



Trim, Co. Meath Ireland

10th February 2014



Scientific basis of the health effects of electric and magnetic fields associated with the electricity supply

Denis L Henshaw

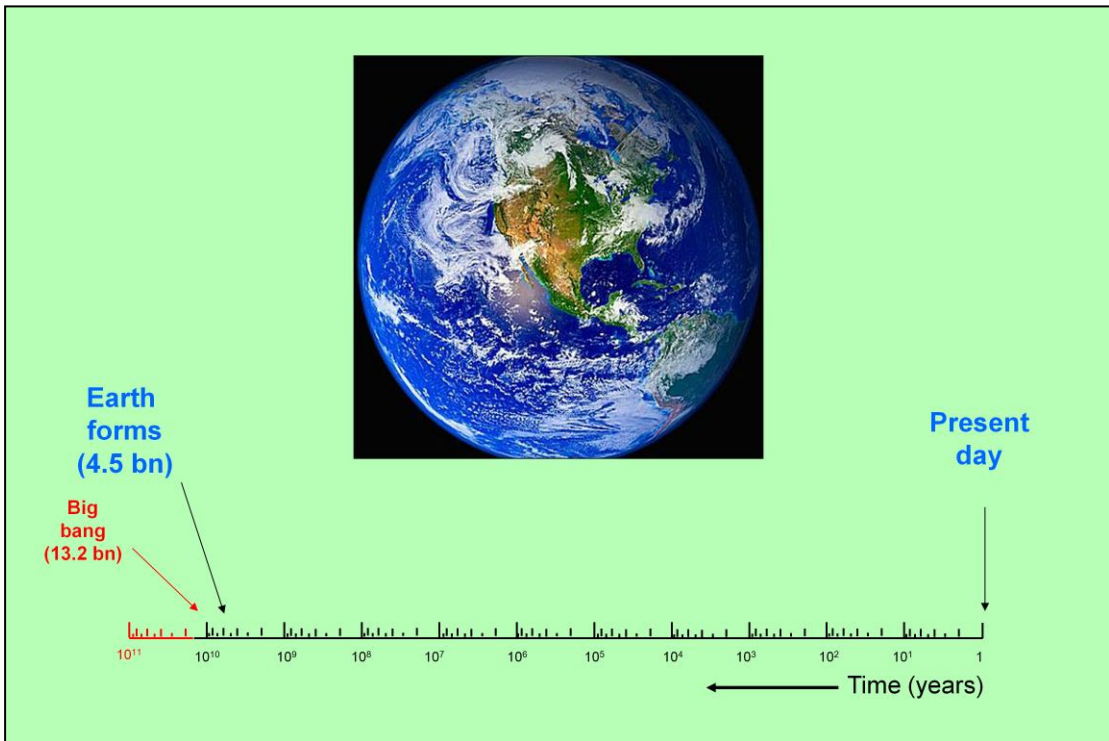
University of Bristol
and
Children with Cancer UK



www.electric-fields.com



First I will demonstrate a magnetic field and an electric field. They are quite distinct. At power frequencies, the two fields are essentially independent and can be treated separately.

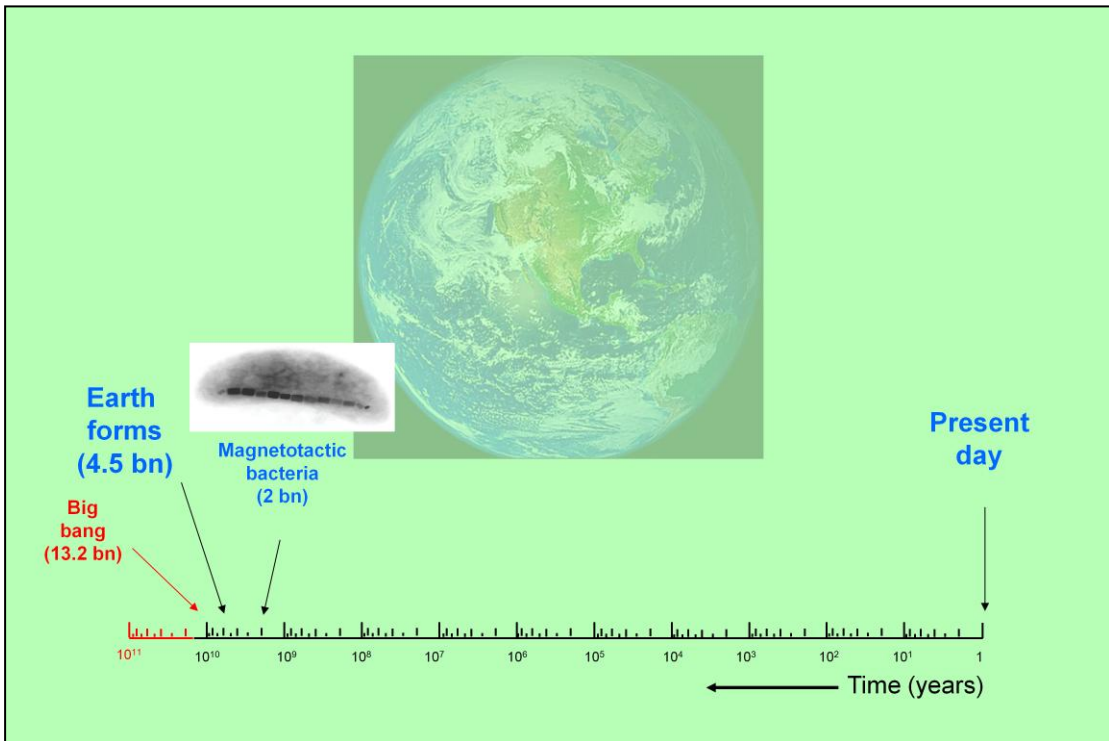


When the Earth was formed 4.5 billion years ago magnetic fields were already present, and had been since the Big Bang some 9 billion years earlier.

2 billion years ago aquatic magnetotactic bacteria evolved which contain a chain of magnetite particles enabling them to swim along the Earth's magnetic field lines to find food.

Over 90 million years ago the avian magnetic compass developed, enabling pigeons to detect magnetic field changes around 0.02 μT , 20 nT, or even lower.

Some 6 million years ago, man evolved, some of whom appear sensitive to solar storm fluctuations in the geomagnetic field of around 0.1 μT or 100 nT.

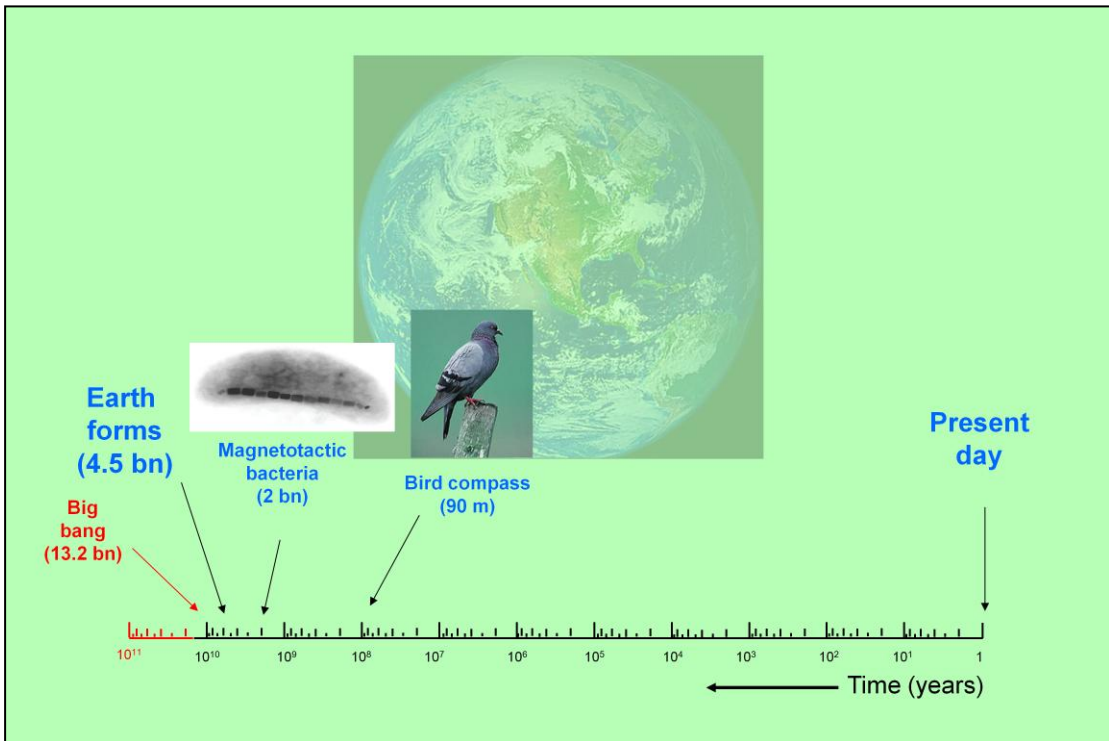


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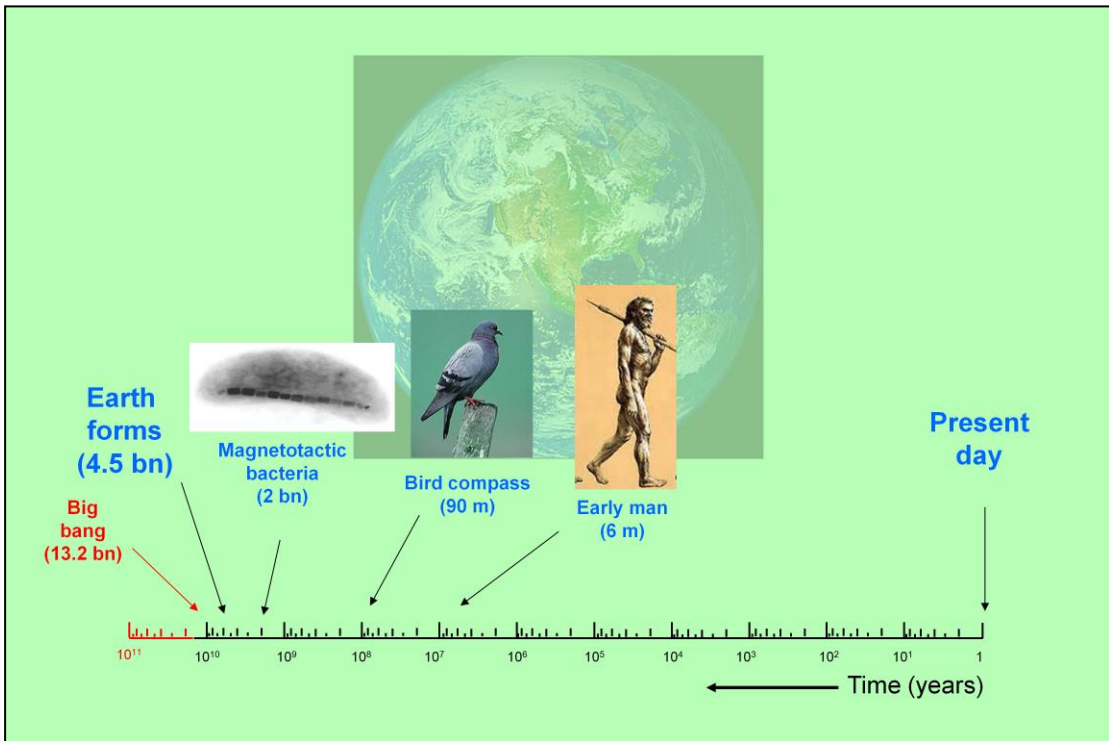


