# The Inventions of Hans Coler


## 1. Overview

Hans Coler was a German Naval officer who, in the early part of the 20th century, invented a remarkable apparatus which produced more DC power out than was input from its batteries. This was examined and tested in 1926 by three Professors, two working as a team and the third working independently. Since the DC currents and voltages were well within the capability of the measuring instruments of the day, and were cross checked against meters provided by the Professors, it can be assumed that the apparatus did exactly what the inventor alleged. In any event all three Professors were satisfied of that, and their examination of the open device ruled out any hidden power source. They did not believe Coler to be a trickster. They all concurred that the apparent "source" of this DC power was the iron rods (used as cores for electromagnets) through which current was passed longitudinally. Although they recognized they could be facing the exploitation of a new source of energy whose further development could be of immense importance, they could not explain this source which seemingly violated scientific principles. Aware no doubt that their reputations were at stake, two of the Professors did not wish their involvement to be made public.

Coler thought the energy came from space. Even today the claim that a simple iron rod can extract energy from space is ridiculed by the scientific establishment. Somehow Coler's iron rods exhibited *absolute negative resistance*, which in 1926 would also have been ridiculed. However recent progress on electron transport at the mesoscopic scale, including quantum effects, have demonstrated that absolute negative resistance *can* be achieved in conduction channels. Of particular interest here is photon assisted transport. Few scientists today would challenge the claim that an electron conduction channel can exhibit negative resistance, i.e. can produce electrical power, if the electrons are pumped by an external source of photons, after all the absorbed photons are the real source of the power! It has even been shown that the power can be DC if the channel is conditioned such that the conduction electrons spiral at the cyclotron frequency, and the pump frequency is made to synchronize with that. What Coler achieved in 1926 was exactly that sort of channel, except the photon source was not external, but *internal* to the channel. The magnetically active electrons within the iron atoms not only provide the iron with its ferromagnetic characteristic, they also precess at the Larmor frequency and are the source for the pumping photons. Since both the Larmor frequency and the Cyclotron frequency are determined by the local **B** field, at the local atomic scale they are automatically synchronized. Coler discovered by accident the means to create, within an iron rod, a self sustaining, power generating DC conduction channel pumped by the magnetically active atomic electrons. The terms *Quantum Ratchet* or *Quantum Dynamo*™ have been used to describe similar pumping actions.

## 2. Background

The author has been studying the report of some work undertaken by British Intelligence after the German surrender in World War 2. As did the USA and the USSR, the British sent teams of scientists into Germany to learn what they could from German military scientists. The British intelligence gathering was co-ordinated by the British Intelligence Objectives Sub-Committee (B.I.O.S.). Reference to this body will be found in the National Archives, but their report of interest here[1] is now archived at The Imperial War Museum. This particular report describes an investigation into the inventions of Hans Coler carried out by Mr. R. Hurst from the British Ministry of Supply and Captain R. Sandberg from the Norwegian Army. Coler and others were interrogated.

Two types of apparatus were invented by Coler, (a) his "Stromerzeuger" allegedly producing DC power in excess of that supplied by batteries and (b) his "Magnetstromapparat" creating AC but, being self oscillating, it required no power source. In the British report the Magnetstromapparat is described in some detail, with a circuit diagram, layout and coil winding details. Having been destroyed by allied bombing, no examples of either invention existed after the surrender, but Coler agreed to replicate one at British expense, the Magnetstromapparat being the one chosen. His attempt and partial success are reported. There have been other attempts since the B.I.O.S. report was declassified and made available to the public in 1979, but with no reported successes.

The Stromerzeuger, which is the subject of this present paper, is described in words only, there are no circuit diagrams or layouts. There doesn't appear to have been any attempts at replication then or since. Coler discovered it by accident, and in 1925 showed a small version to Professor Dr. Ing. Kloss (Berlin), who asked the German government to give it a thorough investigation. This was refused, as was a patent, on the grounds that it was a "perpetual motion machine". The invention was given independent examination in 1926, and ref.[1] contains translations of two German reports on these. One report (Appendix II of ref.[1]) dated 4th March 1926 covers an examination and tests conducted by Professor Kloss in the company of Professor Dr. R. Franke from the Technical College of Berlin. His results are discussed in more detail later in this present paper, but some quotations here are in order. "*The result of the investigation showed an astonishing working of the apparatus, which, without further researches cannot be explained or compared with hitherto known characteristics*". The final paragraph reads "*I should like to ask, however, that the gentleman in question (Coler) not to mention my name and that of Professor Franke nor divulge the results of our tests without our express consent, or to make them known publicly and above all not in the press*". Professors Kloss and Franke had witnessed something that they couldn't explain, that went against scientific principle, and therefore they did not wish their names to be publicly associated with it.

A second examination was carried out by Professor W. O. Schumann (Munich), his report (Appendix III of ref.[1]) is dated 3rd April 1926. It carries this "*After the present examination, carried through as carefully as the limited possibilities of experimentation permitted, I must surmise that we have to face the exploitation of a new source of energy whose further developments can be of an immense importance*". He also wrote "*I do not believe in a deception*".

