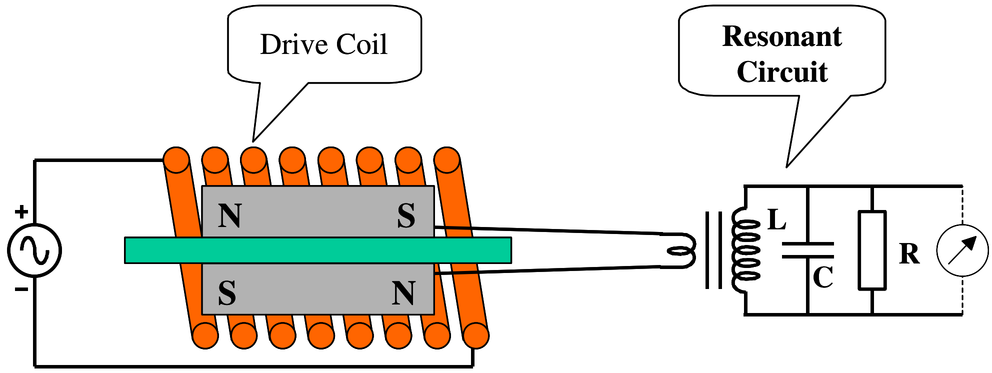


Figure 6. Showing Alternative Step-up Circuit.