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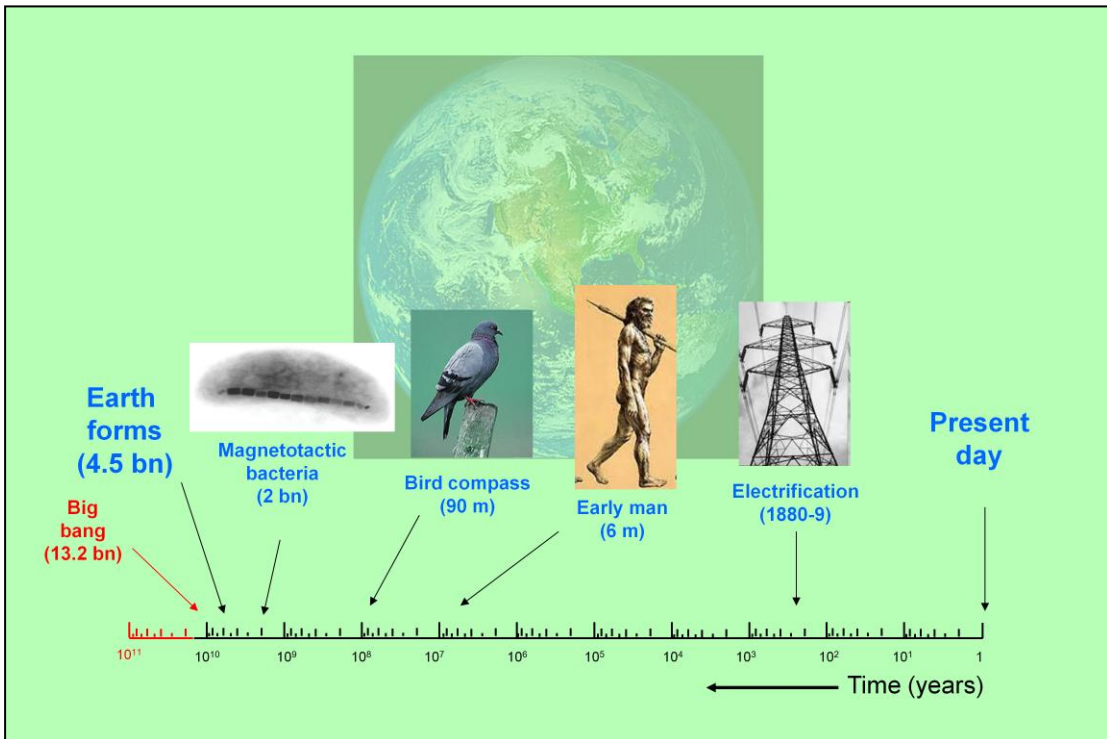


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So, by the time the Dublin electric light company was established in 1880 and, soon after, an experimental public light was erected outside the offices of the Freeman's Journal in Prince's St. Dublin, it was already the case that wide sections of the animal kingdom had evolved to detect and exploit magnetic fields at levels below those associated with this new invention, and with hindsight, a hint that there might be adverse health effects in humans.

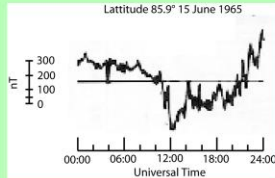
Notes only:

The species whose magnetic compass has been analyzed so far are not at all closely related. Chickens belong to an ancient line of birds, the Galloanseres, that separated from the remaining modern birds, the Neoaves, more than 90 million years ago in the beginning of the Late Cretaceous. Finding the same type of magnetic compass in species of all three groups suggests that this compass

Geomagnetic Storms*

- Arising from charged particles from the sun

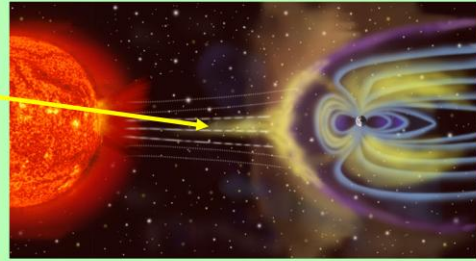
Typical MF profile (Campbell 2003)
(K-value – maximum fluctuation over a 3-hour period)



Storms of interest last 1–5 days and have a magnitude of about 100 nT

Acute health effects include*: increase in depressive illnesses, melatonin disruption, heart rate variability, blood pressure changes.

However, only 10-15% of the population seem affected



Strength of the Storm* (nT)	Frequency
> 100	4.6 per year
> 200	9.4 per 10 years
> 400	9.73 per 100 years

*Superimposed on the static GM field which in Dublin is 49.1 μ T

*Pigeon migration is also disturbed by GM storms (Schiffner & Wiltchko 2011
J Comp Physiol A DOI 10.1007/s00359-011-0640-y

See: http://www.ngdc.noaa.gov/stp/GEOMAG/kp_ap.html

Love & Gannon Ann. Geophys. 27:3101-3131 (2009)
http://en.wikipedia.org/wiki/Geomagnetic_storm

So, start by taking as quick look at Geomagnetic storms

Superimposed on the Earth's static magnetic field of 49.1 μ T in Dublin, are small fluctuations caused by storms of charged particles emitted by the Sun

They are categorised by their K-value, their maximum variation over a three hour period.

The storms of interest are those around 100 nT, there being about 4.6 such events per year.

Acute health effects include: increase in depressive illnesses, melatonin disruption, heart rate variability, blood pressure changes.

However, only 10-15% of the population seem affected

Much of this research was carried out as part of the US and Russian Space Programme

Health effects of Geomagnetic storms

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*Reviews of studies

Here is a short list of some of the studies of health effects resulting from geomagnetic storms, the first two are reviews

Power frequency electric & magnetic fields - especially magnetic fields, MFs[†]



Under powerlines MFs can be several μT or evens tens of μT

**Doubling of Childhood Leukaemia risk
associated with average 0.3/0.4 μT ***

Average MF home levels 0.05 μT

*and 30% increase in risk
above 0.2 μT

*Robust association reiterated in 2014
EU SCENIHR Report

†Magnetic fields are an IARC Class 2B
Possible Carcinogen

So, let's now look at power frequency magnetic fields. In 2002 these were classified by The International Agency for Research on Cancer (IARC) as a Class 2B Possible carcinogen – similar to coffee: drinking 3-8 cups of coffee per day in pregnancy can lead to a 2-3 fold increase in childhood leukaemia risk in offspring.

The average exposure to power frequency magnetic fields in the home is only 0.05 microtesla (μT) or 50 nanotesla (nT). However, close to certain appliances, levels can be tens of μT . Under powerlines MFs can be several μT or evens tens of μT

Crucially a doubling of childhood Leukaemia risk is associated with average exposure of 0.3/0.4 μT . Further analyses of international epidemiological studies indicate a 30% increase in childhood leukaemia risk associated with average magnetic field exposures above 0.2 μT (Zhao et al 2013. Leukaemia Research In press – online early).

What are the adverse health effects linked to power frequency electric & magnetic fields?

- Childhood leukaemia
- Adult leukaemia
- Adult brain tumours
- ALS (motor neurone disease)
- Miscarriage & adverse birth outcomes*
- Depression & depressive symptoms
- Alzheimer's disease
- Breast cancer

*Including newly emerging finds: De Vocht et al 2014 Bioelectromagnetics, in press

Review bodies' assessments of MF association of various diseases.
- IARC has classified Power Frequency MFs as Class 2B – 'possible carcinogen'.

Disease	NIEHS 1999 ¹	IARC ² 2002	California* 2002	EU: SCENIHR 2014 ³	EMF & Health 2011 ⁴
1. Childhood Leukaemia	Yes	Yes	Yes	Yes	Yes
2. Adult Leukaemia ⁵	Yes		Yes		Yes
3. Adult brain cancer ⁵			Yes		Yes
4. Miscarriage			Yes		Yes
5. ALS ⁶			Yes		Yes
6. Alzheimer's disease				Yes ⁷	Yes

¹US National Institute of Environmental Sciences

²International Agency for Research on Cancer

³EU: Scientific Committee on Emerging and Newly Identified Health Risks:
Possible effects of Electromagnetic Fields (EMF) on Human Health.

⁴EU: EMF & Health, Brussels Nov 2011

⁶Motor neurone disease

⁷Studies more recently published

⁵Aggregated data is highly significant:

O'Carroll and Henshaw 2008, Risk Analysis
28:225-234.

Kheifets et al. 2008, JOEM 50:677-688.

*<http://www.ehib.org/emf/RiskEvaluation/riskeval.html>

Here is what various review bodies have said about Magnetic Field and adverse health effects

IARC 2002 must have had a bad day because their own listing of studies shows strong evidence of association (See O'Carroll & Henshaw 2008 and also Kheifets et al 2008). In fact the MF link with adult leukaemia is, if anything, even stronger than the link with childhood leukaemia

Representative results from 33 independent adult leukemia studies tabled by IARC yielded 23.5 positives

($p \approx 0.01$) and 9 significant-positives ($p < 10^{-7}$). From 43 representative results from

CDHS, there were 32 positive ($p < 0.001$) and 14 significant-positives ($p < 10^{-12}$). There were

no significant-negative results in either list. Results for adult brain cancer gave a similar, but

less clear message.

Features of the above Reports

- Not peer-reviewed (although the California report* used a structured assessment procedure)
- Dominated by **epidemiology** and not underlying science
- Cite at most only a few 100 papers against possibly over 100,000 available
- Do not discuss (out of remit):
 - Magnetoreception in microorganisms and fungi
 - Magnetoreception in plants
 - Animal magnetoreception and navigation
 - EMF effects on pain threshold in animals
 - Health effects of geomagnetic storms
 - Use of EMF in health treatment including cancer

But it is in these areas that significant advances in understanding how EMFs interact with biology have been made

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2. Adult Leukaemia ⁵	Yes	- (why?)	Yes		Yes
3. Adult brain cancer ⁵		- (why?)	Yes		Yes
4. Miscarriage			Yes		Yes
5. ALS ⁶			Yes		Yes
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IARC & California assessment of epidemiological studies

Why the difference for adult leukaemia & brain cancer?

How epidemiology works

- The epidemiological studies look at cancer rates near MF sources and compare these with rates well away from MF sources
- We obtain risk ratio, RR:
 - If cancer rates are the same near and away from MF sources $RR = 1$,
 - if cancer rates are doubled near MF sources, $RR = 2$

We also look at the probability of the finding being just due to chance (being just a fluke)
– This is known as the “p-value”

If the probability of the finding being due to chance is better than **1 in 20 ($p < 0.05$)** we say the finding is statistically significant.