It is worth noting here that the Stromerzeuger consumed power from batteries whilst delivering DC to a load, so the measurements of DC voltage and DC current were well within the capability of laboratory instruments at that time. Both reviewers used their own meters to verify the readings of those in the Coler machine. They both concluded that the device gave out significantly more power than it consumed.

In 1933 Coler and von Rugh developed the Magnetstromapparat and also made a larger model of the Stromerzeuger. This was demonstrated to Dr F. Modersohn who consented to back the invention, and formed a company (Coler GmBh) to continue the development. At the same time a Norwegian group had been giving financial support to Coler, and the two groups clashed. Coler later claimed there were "*unpleasant differences with the financiers, mostly foreigners*". Coler suffered a nervous breakdown and "*the apparatus and the original theories were lost*". It is reputed that Coler built a larger version (6KW), but Coler's own statements suggest that the effect could only occasionally be successfully reproduced. The outbreak of war put a temporary end to the experimental work.

In 1942 Coler and Dr. Modersohn applied to the OKM to supply them with materials, hoping that the apparatus could be made to work continuously. The OKM agreed and procured their release from other work so that this project could proceed apace. The OKM put Dr. Heinz Frohlich, who had experience in scientific measurements, onto the project. Dr. Frohlich, who was convinced of the reality of the phenomenon, set about investigating the fundamentals of the device. Ref.1 contains the translation of a report written by Hans Coler and Dr. Frohlich, dated 27th September 1943, which summarises OKM sponsored work conducted at the Research Department of the Admiralty (OKM) Berlin from 1st April to 30th June 1943 and work carried out at the Physical Institute of the Technical University of Berlin from 1st July to 25th September 1943. This concentrated on the energy changes which occur on the opening and closing of inductive circuits.

## 3. The Stromerzeuger re-examined.

From the written descriptions it is possible to build a perception of the Stromerzeuger construction. The following is the author's perception and may not be exact: certainly there are many details which are unknown.
The device consisted of a pair of coil structures with their axes horizontal, separated rather in the manner of a Helmholtz double-coil arrangement, as shown in Figure 1. Each coil structure actually consisted of two coils inter-wound in the bifilar manner. One of the coils in each structure was made from copper strip, and therefore had a limited number of turns. Inter-wound between these turns was a second coil of insulated wire, this coil having many more turns since each turn of the copper strip accommodated a layer of wire turns. The two copper strip coils connected together formed the "*plate*" circuit, while the two coils made from wire, also connected together, was called the "*spool*" circuit. Branch connections were made between certain turns of the two plate coils via iron rods which acted as the cores of electromagnets. Each rod also had its own coil, these electromagnet coils forming the "*exciter*" circuit.
Figure 2 shows the basic circuit diagram. Three separate 6V batteries supplied current to each of the three circuits. The *exciter* circuit was completely independent of the other two and of the load, but its power consumption was included in the efficiency calculations. While the input connections of the *plate* and *spool* circuits were each connected to their respective battery, the outputs from each were connected together

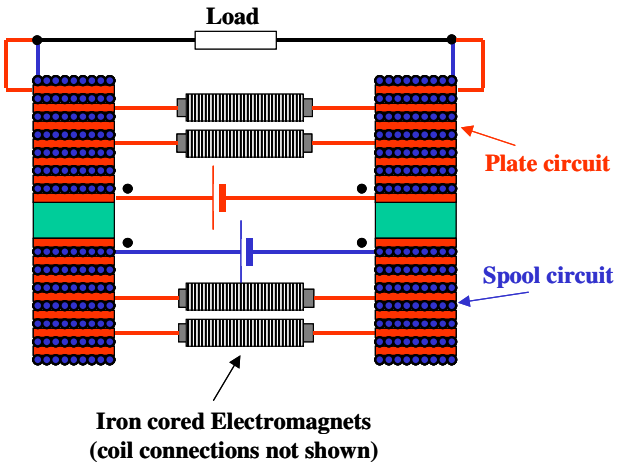
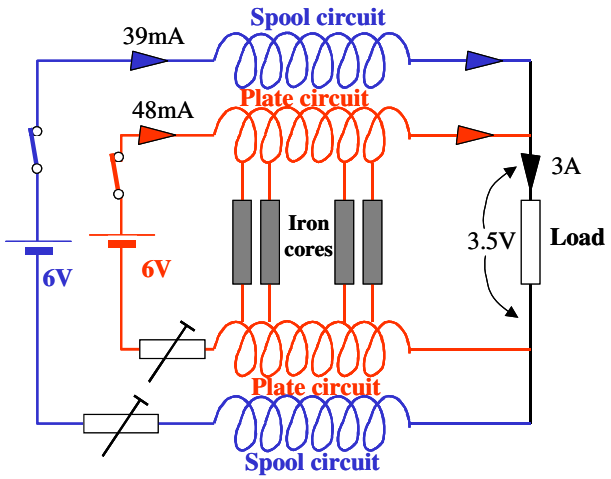



**Figure 1. Stromerzeuger Layout**



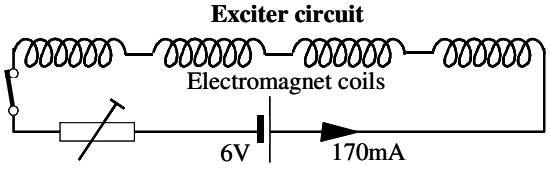




**Figure 2. Circuit**

to feed a common load, this being a number of parallel connected light bulbs. Each circuit had adjustable resistors, built in voltmeters and ammeters.