Sometimes p-values, especially for many studies considered together can be far more significant

e.g. $p < 0.001$ or 1 in 1000 probability of the finding being just chance

Nobel Prize in Physics 2013



François Englert
Université Libre de Bruxelles



Peter W. Higgs
University of Edinburgh

Following the discovery at CERN, Geneva of the new particle known as the Higgs boson

Confirmed (established) when the probability of the finding being just due to chance was less than

1 in 10 million

or p-value $< 10^{-7}$ or 99.99999% “proof”

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs “for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN’s Large Hadron Collider”

IARC & California assessment of epidemiological studies
O'Carroll and Henshaw

Adult Leukaemia:

(Risk Analysis 2008; 28:225-234)

IARC listed 33 independent studies: Claimed “No association with MFs”
- but offered no evidence for this conclusion

We analysed the 33 studies taken together: Evidence of association with MFs

- We calculated the p-value for this association:

1 in 10 million

(the probability that the result occurred simply by chance)

or p-value $<10^{-7}$ → 99.99999%

By any definition: proof/established that the association is not a fluke

Kheifets et al. 2008. JOEM 50:677-688

By any accepted definition, there is an established association between magnetic fields from the electricity supply and adult leukaemia and brain cancer

Bioinitiative 2012:

- a biologically-based EMF Report

<http://www.bioinitiative.org>

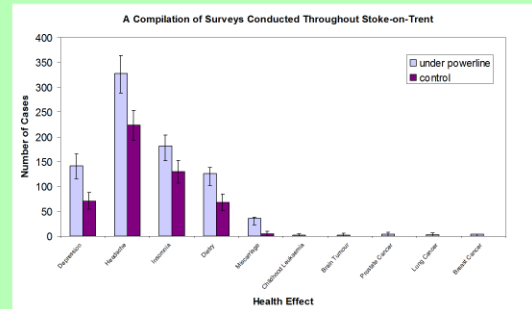
- Highly authoritative – 12 authors representing world-class leading EMF scientists including **three former Presidents of the International Bioelectromagnetics Society**
- Concentrates on the underlying biology of ELF and RF EMF
- Special chapters on **melatonin disruption, childhood cancers, breast cancer & Alzheimer's disease**
- Cites approximately 1800 peer-reviewed studies
- **Strongly recommends precaution against EMF exposure at levels well below current International guidelines.**

Health effects of people living near powerlines in Stoke-on-Trent*

<http://www.electric-fields.com/SAGESurvey.html>

Pooled findings from three surveys in Stoke-on-Trent area from 2002 – 2006
(Males and females combined and scaled for equal number of questionnaires from cases and controls)

Health endpoint	Living <25 m of powerline	Living > 25 m from powerline
Depression: Total reported	141	71
No. requiring doctor	35	3
No. requiring hospital	10	2
Headache: Total reported	327	223
No. requiring doctor	19	5
No. requiring hospital	4	2
Insomnia: Total reported	181	130
No. requiring doctor	15	4
No. requiring hospital	3	-
Dietary: Total reported	126	68
No. requiring doctor	23	5
No. requiring hospital	14	1
Miscarriage	35	5
	2	-
Cancer: Childhood Leukaemia	3	-
Brain Tumour	2	-
Prostate Cancer	34	-
Lung Cancer	-	-
Breast Cancer	-	-



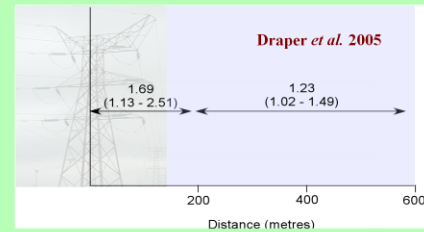
*Surveys carried out by the late Maureen Asbury

These surveys were carried out in three estates with very similar private housing, away from major roads or sources of industrial pollution. While this is not a professional survey, the findings closely mirror those published in the peer-reviewed literature.

Increased incidence of childhood leukaemia near HV powerlines, beyond the range of the direct AC fields (~100 m)

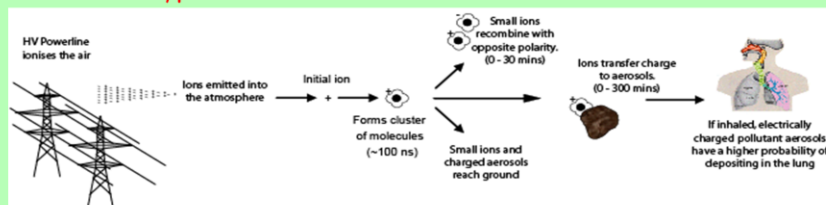
Study	Number of Cases	Increased risk to
Draper et al. 2005 BMJ 330:1290-3	322	600 m (1.23, 95% CI: 1.02 - 1.49)
Lowenthal et al 2007 Internal Med J 37:614-19	854	300 m (2.06, 95% CI: 0.87 - 4.91) ¹ (4.74; 95% CI: 0.98-22.9) ²
Feizi & Arabi 2007 Asian Pacific J Cancer Prev 8:69-72	60	500 m (8.67, 95% CI): 1.74-58.4)
Sohrabi et al. 2010 Asian Pacific J Cancer Prev 11:423-27	300	600 m (2.61, 95% CI: 1.73 - 3.94)

¹Adults: Ever lived within 300 m; ²0-5 years of life within 300 m



AC fields at background by ~100 m

Corona ion hypothesis

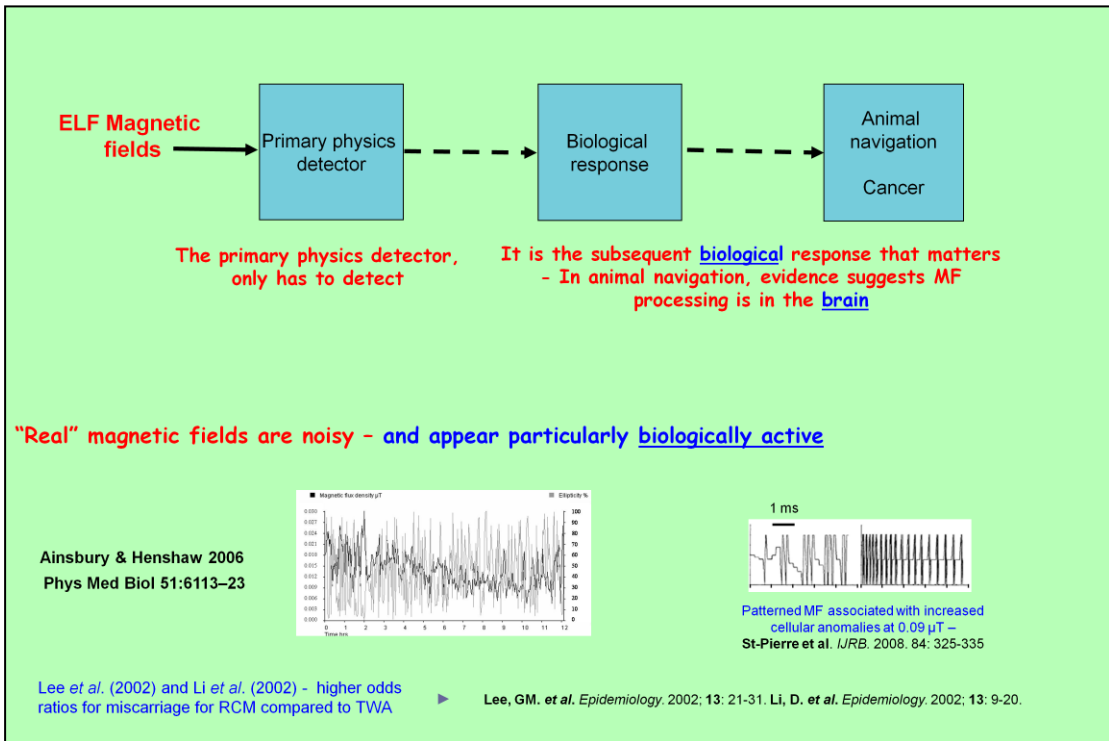


Henshaw 2002 *Med Hyp* 59:39-51; Fewes et al. 1999 *IJRB* 75:1523-31; Fewes et al. 2002 *Atmos Res* 63:271-289; Henshaw et al. 2008 *J Pineal Res* 45:341-350.

The literature includes four studies showing increased leukaemia risk up to 600 metres from powerlines which is well beyond the range of the AC fields, although well within range of corona ion emission. The findings could be explained by two possible models: that corona ions attach to particles of air pollution making them more likely to be retained in the lung when inhaled, and that corona ion disturbance of the natural electric field of the Earth results in melatonin and circadian rhythm disruption.

EMF effects on cattle

- Rodriguez M, Petitclerc D, Burchard JF, Nguyen DH, Block E. 2004. Blood Melatonin and Prolactin Concentrations in Dairy Cows Exposed to 60 Hz Electric and Magnetic Fields During 8 h Photoperiods. *Bioelectromagnetics* 25:508-15.
- Rodriguez M, Petitclerc D, Burchard JF, Nguyen DH, Block E, Downey BR. 2003. Responses of the estrous cycle in dairy cows exposed to electric and magnetic fields (60 Hz) during 8-h photoperiods. *Animal Reproduction Science* 77:11–20.
- Burchard JF, Nguyen DH, Richard L, Block E. 1996. Biological Effects of Electric and Magnetic Fields on Productivity of Dairy Cows. *Journal of Dairy Science* 79:1549-1554.
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- Burchard, J. F., Nguyen, D. H. and Rodriguez, M., 2006. Plasma concentrations of thyroxine in dairy cows exposed to 60 Hz electric and magnetic fields. *Bioelectromagnetics* 27:553-559.
- Burchard JF, Nguyen DH and Monardes Hg, 2007. Exposure of pregnant dairy heifer to magnetic fields at 60 Hz and 30 μ T. *Bioelectromagnetics* 28:471-476.
- Lee, JR JM, Stormshak F, Thompson JM, Thinesen P, Painter LJ, Olenchek EG, Hess DL, Forbes R, Foster DL. 1993. Melatonin Secretion and Puberty in Female Lambs Exposed to Environmental Electric and Magnetic Fields. *Biology of Reproduction* 49:857-864 – **total melatonin unaltered, but severe disruption of circadian rhythms**
- Lee, JR JM, Stormshak F, Thompson JM, Hess DL, Foster DL. 1995. Melatonin and Puberty in Female Lambs Exposed to EMF: A Replicate Study. *Bioelectromagnetics* 16:119-123.

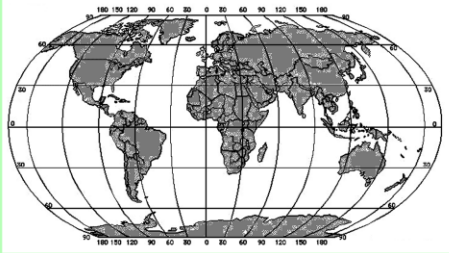


There is a key difference between the initial detector which senses magnetic fields, and the subsequent biological response. For example, the ear senses music, but the brain decides whether it likes it or not.

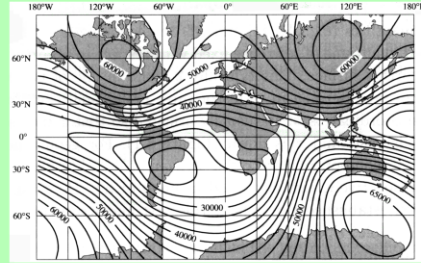
Some underlying biology.....

Navigation across the Earth

- requires two measurements



Humans use latitude & longitude



Many animals use magnetic intensity and compass direction of the Earth's magnetic field

Magnetite* and other iron-mineral particles in animals and man
(Magnetic intensity)



All possess biogenic magnetite* or other membrane bound iron-mineral particles (magnetosomes) used for navigation

*Magnetite: Fe_3O_4

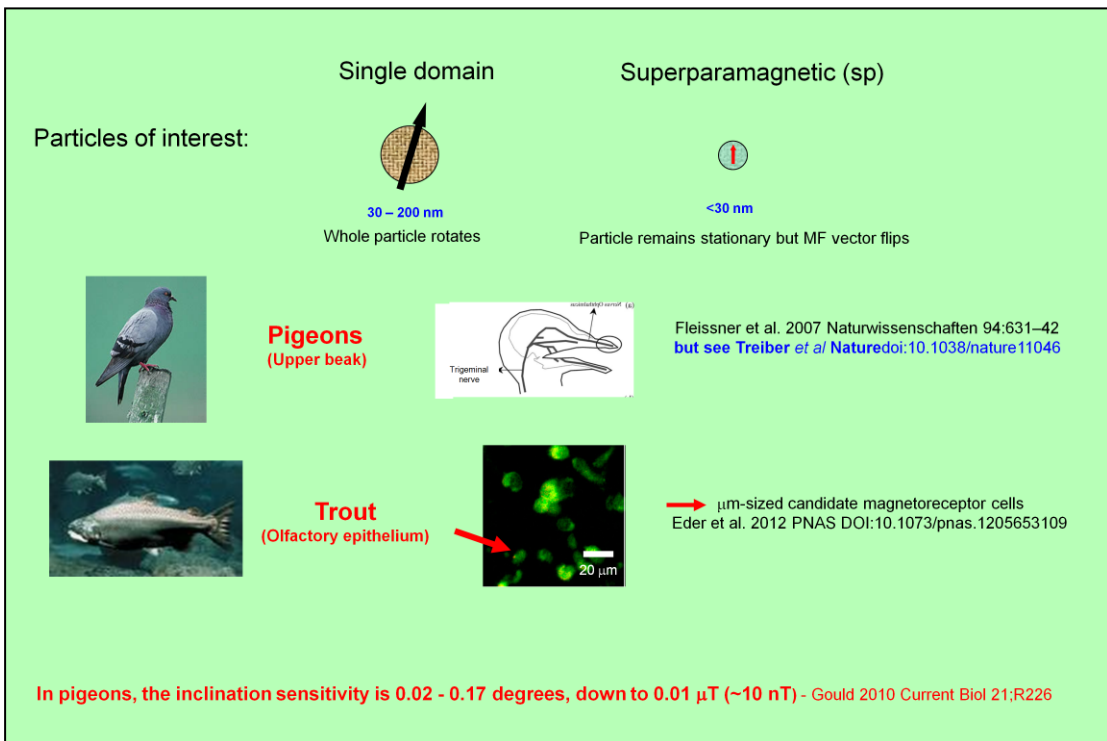
(magnetic sensitivity exists in all major groups of vertebrate animals, as well as in some molluscs, crustaceans and insects, including flies, chickens and mole rats)

Magnetic sensitivity is widespread throughout the animal kingdom, and these are some of the animals which possess biogenic magnetite or other iron-mineral particles used for navigation

Notes:

Jogler C, Schüler D. 2009. Genomics, Genetics, and Cell Biology of Magnetosome Formation. Annual. Review of Microbiology 63:501–21.

Lohmann: magnetic sensitivity is phylogenetically widespread; it exists in all major groups of vertebrate animals, as well as in some molluscs, crustaceans and insects. The list includes groups such as flies, chickens and mole rats, none of which migrate.



Single domain permanent magnets, particles >50 nm where the whole particle physically rotates in an MF

And

Superparamagnetic particles which remains stationary but the MF vector quantum flips

Flessner et al 2007 Goethe-Universität, Frankfurt

Treiber et al 2012 1Institute of Molecular Pathology, Dr Bohr-Gasse, 1030 Vienna, Austria

Eder & Michael Winklhofer Ludwig-Maximilians-University Munich

Notes:

Heyers D, Zapka M, Hoffmeister M, Wild JM, Mouritsen H. 2010. Magnetic field changes activate the trigeminal brainstem complex in a migratory bird. Proceedings of the National Academy of Sciences USA 107:9394-9399.

BUT: Zapka M, Heyers D, Hein CM, Engels S, Schneider N-L, Hans J, Weiler S, Dreyer D, Kishkinev D, Wild JM, Mouritsen H. 2009. Visual but not trigeminal mediation of magnetic compass information in a migratory bird. Nature 461:1274-1278. doi:10.1038/nature08528

Magnetic particles in human brain and ferritin

(Kirschvink et al. (1992) PNAS 89:7683-7 and Allen et al. 2000 Biochimica et Biophysica Acta 1500:186-196)

1. Human brain:

Kirschvink et al. characterised magnetite biomineralisation in adult human brain:

- Sizes **10 – 70 nm** & **90 – 200 nm**, some **600 nm**. 5 million single-domain crystals/g for most brain tissues, >100 million crystals/g for pia and dura – the layers near the skull.
- Particles in clumps of between **50** and **100** particles; **U/kT values between 20 and 150.**
- **The larger particles could respond to a 50 Hz field at 0.4 μ T - putting mechanical stress on neighbouring cells**

2. Ferritin:

- has a natural ferrihydrite nano-particle, ~8 nm, superparamagnetic, SP at room temperature.
- 1 – 200 mT fields in their vicinity; ~1 mT at 50 nm away
- SP particle would effectively "**amplify**" a 0.4 μ T 50 Hz field by induced magnetisation - [Binhi 2008 IJRB 84:569-579](#)

Superparamagnetic (SP)



<30 nm

Particle remains stationary
but MF vector flips

Notes:

Binhi 2008 IJRB 84:569-579

In horse spleen ferritin, up to 30% of the core exhibits magnetite/maghemite structure (Brem et al 2006)

See also, magnetite in the brain of Alzheimer's patients and human heart, liver and spleen

(Dobson 2001, Brem et al. 2006, Collingwood et al. 2008), (Grass-Schultheiss et al. 1997).

Vanderstraeten J. Gillis P. 2010. Theoretical Evaluation of Magnetoreception of Power-Frequency Fields. Bioelectromagnetics 31:371-379

Joseph L. Kirschvink 1996. Microwave Absorption by Magnetite: A Possible Mechanism for Coupling Nonthermal Levels of Radiation to Biological Systems. Bioelectromagnetics 17:187-194 (1996)

Allen et al. 2000. Low-frequency low-field magnetic susceptibility of ferritin and Hemosiderin Biochimica et Biophysica Acta 1500:186-196

A second mechanism of low level MF detection

(Magnetic compass)

- The process known as the Radical Pair Mechanism, RPM

- Low intensity MFs can increase the lifetime of free radical pairs*
- This leads to changes in chemical reaction products which can form the basis of a chemical magnetic compass
- The process also results in free radicals becoming more available to cause biological damage

*They do so by altering the spin states of radical pairs- Increasing the rate of transition from the short-lived singlet (S) to the longer-lived triplet (T) state - details at end of talk

A full explanation of the RPM may be found in slides at the end of this talk.

Now let's look at a second mechanism of MF detection in animals

– a chemical compass in the eye based on the RPM*



*Note that in salamanders the MF compass is housed in the pineal gland. The gland is also involved in the light-dependent compass in frogs, lizards and some fish

These species all have a light-dependent compass with evidence that it is based on the RPM. Notice that in some cases, this is in addition to magnetite. Notice also the involvement of the pineal gland in some species

From Lohmann 2010: Figure 1 | Animal magnetism. Diverse species have magnetic compasses, including (clockwise from top left) the European robin, the loggerhead sea turtle, the brown bat, the Caribbean spiny lobster and the red-spotted newt. A few, including turtles, lobsters and newts, also have magnetic maps.

Proposal by Ritz et al. 2000 (Biophys J 78:707-718)

-proposed that the MF reception in birds was mediated via the RPM on cryptochromes in the eye

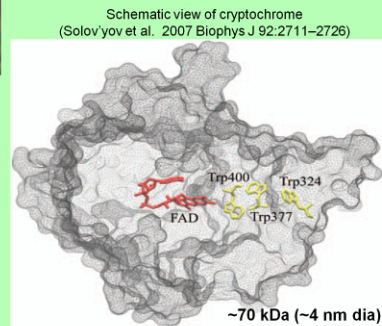


-50-90 kDa blue-light photoreceptor; flavoproteins - best known for their role in controlling circadian rhythms. High sequence-homology to DNA photolyases.

Requirements of a chemical compass:

- ✓ produces a radical pair by blue light photon absorption and electron transfer
- ✓ Undergoes increased S-T interconversion in GM field
- ✓ RPs have a lifetime $\sim 1 \mu\text{s}$ or longer¹
- ✓ Has an anisotropic response
- ✓ Can be anchored (in the eye)²

Ritz proposed that RF fields $\sim 1 \text{ MHz}$ might interfere with the MF compass



FAD = flavin-adenine dinucleotide

Radical pair consisting of FADH^\bullet and the terminal Tryptophan residue of the cryptochrome Trp-triad, RP separation is $\sim 1.9 \text{ nm}$ (Efimova & Hore 2008)

¹Liedvogel et al. 2007 *PLoS One* 2(10): e1106; ²Cry1a located in UV/V-cones Niessner et al. 2011 *PLoS ONE* 6(5): e20091

Ritz et al 2000 proposed that the avian compass was based on cryptochrome molecules in the eye and that as an experimental test, this might be interfered with by application of an appropriate RF field

RP lifetimes up to 20 ms – five orders of magnitude higher than 1 mS required have been observed: Liedvogel et al. 2007, Chemical magnetoreception: bird cryptochrome 1a is excited by blue light and forms long-lived radical-pairs” *PLoS One* 2(10): e1106; and

Cry1a located in UV/V-cones in robins and chickens, in ordered bands along the membrane discs (Niessner et al. 2011 *PLoS ONE* 6(5): e20091)

FAD = flavin-adenine dinucleotide

Ritz et al. 2004

Nature 429:177-180

Birds: European robins, *Erithacus rubecula*: 12 individually tested in spring migration season.

MF exposure: Local GMF 46 μT , inclination 66° and 565 nm light (control) plus: (i) broadband 0.1 – 10 MHz, 0.085 μT ; (ii) single frequency 7 MHz, 0.47 μT ; all parallel, 24° or 48° to GMF vector.

Results:

- RF magnetic fields disrupt the magnetic orientation behaviour of migratory birds.
- Robins were disoriented when exposed to a vertically aligned broadband (0.1–10 MHz) or a single-frequency (7-MHz) field in addition to the geomagnetic field.
- In the 7-MHz oscillating field, effect depended on the angle between the oscillating and the geomagnetic fields.
- Birds exhibited seasonally appropriate migratory orientation with no applied RF or when the RF field was parallel to the geomagnetic field, but were disoriented when it was presented at an angle of 24° or 48° at 0.085 μT .



Conclusion:

These results are consistent with a resonance effect on singlet-triplet transitions and suggest a magnetic compass based on a radical pair mechanism.

These findings have been replicated in robins and seen in chickens, zebra finches and American cockroaches

FAD = flavin-adenine dinucleotide

Effects of animal magnetic compass orientation with RF and ELF EMF exposures (GMF = geomagnetic field).

Study	MF and light exposure	Findings
Ritz et al. 2004: European robins, <i>Erithacus rubecula</i>: 12 individually tested in spring migration season.	Local GMF 46 μ T, inclination 66° and 565 nm light (control) plus: (i) broadband 0.1–10 MHz, 0.085 μ T; (ii) single frequency 7 MHz, 0.47 μ T; all parallel, 24° or 48° to GMF vector.	Birds exhibited seasonally appropriate migratory orientation with no applied RF or when the RF field was parallel to the geomagnetic field, but were disoriented when it was presented at an angle of 24° or 48° at 0.085 μT .
Thalau et al. 2005: As in Ritz et al. 2004 using 12 robins in spring and 16 robins in autumn.	As in Ritz et al. 2004, but applying RF at the local Larmor frequency of 1.315 MHz at 0.485 μ T, parallel and at 24° to GMF vector.	Birds exhibited seasonally appropriate migratory orientation in both spring and autumn with no applied RF or when the RF field was parallel to the geomagnetic field, but were disoriented when applied at 24° at 0.485 μT .
Wiltshcko et al. 2007: Domestic chickens, <i>Gallus gallus</i>, 36 in total, between 12 and 22 days old.	Local GMF 55.9 μ T, inclination 62°, artificially orientated East as control; and white, 465 nm blue or 645 nm red light plus: (i) local Larmor frequency 1.566 MHz* at 0.48 and 0.048 μT vertical (28° from GMF vector); (ii) 50% weaker and stronger: 27.9 μ T and 83.8 μ T and (iii) 25%, weaker and stronger: 41.9 μ T and 69.9 μ T.	1. Chickens orientated well in control field, but in general not in the weaker and stronger fields, suggesting a functional window around the GMF. 2. Tendency to orientate well under white and blue light, but not red, but results not statistically significant. 3. Exposure to 1.566 MHz led to disorientation suggestive of an underlying radical pair mechanism.
Stapput et al. 2008: European robins, <i>Erithacus rubecula</i>, 12–16 per test	Local GMF 46 μ T, inclination 66° and 565 nm green light or total darkness, alone (control) or plus 1.315 MHz at 0.48 μ T, 24° to GMF vector.	Normal seasonal migratory orientation under 565 nm light. In total darkness, birds orientated NW, not the migratory direction, and were not disrupted by 1.315 MHz fields, although were disrupted by anesthesia of the upper beak. Findings suggestive of two magnetic compass systems: (i) an inclination compass based on radical-pair processes allowing orientation in the migratory direction and (ii) an iron-based system that, aside from providing “map” information, can affect orientation in “fixed directions” in the absence of light, but is normally dormant when the radical-pair mechanism is operating.
Keary et al. 2009: Zebra finches, <i>Taeniopygia guttata</i>, 10 for MF orientation, 7 for visual perception	Local GMF 43 μ T, inclination 67° daylight. Local Larmor frequency 1.156 MHz at 0.47 μ T, horizontal component of GMF shifted 90° clockwise (control), RF added in same vector direction. Separately, birds were trained to orientate with respect to visual clues.	Birds exhibited migratory orientation in the 90° shifted control field, but this was disrupted when the RF field was added. Birds trained for visually guided orientation were unaffected by either the static or RF fields.