The currents and voltages shown in Figure 2 are taken from Professor Schumann's report. The switch-on sequence was important to get the device to work. First the *spool* circuit was connected to its battery, and drew about 100mA. Next the *plate* and *exciter* batteries were simultaneously connected, whereupon the *spool* current dropped to about 39mA. The plate current rose to 48mA, and the exciter circuit drew 170mA. The astonishing feature was that, although the two (plate and spool) input currents were only 88mA, *the current into the load bulbs was 3A. Excess current was being generated within the device*, and examination of the circuit diagram shows this *had* to be within the iron cores. Both Professor Kloss and Professor Franke admitted to the iron cores being the source, Kloss stating "*Solely the conjecture can be expressed that the magnet-system is the source of the energy*" whilst Franke says "*According to the statement of the inventor, the production of energy principally takes place in these iron rods*". The total power consumption from the three batteries (39mA, 48mA and 170mA each from 6V) was 1.54W. The power dissipated in the load was 10.5W (3.5V and 3A). *Not only were the cores acting as DC generators, they were delivering excess power.* Both Professors Kloss and Schumann introduced their own measuring instruments in order to find the reason for this extraordinary result, and both concluded that the result was real. Further they both employed an alternative photometric technique to check the output power, comparing the brightness of the bulb lit by the machine with one lit to the same brightness from a separate battery. They both concluded that the machine did indeed deliver more electrical power to its load than was taken from its batteries. Kloss even went so far as to try a different hot wire instrument in case the output had some AC superimposed. He concluded that there was none, and that the output was indeed DC.

16 years later in 1943 we find the OKM-imposed Dr. Frolich claiming (incorrectly) that the Kloss/Schumann results were *interrupted* DC, then driving the OKM sponsored research along a fruitless avenue exploring energy exchange on the opening and closing of inductive circuits. Despite the fact that, in order to obey Kirchoff's Law the iron cores *had* to be the "source" of the excess current and power, Frohlich's experiments did not include the passage of current through cores. He was convinced that there were oscillations within the various branches and circuit loops of the system and concluded vaguely that "*The activity of the apparatus must take place in the ten oscillating circuits in a phase-like manner*". Little wonder that his work shed no light on the subject!

The remainder of this present paper looks at what is required for a simple iron core to become a DC source of free power. At first sight this seems so incredible as to not even warrant consideration by the scientific establishment, but the reader is asked to withhold judgment until the whole paper has been read.

## 4. Precessing Electrons as Power Sources

This paper now examines precessing electrons acting as *Quantum Dynamos*[2] to generate useful quantities of power. Coler was convinced that conduction electrons were magnetic monopoles, hence were pulled along by the internal magnetic field. Although we know this to be not the case, it does tell us that the source of Coler's excess energy is within the magnetic materials he used as cores. No information is available regarding the composition of these rods, other than the statements in ref.[1] where the Magnetstromapparat had permanent magnet rods (possibly an early Alnico) and the Stromerzeuger used electromagnets with iron cores.

### 4.1. Electron spins responsible for Magnetization.

It is known that magnetization, be it permanent or soft, comes from atomic bound electrons having aligned spins (Figure 4). Each electron acts like a tiny bar magnet. However this is not the complete picture. Quantum rules prohibit the electron spin from being aligned with its local magnetic field, it must be at an angle to it. Because the electron spin has angular momentum, the only way this misalignment can occur is by precession, each electron acts like a tiny gyroscope precessing about the **B** field (Figure 5). The precession rate is known as the Larmor frequency, and is proportional to the magnitude of the **B** field. Within bulk material, local variations in the **B** field cause a spread of frequencies which results in random phases of the individual precessions. Thus we don't normally observe any radiations from these. In very small samples placed within a uniform field, the spread of precession frequencies is small enough that they can be forced into phase for a period of time. This is known as electron spin resonance (ESR) or, in the case of ferromagnetic material considered here, ferromagnetic resonance (FMR). Under normal circumstances, using excited FMR as a power source in bulk material is not feasible, the frequency spread is too great. However it may be possible to provide special conditions such that power can be extracted, as Coler discovered.

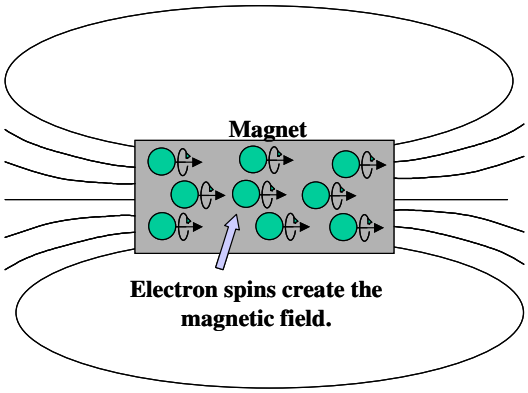



**Figure 4**.

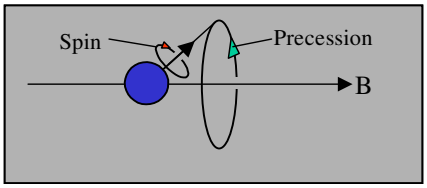



**Figure 5**

### 4.2. Precessing Electrons as Quantum Dynamos™.

We are interested in the possibility that the electron precessions can produce electrical power. Each magnetizing electron can be modelled as two tiny bar magnets, one aligned along the B field (and in bulk, responsible for it) with the other transverse and rotating at the Larmor rate (Figure 6). The rotating bar magnet can be considered to be the rotor of a Quantum Dynamo™. It is therefore instructive to look at a real dynamo to see what needs to be done to extract energy from the bulk array of Quantum Dynamos™.

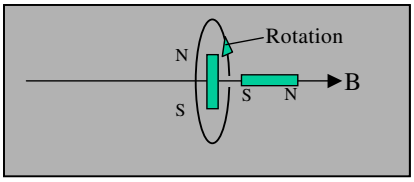



**Figure 6**

Figure 7 shows a form of dynamo suitable for our needs. A bar magnet rotates within a soft iron cylinder which provides the flux return from N to S pole. A single insulated conductor is fixed to the inside of the cylinder protruding from each end. An external load is connected to each end of this conductor. This is a simple form of AC generator, which has the right cylindrical geometry. The conduction electrons within the

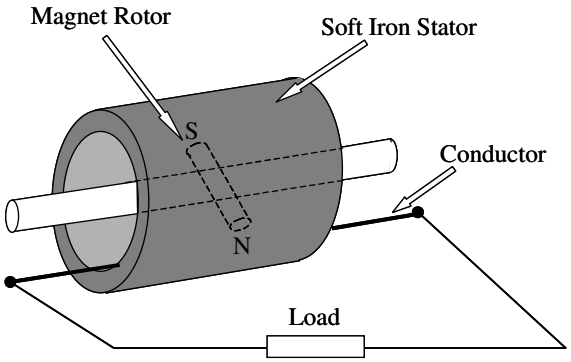



**Figure 7**

copper move longitudinally, along the major axis, as Coler's conduction electrons move en-masse along the magnetized rod. They obtain induction from a magnet rotating about that longitudinal axis, as might Coler's electrons gain induction from the precessing electrons. And, since the precessing electrons are within ferromagnetic material, the stator flux return path is already there within Coler's cores. Thus a magnetized ferromagnetic and electrically conductive core can be considered as an enormous array of AC generators having a spread of frequencies with no phase coherence. It would be expected that such an array would produce RF noise measured across the ends of the core, and experiments seem to confirm this. However we know that Coler's Stromerzeuger produced DC, not AC, so we need further refinement.

Figure 8 shows the same set-up but with a number of conductors along the cylinder. At each end is a commutator, thus ensuring that the load is always connected to a conductor that is at the position of maximum induction (close to the passing N pole say). The output is now DC. Of course we could shrink this dynamo down to nano-size then connect a vast array in series-parallel. All this is feasible (but maybe not practical!)

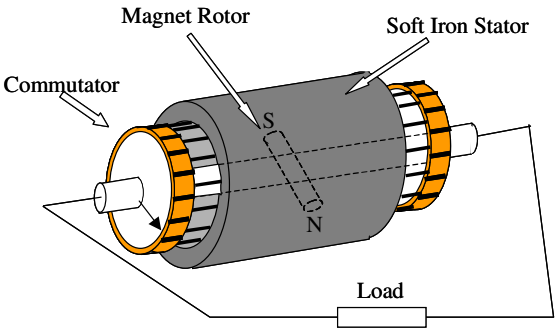



**Figure 8**

Now we must imagine the real dynamo of Figure 8 shrunk down to atomic dimensions. We can see that ferrous metal has most of the attribues needed. Such a material contains an array of rotors as precessing electrons. The metal is electrically conductive, thus providing the conduction electron paths that pass by each rotor. What is missing is the commutator action, and the interconnections to ensure that the conduction electrons on average gain energy from the precessions. It is posited that these can also be provided within ferrous material.

If we look at a single precessing electron, conduction electrons that pass by traveling longitudinally (i.e. along the B field) are either accelerated or decelerated by the quantum rotor (Figure 9). Calculations for such a pass are given in the Annex. Most of the induction occurs along that part of the trajectory close to the precessing electron, within ± one miss distance measured from the point of nearest miss. Rough calculations using typical distances and precession frequencies show that this induction, if it can be commutated correctly from one atom to another, will yield useful voltages.