*This corresponds to the Larmor frequency for the **free electron** in the local GMF

Ritz et al. 2004 Nature 429:177–180, Thalau et al. 2005 Naturwissenschaften 92:86–90, Wiltshcko et al. 2007 J Exp Biol 210:2300–2310, Stapput et al. 2008 Curr Biol 18:602–606, Keary et al. 2009

This and the next slide:

The findings of Ritz et al 2000 have now been repeated in robins and also in chickens, zebra finches and American cockroaches

The table is very busy but I just want to point out the very low level of RF fields that disturb the compass and at frequencies corresponding to the Larmor precessional frequency of the free electron

Ritz T, Thalau P, Phillips JB, Wiltshcko R, Wiltshcko W. 2004. Resonance effects indicate a radical-pair mechanism for avian magnetic compass. Nature 429:177–180.

Thalau P, Ritz T, Stapput K, Wiltshcko R, Wiltshcko W. 2005. Magnetic compass orientation of migratory birds in the presence of a 1.315 MHz oscillating field. Naturwissenschaften 92:86–90. (DOI 10.1007/s00114-004-0595-8)

Ritz T, Wiltshcko R, Hore PJ, Rodgers CT, Stapput K, Thalau P, Timmel CR, Wiltshcko W. 2009. Magnetic compass of birds is based on a molecule with optimal directional sensitivity. Biophysical Journal 96, 3451–3457. (doi:10. 1016/j.bpj.2008.11.072)

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Begall S, Cerveny J, Neef J, Vojtech O, Burda H, 2008. Magnetic alignment in grazing and resting cattle and deer. Proceedings of the National Academy of Sciences of the USA 105:3451–13455.

Burda H, Begall S, Cerveny J, Neef J, Nemec P. 2009. Extremely low-frequency electromagnetic fields

**Effects of animal magnetic compass orientation with RF and ELF EMF exposures (GMF = geomagnetic field).
Continued:**

Study	MF and light exposure	Findings
Vácha et al. 2009: American cockroaches: 11 individually isolated from each other.	Local GMF 42.9 μ T, inclination 64°, white light: (i) These conditions as control (ii) GM North was rotated 60° in 5 min intervals Adding vertically to both of these: (iii) 1.2 MHz, 0.044 μ T, reducing (iv) 2.4 MHz, 0.044 and 0.018 μ T (v) 7 MHz, 0.044 μ T	Cockroaches were tested for locomotive activity using double-blinded procedure. 1. Changes in activity between stable and 60° periodic field rotations, indicating functionality of basic MF sense; 2. 1.2 MHz interfered with above changes, disruption threshold between 12 – 18 nT ; 3. 2.4 MHz interfered with above changes, disruption threshold between 18 – 44 nT ; 4. 7 MHz produced no disruption at 44 nT.
Ritz et al. 2009: European robins, <i>Erithacus rubecula</i>: 12 individually tested in spring migration season	(i) Local GMF 46 μ T, inclination 66° 565 nm green light, plus 8 frequencies from 0.01 to 7.0 MHz, including Larmor 1.3 15 MHz* , 0.47 – 0.48 μ T (ii) GMF artificially doubled to 92 μ T, plus 1.315 and (matched Larmor) 2.63 MHz	1. GMF of 46 μ T: (i) GMF alone: well orientated; (ii) 0.01 and 0.03 MHz: no interference; (iii) 0.1 and 0.5 MHz: weak axial response characteristic of compass on its limit of operation; (iv) 0.658 MHz and higher: disorientation; (v) Larmor frequency of 1.315 MHz* : disoriented even at 15 nT , not affected at 5 nT. 2. Static field set artificially at 92 μ T: (i) 92 μ T alone: well orientated; (ii) 1.315 MHz at 150 or 48 nT orientation no longer affected; (iii) 2.63 MHz : disorientation at 15 nT .
Begall et al. 2008: Worldwide satellite observations: 8,510 Domestic cattle in 308 pastures and 2,974 Roe deer at 241 localities	The natural GMF, daylight observations.	Domestic cattle across the globe, and grazing and resting red and roe deer, align their body axes in roughly a N-S direction . Roe deer orient their heads northward when grazing or resting. At high magnetic latitudes, magnetic North was a better predictor of alignment than geographic North.
Burda et al. 2009: As in Begall et al. 2008, including 153 localities/herds (cattle) and 47 localities/herds (roe deer) within 150 m of high voltage powerlines	Separate analysis of orientation of animals near high voltage powerlines, exposed to the GMF and power frequency electric and magnetic fields and corona ion disturbances of the atmospheric electric field.	The natural N-S orientation of cattle and deer was disrupted, with random orientation within 150 m of high voltage powerlines. However, directly under powerlines animals aligned themselves E-W under E-W lines, N-S under N-S lines and randomly under NE-SW or NW-SE lines. Furthermore, the alignment of cattle as a function of distance from E-W lines progressively rotated from E-W under the line to N-S at distances >150 m away . In the case of E-W powerlines, cattle and deer oriented better on the north side compared with the south side . Overall, the evidence supports a magnetic compass in cattle and deer based on an intensity-dependent mechanism.

*This corresponds to the Larmor frequency for the **free electron** in the local GMF

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0.092 μ T between 10 – 400 MHz

0.2 μ T at 2 GHz

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More underlying biology.....

What links these apparently disparate EMF health outcomes?

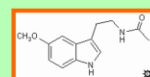
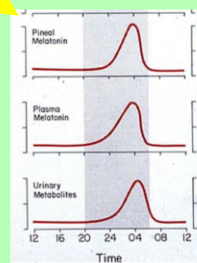
- Childhood leukaemia
- Adult leukaemia
- Adult brain tumours
- ALS (motor neurone disease)
- Miscarriage & adverse birth outcomes
- Depression & depressive symptoms
- Alzheimer's disease
- Breast cancer

They could all be explained by
Melatonin & circadian rhythm
disruption by
electric & magnetic fields

Circadian rhythm & melatonin* disruption

- could potentially explain many of the EMF health effects

- Melatonin, a key component of circadian rhythms, is produced in the pineal gland mainly at night when light levels fall below ~200 lux
- Broad-spectrum, ubiquitously-acting antioxidant and anti-cancer agent, highly protective of oxidative damage to the human haemopoietic system¹ – **relevant to leukaemia**
- Disruption by light-at-night associated with (i) increased cancer risk in animals and in humans, (ii) with **depression, Alzheimer's disease and possibly miscarriage**
- Stevens (1987)² proposed that exposure to **light-at-night and EMF** may increase breast cancer risk, by melatonin disruption
- Night-shift workers have about 50% increased risk of breast cancer
- **IARC 98 (2010) has classified night-shift work as a Class 2A Probable carcinogen**



¹Vijayalaxmi et al 1996 Mutation Research 371:221-228; ²Stevens 1987. Am. J Epidemiol. 125:556-61.

*N-acetyl-5-methoxytryptamine

The adverse health effects associated with ELF MF exposure could all potentially be explained by circadian rhythm disruption

Melatonin is a broad-spectrum, ubiquitously-acting antioxidant and anti-cancer agent. Which also reduces growth of human myeloid leukemia cells and whose disruption by light-at-night is associated with increased cancer risk.

Magnetic field disruption of melatonin, pineal cells, cryptochromes and circadian rhythms

- in humans
 - Not revealed in volunteer short exposures to pure AC MFs
 - Seen in populations exposed to "real" EMFs¹ – down to 0.2 μ T
- in animals
 - Most effects observed with non-smooth AC MFs
 - Strong findings in cows and sheep with "real" EMFs²
- on pineal cells
 - Small but detailed literature – action in synthesising melatonin disrupted. Some animals have MF compass in the pineal gland

Circadian rhythms are controlled by Clock genes

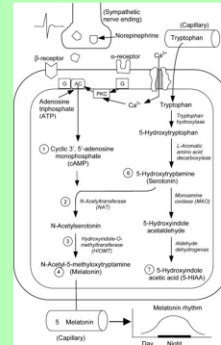
– the gene *Cry1* codes the Cryptochrome³ protein molecule, CRY1, in the eye, which in turn is involved in the regulation of circadian rhythms.

Cryptochrome acts as the magnetic compass in animals

¹Henshaw & Reiter 2005 BEMs Suppl 7:S86-S97

²Burda et al 2009. ELF-MFs disrupt magnetic alignment of ruminants. PNAS 106:5708-13.

³Evolved ~2.5 bn years (Gu 1997 Mol Biol Evol 14:861-866)



Interactions of the post-ganglionic sympathetic neuron with the pinealocyte and the synthesis of melatonin. Each of the numbered sites has been reported to be influenced by magnetic Fields¹.

Yoshii, Ahmad, Helfrich-Forster 2009 Cryptochrome mediates light-dependent magnetosensitivity of *Drosophila*'s circadian clock. PLoS Biol 7(4): e1000086.
doi:10.1371/journal.pbio.1000086

So what about magnetic field effects on melatonin, pineal cells, cryptochromes and circadian rhythms?

Melatonin disruption in humans is really seen in populations exposed to "real" fields – down to 0.2 μ T

Similarly in animals, effects are seen in "real" fields, both in the laboratory and outdoors

There's a small but detailed literature – that MFs interfere with the action of pineal cells in synthesising melatonin.

The human light-detection threshold is sensitive to MF exposure

But most importantly, cryptochrome, expressed by the CRY genes **controls the mammalian circadian clock and acts as the magnetic compass in animals.**

Are human cryptochromes magnetosensitive? - Yes

Foley, Gegear & Reppert 2011 Nature Comm ncomms1364:

"Human cryptochrome exhibits light-dependent magnetosensitivity"

- **Study:** Magnetic behavioural response of CRY-deficient and hCRY2 *Drosophila melanogaster* (10 – 12 groups of 100-150 individual flies per test), under control of *tim-GAL4 driver*.
- **Methods:** Flies exposed between 10 – 500 μ T with full spectrum and blocked (>500 & >400 nm) light
- **Findings:** (i) CRY-deficient flies showed no MF response; (ii) Human CRY-rescued flies showed light-dependent magnetosensitivity: positive response under full spectrum light was blocked at >500 nm but partially restored at >400 nm.

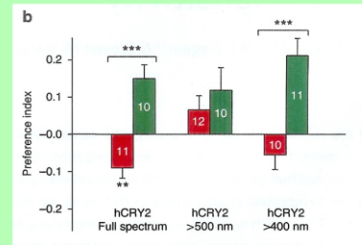
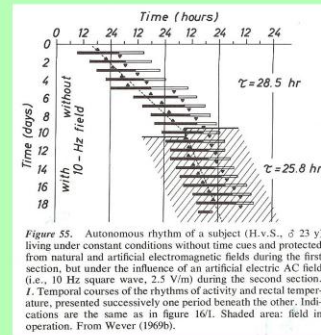


Figure 1b

Electric fields also affect circadian rhythms in humans

Wever (1979)*: In a long series of experiments, human volunteers were exposed for several weeks to 10 Hz square wave **electric fields** of only **2.5 V/m**. The 24 h circadian rhythm was disrupted. Volunteers were immediately entrained to the external signal. Effect lasted for a few days, indicating E-fields acting as zeitgebers



*Wever 1979. The circadian system of man. In: Results of Experiments Under Temporal Isolation. Schaefer KE, ed. Springer-Verlag, New York

Magnetic fields and routes to cancer

- | | | |
|-------|--|---|
| (i) | Magnetic particles | Mechanical stress or
free radical damage
via the RPM |
| (ii) | Cryptochromes
(in the eye) | Circadian rhythm
disruption |
| (iii) | Cryptochromes
(in peripheral blood cells) | Free radical damage
by the RPM |
| (IV) | Genomic instability | Clearly relevant to cancer as it
might lead to accumulation of
mutations required for cancer formation* |

*Luukkonen et al 2014 Mutation Research 760:33-41

Some other key MF effects relevant to childhood leukaemia and cancer

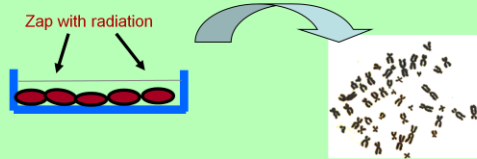
MFs Release reactive oxygen intermediates in human cord blood-derived monocytes (Lupke et al 2004. Free Rad. Res. 38:985–993) - **This alone would provide a model of how MFs increase childhood leukaemia risk***

Induction of **genomic instability, oxidative processes**, and mitochondrial activity by 50 Hz magnetic fields in human SH-SY5Y neuroblastoma cells. [Luukkonen et al 2014 Mutation Research 760:33-41](#) - **Clearly relevant to cancer, first observed with ionising radiation, now with magnetic fields**

*IARC Report no 102, 2013 states that there are well performed studies showing induction of ROS and oxidative DNA damage by RF EMFs

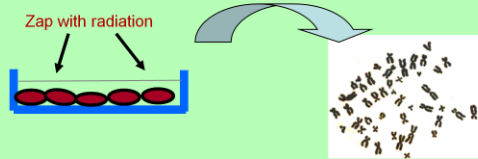
The Bystander Effect & Genomic Instability

50 years of dogma



The Bystander Effect & Genomic Instability

50 years of dogma



Look at the chromosomes at metaphase and note the damage ("DNA strand breaks")

Bystander effect (c1992)

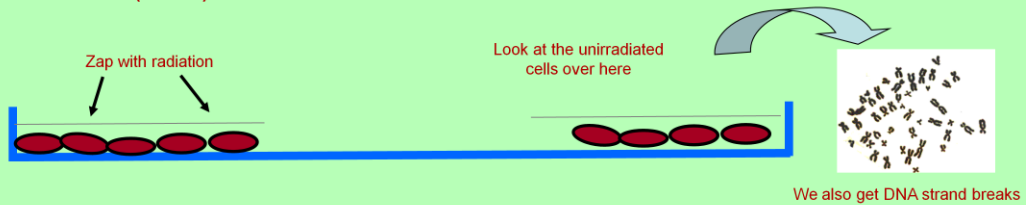


The Bystander Effect & Genomic Instability

50 years of dogma



Bystander effect (c1992)



See the work of Prof Carmel Mothersill at the Dublin Institute of Technology

Mothersill et al 2006: *Dose-Response*, 5:214–29: "It is concluded that bioelectric or magnetic effects may be involved in producing bystander signaling cascades commonly seen following ionizing radiation exposure."

Genomic instability (c1994)

50 years of dogma

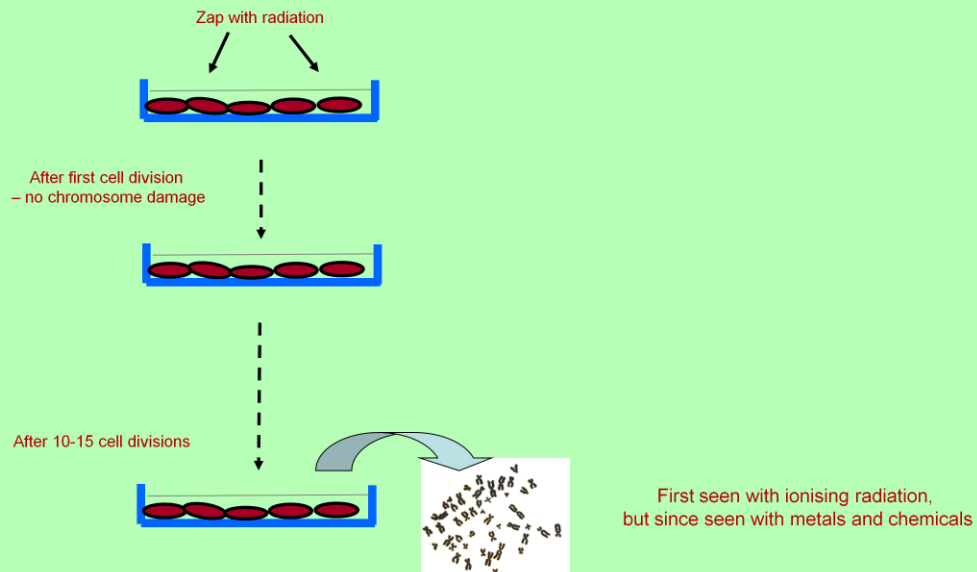
Zap with radiation



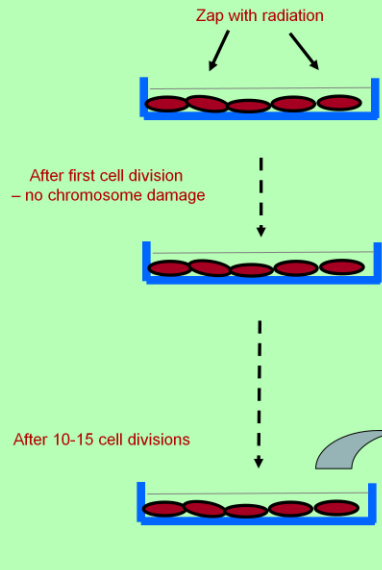
After first cell division
— no chromosome damage



Genomic instability (c1994)



Genomic instability (c1994)



2014:

Genomic instability observed with magnetic fields:

"Induction of genomic instability, oxidative processes, and mitochondrial activity by 50 Hz magnetic fields in human SH-SY5Y neuroblastoma cells" Jukka Luukkonen et al 2014 Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis 760:33-41

First seen with ionising radiation,
but since seen with metals and chemicals

Summary

- Biological studies show that magnetic fields **have key hallmarks of a carcinogen**
- Epidemiological studies strongly associate magnetic field exposure with **a range of adverse health outcomes**
- Precaution against EMF exposure **is highly warranted and cost-beneficial**

In the case of high voltage overhead powerlines, the solution is to bury the lines over populated areas. This eliminates the electric fields and corona ions, and can strongly attenuate magnetic fields

Acknowledgements

Marian Harkin MEP and her colleagues

Illia Solov'yov (Illinois)

Jonathan Woodward (Tokyo)

Mike O'Carroll

and

Children with Cancer UK

Web version: www.electric-fields.com

Session 7, Wed 25th April 2012: www.childhoodcancer2012.org.uk



Last slide

Summary of O'Carroll & Henshaw 2008

Risk Analysis 28:225-234.

Leukaemia:

Report	Number of independent studies	Positives	Significant positives
IARC 2002	33	23.5 ($p \sim 0.01$)	9 ($p < 10^{-7}$)
California 2002	43	32 ($p < 0.001$)	14 ($p < 10^{-12}$)

There were no significant-negative results in either IARC or CHD list.

Results for adult brain cancer gave a similar, but less clear, message.

*Aggregating all the studies suggests that results for childhood leukemia are not stronger, numerically, than those for adult leukemia. CDHS did not note the number of significant-positives, but noted the meta-analytic summary and the number of positives, forming a view about the strength of these findings.

IARC shows no evidence of considering the aggregation of results other than subjectively. It considered individual studies but this led to a tendency to fragment and dismiss evidence that is intrinsically highly significant"

Bioinitiative 2012:
- a biologically-based EMF Report
<http://www.bioinitiative.org>

SECTION 13: Page 16:

III. ALZHEIMER'S DISEASE

A. Possible Biologic Pathways from ELF MF Exposure to Alzheimer's Disease

A.1. Over-Production of Peripheral Amyloid Beta Caused by ELF MF Exposure

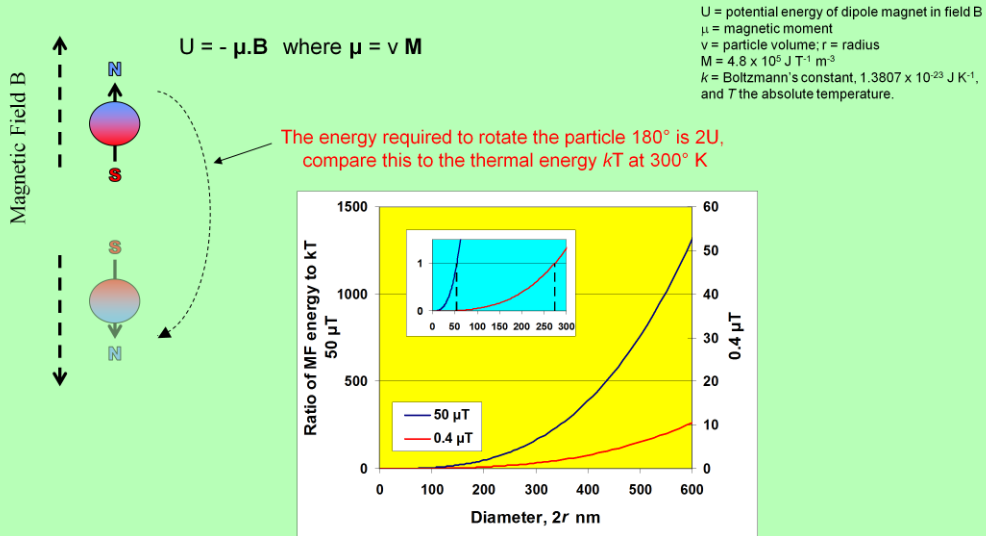
***Conclusion:** There is now evidence that (i) high levels of peripheral amyloid beta are a risk factor for AD and (ii) medium to high ELF MF exposure can increase peripheral amyloid beta. High brain levels of amyloid beta are also a risk factor for AD and medium to high ELF MF exposure to brain cells likely also increases these cells' production of amyloid beta.*

**Alzheimer's disease is linked to reduced
melatonin production in the elderly**

OXIDATIVE DAMAGE IN THE CENTRAL NERVOUS
SYSTEM: PROTECTION BY MELATONIN
RUSSEL J. REITER, Progress in Neurobiology Vol. 56, pp. 359 to 384, 1998

A selected extract from the 2012 Bioinitiative report

Potential energy of magnetic particle in the Earth's field - Compare this with the thermal energy kT



But the sensitivity is magnified with arrays & clusters of iron-based minerals

Magnetite can readily transduce a $0.4 \mu\text{T}$ 50 Hz field

See: Vanderstraeten J. Gillis P. 2010. Theoretical Evaluation of Magnetoreception of Power-Frequency Fields. Bioelectromagnetics 31:371-379

Common question: Given that we are all exposed to the geomagnetic field of $50 \mu\text{T}$, how can a 100 nT fluctuation or a $50 \text{ Hz } 0.4 \mu\text{T}$ field make any difference?