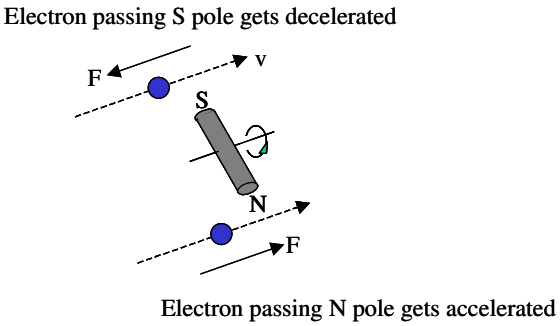



**Figure 9**

What we now need is something to mimic the commutator action, which makes it more likely that conduction electrons pass by the pole responsible for acceleration (Figure 10). The fields responsible for this "steering" must be linked to the electron-rotor phase, or the phase of the previous electron-rotor assuming there is some

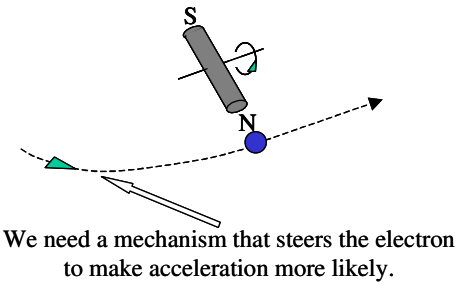



**Figure 10**

local phasing of these rotors. *Such a mechanism exists in the induction fields around each rotor.*

Figure 11 shows the magnetic field around a bar magnet. As the magnet is rotating (about the horizonta axis) we can deduce the induction electric field from the motion of the flux lines (into or out of the paper). Such E field lines are shown in red. An interesting feature is the field that influences the electron *before* it reaches the plane of rotation. Whether the electron is already arrriving on the N side (such as #1 in the figure) or on the S side (such as #2) the boost from the E field is always in the N direction. Thus a "S side" electron such as #3 can be

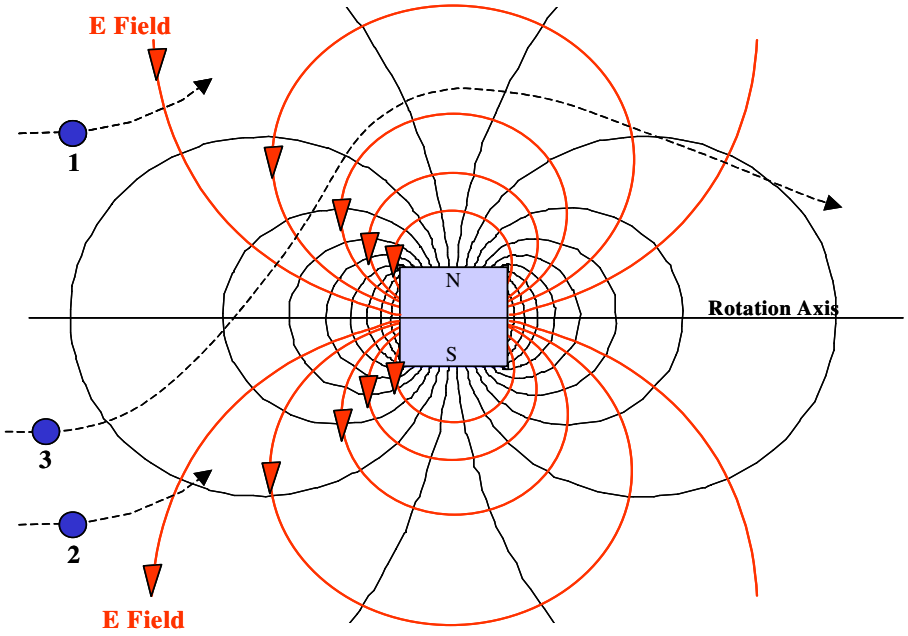



**Figure 11**

diverted to the N side to then be boosted as it passes close by the N pole. *The input commutator action is there, in the leading edge of the E field.* What is now needed is the output commutator action, i.e. the coupling to the next precessing electron. That could, among other things, be down to the geometry of the lattice relative to the conduction direction, the velocity of the electron which determines the time to reach the next atom and the local phasing between adjacent atoms. Since the conduction electrons themselves can carry phase (they too are precessing) it seems possible that, given the right impetus and uniformity of B field, a self sustaining conduction current might occurr.

One possiblity which might aid this action is the presence of the longitudinal **B** field component which will cause the electron trajectories to spiral (Figure 12). It may be noted that the electron cylcotron frequency is related to the Larmor (rotor) frequency, so the curvature could possibly be controlled so as to synch with the rotor movement from atom to atom. The next section examines evidence which shows that this is indeed possible.

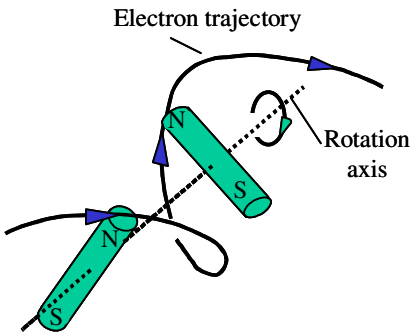



**Figure 12**

## 5. Absolute Negative Resistance

Coler's rods, which acted as DC power generators, can be considered as exhibiting *absolute* negative resistance. The appearance of *differential* negative resistance is known in many systems, leading to instability and self-oscillation, but absolute negative resistance is a newly found phenomenon which shows up as a current flowing in the direction *opposite* to applied DC bias. It has been discovered in photon assisted electron transport systems, see for example *Dakhnovskii & Metiu*[3], *Niu & Lin*[4] and *York, Coalson & Dahnovsky*[5].

Of particular interest is *Durst et al*[6] where detailed and non-perturbative calculations of the non-equilibrium response of a 2D electron gas are presented, to explain the results from experiments that had shown microwave radiation to induce dramatic changes in DC transport properties. Here the electron gas is given a static **B** field and a co-aligned static **E** field. When exposed to microwaves at a fixed frequency, the DC resistance is shown to vary cyclically as the **B** field, and hence the cyclotron frequency $\omega_c$, is varied. The cycles repeat at $\omega_c$ intervals which are integer numbers of the microwave frequency, and for the first few cycles the negative excursions actually reach significant values of absolute negative resistance. Under this condition the electron gas can supply DC power to an external circuit, Figure 13. Clearly the power actually comes from the external microwave source, absorbed photons being the pump action required to drive the electrons through the load. To quote *Shi & Xie*[7] discussing such an anomaly in a 2D electron gas:-

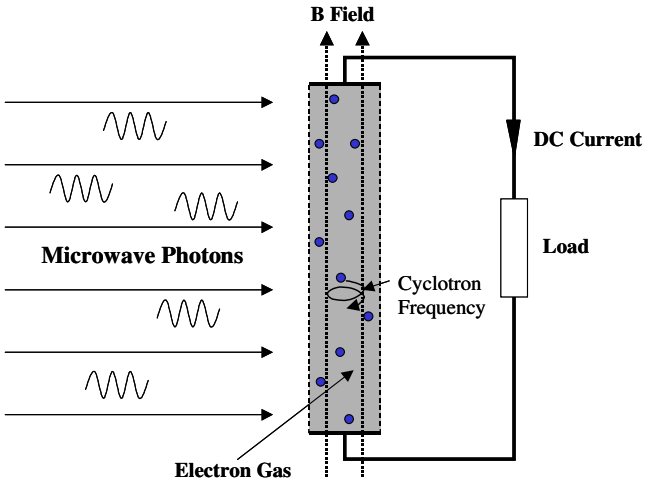



**Figure 13. Microwave pumped electron gas as a DC power source**

> *•The transport anomaly (negative resistance) is the result of photon assisted transport and the non-trivial electron density of states of the system.*
>
> *• The transport anomaly is NOT a special property of 2DEG. Similar anomaly could also be observed in other systems, provided the necessary conditions are met.*

Coler's iron rods met this requirement. Like the 2DEG they had longitudinal **E** field provided by the batteries, and longitudinal **B** field provided by the energized coils.

> *• When the conductivity becomes negative, the system will be driven to a far-from-equilibrium regime where nonlinear and self-organization effects dominate.*

After the correct switch-on sequence Coler's rods drove themselves into a self-organized, DC power-producing regime.

*The phenomena could be observed in other uniform systems, provided:*

*• An effective way to couple the radiation field and the electron motion*

*• Non-trivial density of states*

*• Strong enough radiation.*

Unlike the 2DEG, Coler's rods were not exposed to an external source of microwave radiation, the microwaves existed *inside* the material, sourced from the precessions of the magnetically active atomic electrons. A density of one conduction electron per precessing source, and the close spacing, assured effective and strong coupling between the radiation field and the electron motion, see Figure 14 for comparison with Figure 13. Coler demonstrated in 1926 an effect which only in recent years has been deemed feasible.

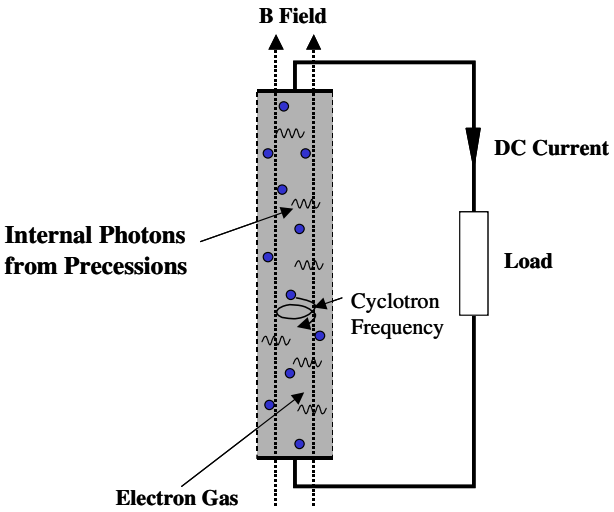



**Figure 14. Internally pumped electron gas as a DC power source**

It will be argued by some scientists that Larmor precession is an absorption resonance phenomenon, it can't emit power. That effectively says these precessions cannot emit photons, but the evidence says otherwise. Free induction decay and spin echoes are regularly used in these spin resonance experiments, if photons were not emitted it would be impossible to detect these.