Turtles

- Kloc et al 1996 Reported that turtles with magnets on their shells when released well away from their nesting sites were initially confused.
- However, they eventually found their way back to their nesting sites

- see Irwin & Lohmann 2003 J Exp Biol 206:497-501; Lohmann et al 2011 Curr Opin Biol 22:1-7



$7,400 \mu\text{T}$ near the poles

Pigeons

Mora and Walker 2012 doi:10.1016/j.anbehav.2012.05.005

- Homing pigeons with $2,500 \mu\text{T}$ magnets on their beaks.
- Released from 26 sites up to 42 km from their loft.
- Initially flew to the right of their homing direction
- This was corrected within 2.5 km
- No effect on the speed or success of homing



NdFeB magnets, $2,500 \mu\text{T}$, 50 times GMF
1-4 year olds, trained to home from 40 km
Up to 40 pigeons in repeated releases

Now a common question that physicists ask is how can a field of $0.4 \mu\text{T}$ (at ELF frequency) make any difference alongside the existing DC field from the Earth?

The results of these studies show that turtles and pigeons respond changing magnetic fields and are not disturbed by a static (DC) field.

Static MFs alter circadian rhythms via cryptochromes

Yoshii *et al* 2009 (PLoS Biol 7(4): e1000086)

Study: *Drosophila melanogaster*. 23-29 flies per group: mean circadian period under blue light 25.8 ± 0.14 h.

Methods: Wild type flies exposed 0 and 300 μ T, red light, then 0, 150, 300, 500 μ T, blue light plus:

- (i). FAD impaired (*cryb*)
- (ii). Mutants lacking CRY (*cryOUT*)
- (iii). Clock-gene promoter/CRY over-expressed (*tim-gal4 uas-cry*) flies

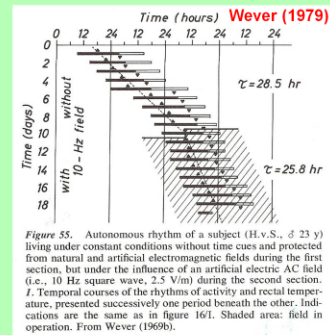
Findings: No MF effect under red light. Under blue light circadian rhythm lengthened >0.5 h at 300 μ T and (i) *cryb*: no MF effect; (ii) *cryOUT*: no MF effect and (iii) *tim-gal4 uas-cry*: at 300 μ T, 2 h period lengthening and most flies arrhythmic

What about effects in humans?

Wever (1979): In a long series of experiments, human volunteers were exposed for several weeks to 10 Hz square wave **electric fields** of only **2.5 V/m**. The 24 h circadian rhythm was disrupted. Volunteers were immediately entrained to the external signal. Effect lasted for a few days, indicating E-fields acting as zeitgebers

FAD = flavin-adenine dinucleotide

Wever 1979. The circadian system of man. In: Results of Experiments Under Temporal Isolation. Schaefer KE, ed. Springer-Verlag, New York



Here I talk through the significance that cryptochromes control circadian rhythm
Yoshii T, Ahmad M, Helfrich-Förster C (2009) Cryptochrome mediates light-dependent magnetosensitivity of *Drosophila*'s circadian clock. PLoS Biol 7(4): e1000086.

doi:10.1371/journal.pbio.1000086

FAD = flavin-adenine dinucleotide

Light, cryptochrome expression and reduced plasma melatonin

Chen *et al* 2005 [Pediatric Research 58:1180-1184] – 61 jaundiced full term neonates*:

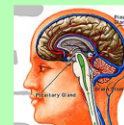
- Jaundiced neonates treated by blue light exposure with the eyes covered*
- **Expression** of circadian genes: *Bmal1* and *Cry1* in peripheral blood mononuclear cells and **reduction** in plasma melatonin
- Reduction in plasma melatonin usually interpreted as reduced **production** in the pineal gland
- Could indicate increased **consumption** in quenching free radicals in the bloodstream
- Could it be that the blue light also creates **radical pairs** in the cryptochromes, so that plasma melatonin was **consumed** in quenching these radicals?
- If so, could **environmental MFs** exacerbate this effect – resulting in increased radical damage to blood cells?

*Zhejiang Children's Hospital. 24 h exposure to 5,500 – 7,200 lux from 12 x 20 W fluorescent light bulbs

Circadian rhythms & melatonin* disruption and cancer risk

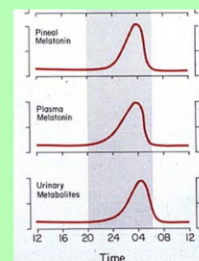
- could potentially explain many of the EMF health effects

■ Stevens (1987)¹ proposed that exposure to light-at-night and EMF may increase breast cancer risk, by melatonin disruption



■ Night-shift workers have ~50% increased risk of breast cancer

■ IARC 98 (2010) night-shift work 2A Probable Carcinogen



Melatonin produced in the pineal gland at night when light levels fall below ~200 lux

*Broad-spectrum, ubiquitously-acting antioxidant and anti-cancer agent, highly protective of oxidative damage to the human haemopoietic system²

¹Stevens 1987. *Am. J Epidemiol.* 125:556-61.

²Vijayalaxmi et al 1996 *Mut Res* 371:221-8

The adverse health effects associated with ELF MF exposure could all potentially be explained by circadian rhythm disruption

Melatonin is a broad-spectrum, ubiquitously-acting antioxidant and anti-cancer agent. Which also reduces growth of human myeloid leukemia cells and whose disruption by light-at-night is associated with increased cancer risk.

Richard G. Stevens 2012 Hypothesis: Does electric light stimulate cancer development in children?

Cancer Epidemiology Biomarkers & Prevention, doi:10.1158/1055-9965.EPI-12-0015

Some MF effects *in vitro*

1. At high fields - 1 mT 50 Hz:

Release of reactive oxygen intermediates in human cord blood-derived monocytes (Lupke et al 2004. *Free Rad. Res.* 38:985–993)

Enhance cell proliferation and DNA damage in HL-60 human leukaemia cells (Wolf et al. 2005 *Biochim Biophys Acta* 1743 :120-9)

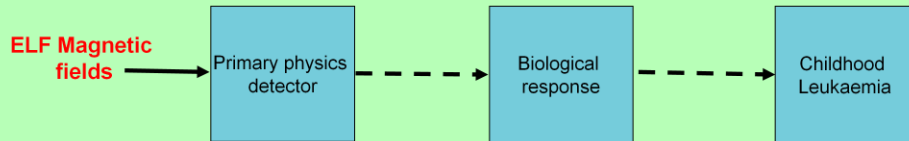
2. At environmentally relevant fields:

Stress response induced in HL-60 cells (10 μ T, 50 Hz: Tokalov & Gutzeit 2004. *Environ. Res.* 94:145–51)

A gene–environment analysis in 123 childhood ALL patients revealed an association between DNA repair enzymes and average MF exposure of 0.18 μ T.
- Yang et al. 2008 *Leuk Lymphoma* 49:2344–50 – Shanghai School of Medicine

Epidemiological Studies show a doubling of **Childhood Leukaemia** risk associated with average 0.3/0.4 μT , 50/60 Hz magnetic field exposure – and links with other adverse health outcomes too...

Is the magnetic field association with childhood leukaemia causal?



Some MF effects *in vitro*

1. At high fields - 1 mT 50 Hz:

Release of reactive oxygen intermediates in human cord blood-derived monocytes (Lupke et al 2004. *Free Rad. Res.* 38:985–993)

Enhance cell proliferation and DNA damage in HL-60 human leukaemia cells (Wolf et al. 2005 *Biochim Biophys Acta* 1743 :120-9)

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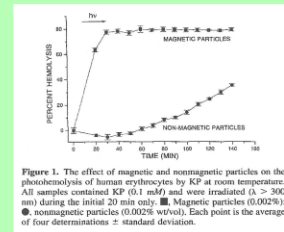
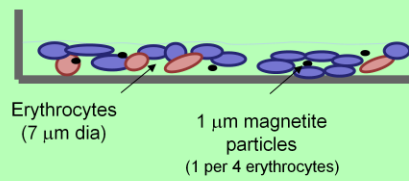
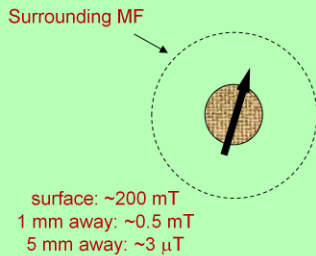
A gene–environment analysis in 123 childhood ALL patients revealed an association between DNA repair enzymes and average MF exposure of 0.18 μ T.
- Yang et al. 2008 *Leuk Lymphoma* 49:2344–50 – Shanghai School of Medicine

- An evidence-based possible cause of childhood leukaemia should in any reasonable interpretation for the public mean an adverse effect. People don't want to expose their children to an evidence-based possible cause of childhood leukaemia, even if there isn't not a fully proven cause.
- Further down the web page, this paragraph (which is given in quotes in the article) is blatant spin by the well used but crude technique of saying what was NOT said but hiding what WAS said:
- "National and international health and scientific agencies have reviewed more than 30 years of research into electromagnetic fields. None of these agencies has concluded that exposure to electromagnetic fields from power lines or other electrical source is a cause of any long-term adverse effects on human, plant or animal health."
- They did of course conclude on the basis of evidence that the exposure was a possible cause.

The RPM may act due to the MF around magnetite particles - increasing the lifetime of free radicals

Chignell & Sik 1998 (Photochem Photobiol 68: 598-601):

1 μm Magnetite particles encapsulated in polystyrene dramatically decreased the time for 50% haemolysis of UV irradiated human erythrocytes.



Binh 2008 (IJRB 84:569-79): - Hypothesised childhood leukaemia arose from SP magnetite particles in blood which transduced/amplified 50 Hz fields, creating free radicals by the RPM

A second mechanism of low level MF detection

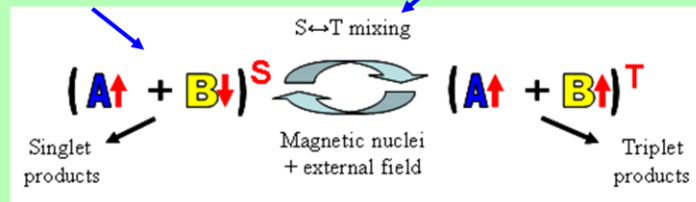
- Low intensity MFs can increase the lifetime of free radical pairs making them potentially more available to cause biological damage

They do so by altering the spin states of radical pairs

- Increasing the rate of transition from the short-lived **singlet (S)** to the longer-lived **triplet (T)** state

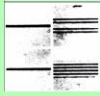
Radical pairs created by - created by light absorption, excitation and electron transfer

typical timescale of $\sim 1 \mu\text{s}$



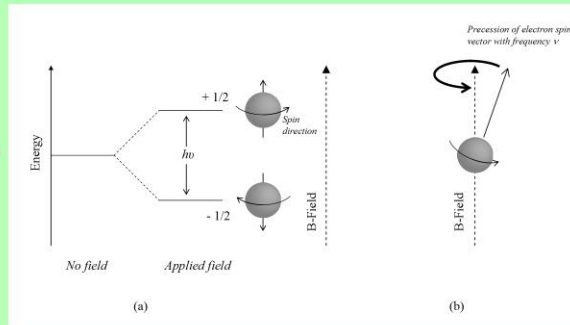
This is known as the Radical Pair Mechanism, RPM

Introduction to RPM – Zeeman splitting and Larmor precession



Zeeman Effect 1896

In a static MF, get splitting of spectral lines due to the electron spin



The equivalent classical model has the electron spin vector precessing at the Larmor frequency of 1.4 MHz at 50 μ T

Get resonant absorption (ESR) at frequency ν
= 1.4 MHz at 50 μ T

At the GM field in Nottingham, 50 μ T:
- $h\nu$ is $\sim 10^{-7}$ of thermal energy kT