## 6. The Stromerzeuger Reviewed

In light of the consideration that precessing electrons can be responsible for Coler's results, it is now instructive to review the Stromerzeuger. If the precessions are to be somehow controlled and phase-linked via spin coupling from the conduction electrons, uniformity of **B** field, hence also magnetization, through the core would be essential. Simulations have been performed to discover what coil arrangment is needed to meet this requirement. Normally (i.e. in a uniform magnetizing field) the core's own demagnetization characteristic forces the magnetization to be a maximum at the core centre, reducing to about half this value at the ends. To compensate for this the magnetizing field must be non-uniform along the core, and such a field is produced by two pancake coils off the core ends. *This is exactly the layout of the Stromerzeuger spool and plate coils*.

An interesting feature of Coler's work is the quasi-stable nature of the phenomenon, evident from the important switch-on sequence. If the sequence was not followed the cores did not produce energy, indeed their magnetic condition was altered and then the system required readjustment to get back to satisfactory performance (this is typical of magnetic hysteresis). Applying the correct sequence created an energy-producing and self-sustaining conduction path through the core. The first requirement was energization of the spool coils, this would produce uniform magnetization. Next the plate coils and the core's own excitation coil would be energized together. The rise in magnetic field would induce eddy currents into the core, perhaps this initiated the spiral vortex action such as is depicted in Figure 12. During this transient, as the core's began to generate power delivered to the load, the spool current would necessarily drop since this circuit now sees the 6V drive *minus* the 3.5V load voltage. Such a drop in spool current, plus the rise in exciter current, would otherwise alter the uniform magnetization, but this role is now taken by the plate coils. The current (not only from the battery but more importantly the much higher current driven into the load) in the plate coil now provides the uniformity of magnetization. *Geometrically the spool and plate coils must be equivalent to perform this role, and the bifilar winding ensures this. It may also be noted that the much higher output current flowing through the plate coil would need fewer turns than the spool circuit to create the same magnetization field, and this is exactly so*.

## 7. Conclusion

It has been shown that conduction electrons can gain or lose energy as they pass precessing electrons. A precessing electron supplies that energy much like the rotating magnet does in a normal generator, hence the term Quantum Dynamo™ is very apt, but unlike the normal magnet rotor which requires a mechanical drive, electron precession is supplied by Nature. The energy can be harnessed if the conduction electron paths through the material can be made to commutate between each electron-dynamo so that more energy is gained than is lost. It appears that Coler discovered by accident a means for establishing a quasi-stable conduction path through ferromagnetic material whereby this end was achieved. Calculations show that such an approach yields useful voltages which might explain Coler's results.

Hopefully this paper will present researchers with a new avenue to explore Coler's work. Attention can be focused on the characteristics necessary to initiate the quasi-static phenomenon. With modern measuring capability it should be possible to quickly detect anomalous transient behaviour, then to perform experiments to expand the anomaly towards becoming the switch to a new quasi-stable power-producing state. Also, in these days of nanotechnology and molecular engineering, it must surely be possible for the requirements outlined previously to be designed into a ferromagnetic conductor. The challenge really hinges on reproducing the commutator action, ensuring that conduction electrons get a boost from the electron precessions. No one appears to have accepted this challenge. With the impending energy crises linked to global warming, it is time that the scientific establishment took its head out of the sand and did so.

## References.

[1] "The inventions of Hans Coler relating to an alleged new source of power", British Intelligence Objectives Sub-committee B.I.O.S. Final report No. 1043 Item 31.

[2] *Quantum Dynamo* is a trade mark of Magnetic Power Inc.

[3] Yuri Dakhnovskii and Horia Metiu, "Absolute negative resistance in double-barrier heterostructures in a strong laser field", Phys. Rev. B 51, 4193–4199 (1995) [Issue 7 – 15 February 1995].

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## Annex A

In this annex we calculate the E field hence energy lost or gained by an electron flying past a rotating magnet. The geometry is as shown in figure A1.