Pieter Zeeman
(1865-1943)



Joseph Larmor
(1857-1942)

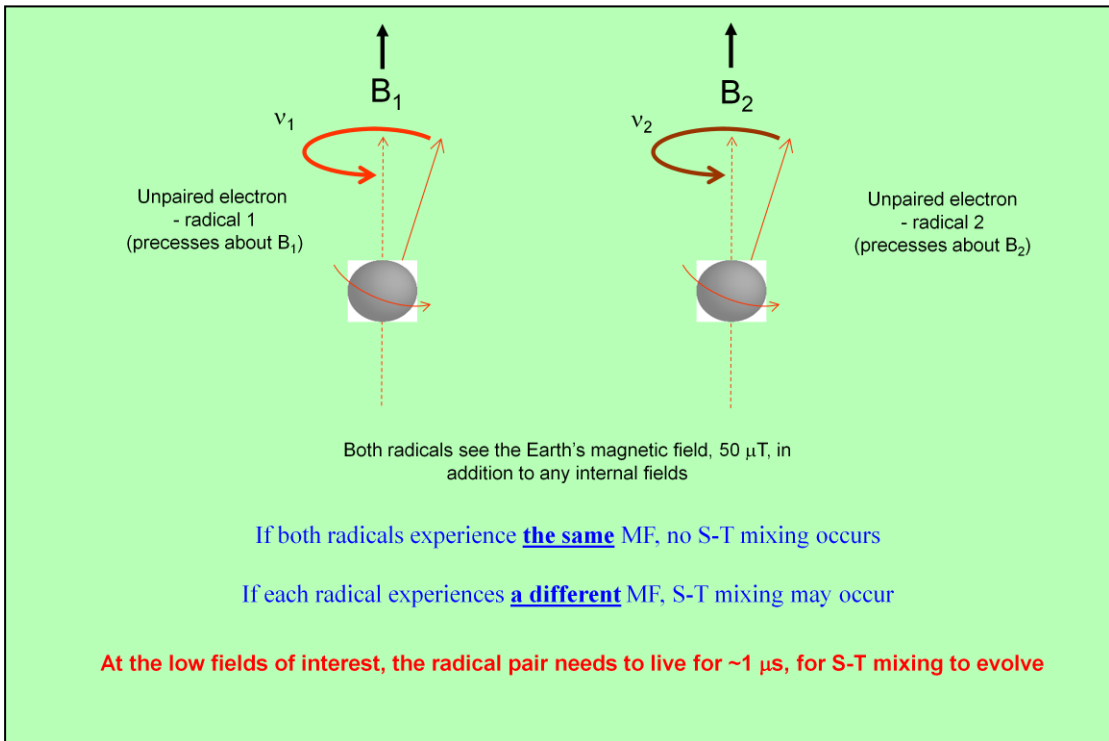
As an introduction to the RPM this slide goes back to basics

On the left we see the familiar Zeeman effect. If you put an electron in a static magnetic field, it will align its spin vector either up or down with respect to the field direction.

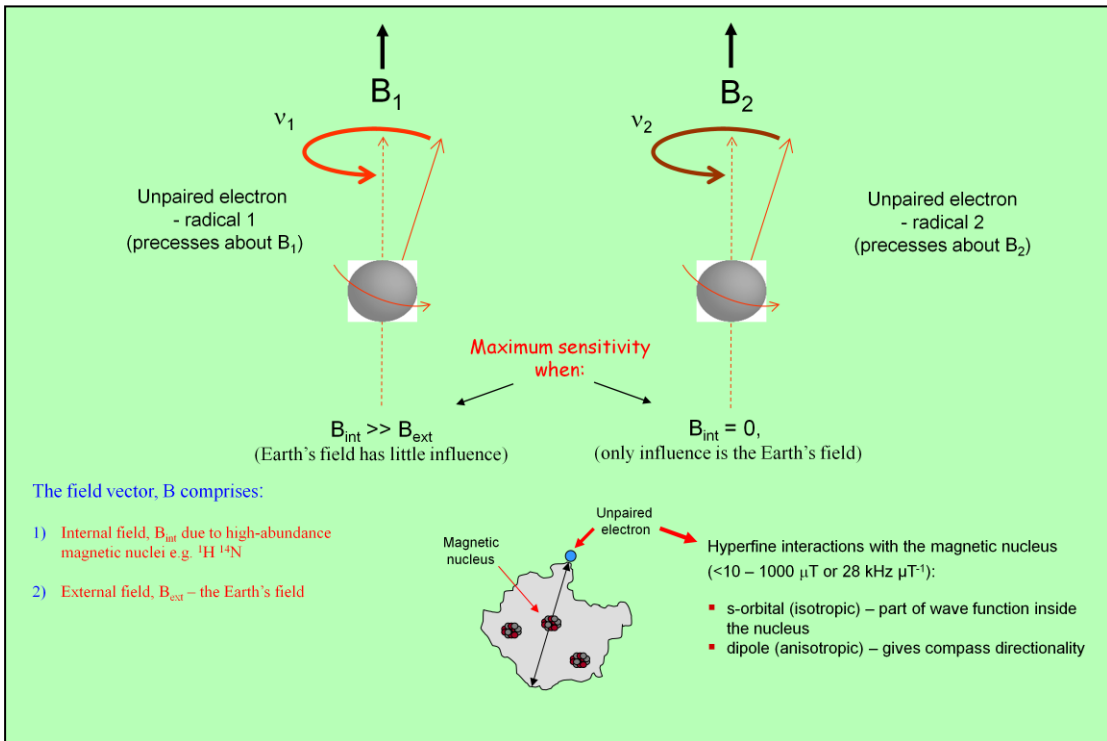
This energy difference between these states may be represented by a photon of energy $h\nu$ where h is Planck's Constant and ν is the photon frequency. A spectroscopic transition can be induced between these energy states by applying radiation at the correct frequency. At 50 μ T, $\nu = 1.4$ MHz.

I am showing this to point out that the energy difference is $\sim 10^{-7}$ of the thermal energy kT . i.e. the phenomenon is not only well below kT , but is has nothing to do with classical energies, rather we are talking about the quantum-mechanical interaction of the magnetic field with the electron spin.

On the right is the classical physics model of this, taken from NMR & MRI, that the electron is precessing about the magnetic field at frequency ν , 1.4 MHz, the so-called Larmor frequency. I will be using this model in a moment.



Here I talk through how RP mixing occurs, using the precession model



Continued:

The field vector, B has two components: (i) due to **high-abundance magnetic nuclei e.g. 1H ^{14}N** , and (ii) due to the **Earth's field**.

For a compass, maximum sensitivity occurs when the Earth's field has little influence on precession on radical 1, but is the only influence on radical 2

The precession is governed by hyperfine interaction with the proton in the nucleus, consisting of an isotropic S-wave, or S-orbital interaction, and an anisotropic dipole interaction.

Radical pair scheme in cryptochrome

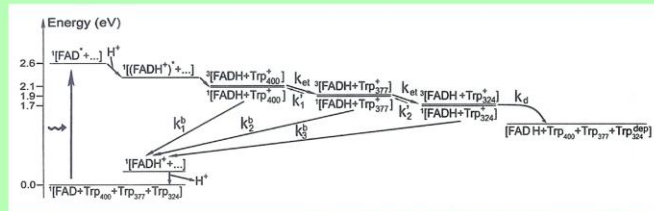


Figure 2. Schematic presentation of the radical-pair reaction pathway in cryptochrome.

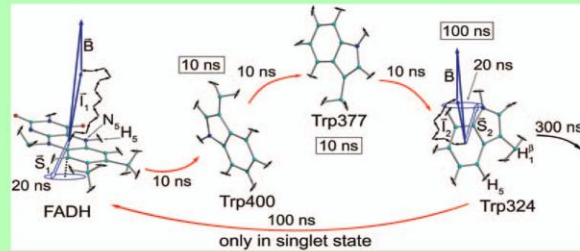


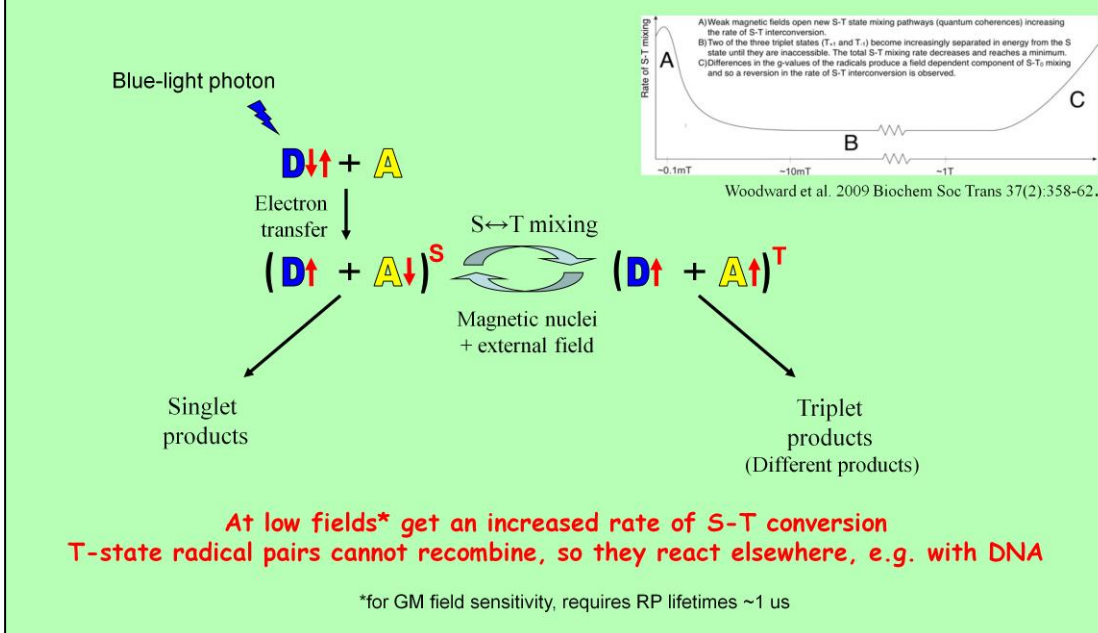
Figure 4 Schematic illustration of electron hole transfer and electron spin dynamics in the FADH cofactor and tryptophan chain.

From Solov'yov et al. (2007) Biophys J 92:2711-2726.

I've slipped this slide in here to point out models of the actual RP pathways in cryptochrome

FAD = flavin-adenine dinucleotide

RPM and the Low Field Effect



Low fields open up new S-T mixing pathways increasing the rate of S-T conversion

Examples of RPM in chemical systems:

Scaiano et al 1997: Photoreduction of benzophenone by 1,4-cyclohexadiene;

Mohtat et al 1998: Radical pair derived from hydrogen abstraction of triplet benzophenone;

Streiner & Ulrich 1989: Table 6 (Molecular crystals): e.g. Naphthalene, 1,4-dibromonaphthalene, anthracene; Table 5: e.g.s of photochemical reactions in the gas phase

Brocklehurst & McLauchlan 1996: benzaldehyde (PhCHO , $\text{Ph} = \text{C}_6\text{H}_5$) in tetrachloromethane; RPs created from UV irradiation of the condensed ring aromatic hydrocarbon pyrene (Py) in solution with 1,3-dicyanobenzene (DCB)

Vink & Woodward (2004): Radical recombination reaction occurring after the photodecomposition of 2-hydroxy-4-(2-hydroxyethoxy)-2-methylpropiophenone (R-HP)

Woodward et al 2002: Pyrene with isomers of dicyanobenzene

References:

Steiner UE, Ulrich T. 1989, Magnetic field effects in chemical reactions and related phenomena. Chemical Reviews. 89:51-147.