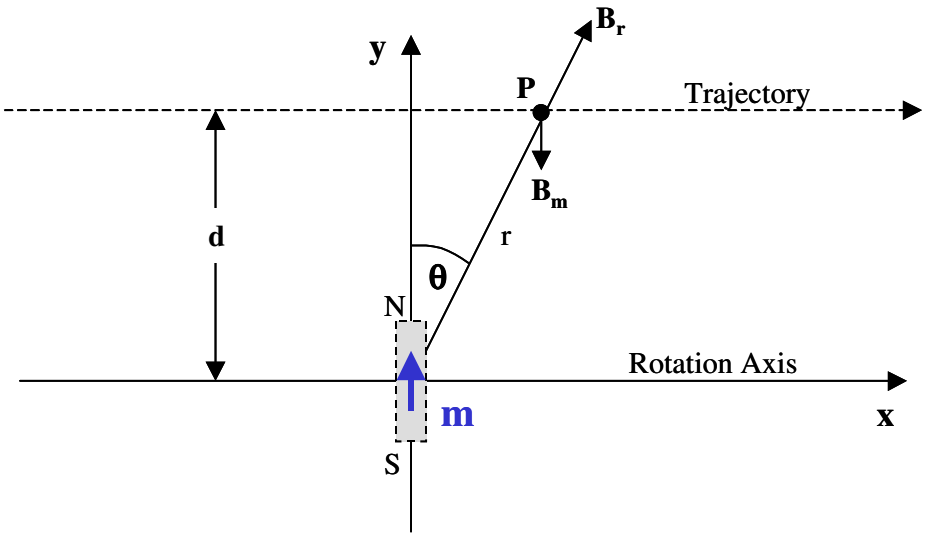


**Figure A1**

The magnet rotates in the y-z plane about the x axis. The electron trajectory is parallel to x with a miss distance of d.

At point P the **B** field from a dipole of moment **m** can be expressed as the sum of a *spherical* radial component $B_r$ and a component $B_m$ aligned with **m**. (Note these two components are not orthogonal. There is another equivalent method which uses orthogonal radial and *tangential* components). The rotating B responsible for induction is the *cylindrical* radial field $B_y$ (in this x-y plane the field component parallel to y) given by $B_y=B_r\cos\theta - B_m$ where θ is the angle between the dipole axis and the radial distance vector **r**. The actual equations are.

$$\mathbf{B} = \frac{\mu_0 m}{4\pi r^3}\left(\left[3\cos\theta\right]\mathbf{i}_r - \mathbf{i}_m\right) \qquad (1)$$

where $\mathbf{i}_r$ is the unit spherical radial vector and $\mathbf{i}_m$ is the unit vector parallel to **m.**

$$B_y = \frac{\mu_0 m}{4\pi r^3}\left(\left[3\cos^2\theta\right]-1\right) \qquad (2)$$

The effective field velocity (due to the rotation) is $\omega d$ where $d$ is the miss distance and $\omega$ is the angular frequency. Since $d$ and $r$ are related by $d=r\cos\theta$, the induced $E_x$ field at the point of interest is

$$E_x = \frac{\mu_0 m\omega}{4\pi d^2}\cos^3\theta\left(\left[3\cos^2\theta\right]-1\right) \qquad (3)$$

A plot of $E_x$ against x distance is given in figure A2, with x normalized to miss distance d. At x distances (from the point of nearest miss) greater than the 1.5d the E field becomes negligible.

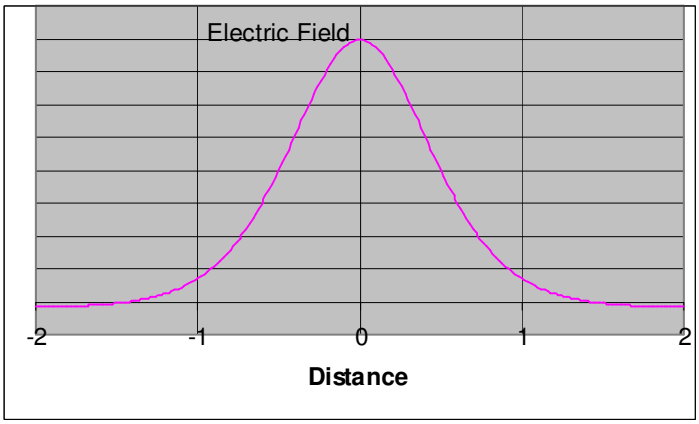


**Figure A2**

To establish the energy gained by the passing electron we need to integrate $E_x$ along x. This gives us voltage which when multiplied by the electron charge gives energy. Using $\int E_x.dx = \int E_x.d\theta \times \frac{dx}{d\theta}$ and since $\frac{dx}{d\theta} = \frac{d}{\cos^2\theta}$ the wanted integral becomes

$$V = \int E_x.dx = \frac{\mu_0 m\omega}{4\pi d}\int \cos\theta\left(3\cos^2\theta - 1\right).d\theta \qquad (4)$$

Using the Mathematica integrator this becomes

$$V = \frac{\mu_0 m\omega}{8\pi d}\left[5\sin\theta + \sin 3\theta\right]_{\theta_1}^{\theta_2} \qquad (5)$$

The integral from $\theta$=-90° to $\theta$=+90° (x=-∞ to x=+∞) becomes

$$V = \frac{\mu_0 m\omega}{2\pi d} \qquad (6)$$

As can be seen from figure A2, most of this voltage induction occurs near the precessing electron, within ± 1.5d.

Using (6) we can find the voltage from a single pass of an electron precessing at say 10GHz. The moment **m** of the electron is in the order of a Bohr magneton ($9.273\times10^{-24}$). At a miss distance of $10^{-10}$m we get about $10^{-9}$ volts. If we had $10^8$ of these passes in series (over a total length of about 0.2m) we would get 100 millivolts induction. These are just rough numbers for guidance, but they do illustrate that this approach could explain Coler's results.