Hingtgen, Robert J

From: Donna Tisdale [tisdale.donna@gmail.com]
Sent: Monday, March 11, 2013 12:52 PM
To: Hingtgen, Robert J
Subject: Fwd: Soitec Solar PEIR MUP Henshaw documents
Attachments: EMF 2001 Henshaw summary CDPH report.pdf; BPG minutes-summary 6-14-12 FINAL.pdf

Robert,

This is my third try . See kicked back message below.

Instead of sending the pdf version of the attached power point by Professor Henshaw, that is apparently too large to send, I am sending the link for it instead: www.electric-**fields**.bris.ac.uk/henshaw_arr_june_2011.ppt . His 2011 power point us titled: The interaction of magnetic fields with biological systems – trying to understand the diversity of reported health effects

Here is a link to the Professor's home page with his credentials and additional information: http://www.electric-fields.bris.ac.uk/d_henshaw.html I have communicated with him briefly.

Please confirm receipt and include the linked and attached documents in the record for the Soitec Solar PEIR MUP.

Thank you,

Donna
619-766-4170

---------- Forwarded message ----------
From: **Donna Tisdale** <tisdale.donna@gmail.com>
Date: Mon, Mar 11, 2013 at 11:19 AM
Subject: Soitec Solar PEIR MUP Henshaw documents
To: "Hingtgen, Robert J" <Robert.Hingtgen@sdcounty.ca.gov>

Hello Robert,

As promised, I have attached the other two documents by Dennis Henshaw, PhD that were attached to my original message with Soitec Solar PEIR MUP comments sent on January 31 that did not go through.

Also attached are Boulevard Planning Group minutes for June 14, 2012 that you requested.

Please confirm receipt of this and previous message with my Soitec Solar PEIR MUP comments.

Thank you,

Donna
619-766-4170

California Health Department Report

(Released for public discussion April 2001)

An Evaluation of the Possible Risks From Electric and Magnetic Fields (EMFs) From Power Lines, Internal Wiring, Electrical Occupations and Appliances*

Summary and Commentary

by

Professor Denis L Henshaw

University of Bristol
H H Wills Physics Laboratory
Tyndall Avenue
Bristol, BS8 1TL, UK

Tel: 0117 9260353, Fax: 0117 9251723, E-Mail: d.l.henshaw@bristol.ac.uk

October 2001

*Access at: http://www.dhs.ca.gov/ehib/emf/RiskEvaluation/riskeval.html
or via
http://www.electric-fields.bris.ac.uk "California EMF Health Report"

California Health Department Report on the Possible Health Risks Associated with Power Frequency Electric and Magnetic Fields (EMFs)

Summary and Commentary by Professor Denis L Henshaw

The California Health Department has released for public discussion a major report on the health effects of power frequency electric and magnetic fields. This comprehensive report and in-depth analysis examines 13 health conditions and suggests an added risk of miscarriage, childhood and adult leukaemia, brain cancer and a greater incidence of suicide as some of the health risks associated with electric and magnetic fields such as those that radiate from powerlines.

The Report runs to over 560 pages. The scientific evidence was first assessed by three expert Reviewers who then had to present and defend their assessments in the form of a draft report to a scientific committee within the California Health Department. A resulting second draft report was then sent to outside consultants and to members of the California Health Department's Science Advisory Panel. Comments received after this draft were incorporated to produce the draft for public comment now available on the Internet.

The Report for public comment is dated April 2001. It was released on the Internet in July 2001 under pressure from a California First Amendment Coalition lawsuit. The deadline for public comment was September 10th 2001.

This commentary summarises the main findings and the detailed arguments behind the conclusions. Below is a summary of the findings in tabular form (table 1) followed by a description of the degree of confidence in causality (table 2). Selected extracts from the Report then follow.

Conclusions in tabular form

Table 1 below summarises the risk assessment from exposure to magnetic fields given in the California Health Department Report. For a given condition, note that the probabilities of a link include a chance that EMFs have no effect. The table on the following page summarises the criteria used by the Assessors.

Condition	Probability of a link with exposure to power frequency magnetic fields
Cancer	
Childhood Leukaemia	Two of the reviewers said 50 – 80% likely; one reviewer said virtually certain (>98% likely)
Adult leukaemia	Two of the reviewers said 50% to 90% possible One reviewer said 10 – 50% likely
Adult Brain Cancer	50% - 90% likely
Childhood Brain Cancer	10% - 50% likely
Male Breast Cancer	10% - 50% likely
Female Beast Cancer	Two of the reviewers said 10% - 50% likely One reviewer said 50% - 90% likely
All Cancers	Very improbable, 2 – 10% likely
Other conditions	
Miscarriage	50% - 90% likely that exposure could add 5-10% to the baseline risk
Birth Defects	Very improbable, 2 –10% likely
Amyotrophic Lateral Sclerosis (ALS)	50% - 90% likely
Heart Disease	10% - 50% likely
Suicide	10% - 50% likely

Table 2 below gives the degree of confidence in causality and the International Agency for Research on Cancer (IARC) classification for the conditions in table 1 that have been statistically associated with EMFs. The following introduction to this mode of presentation of the findings is given in the Report:

To help the reader calibrate this mode of presenting scientific judgments, we include one of the reviewer's judgments on two non-EMF issues. One is an accepted environmental association (air pollution and the exacerbation of asthma attacks) and the other a more controversial environmental association (fine particulate pollution and fluctuations in cardio-respiratory death). One can see that reviewer 2 was virtually certain that air pollution can trigger asthma attacks. The range of uncertainty was narrow. The reviewer was still quite confident that particulate air pollution could cause deaths, even though the mechanisms for this are not understood. However, the range of uncertainty is larger for this relationship.

We also show the initial or prior degree of confidence, prior to considering specific EM evidence, that EMFs could cause epidemiologically detectable disease. As with any new agent taken at random, all reviewers thought that, on average, it is improbable that EMFs would cause epidemiologically detectable disease at usual occupational and residential exposures and the range of uncertainty is fairly narrow.

TABLE 1 DEGREE OF CONFIDENCE IN CAUSALITY AND IARC CLASSIFICATION FOR CONDITIONS THAT HAVE BEEN STATISTICALLY ASSOCIATED WITH EMFs

CONDITION	REVIEWER	IARC CLASS	CONFIDENCE IN CAUSALITY	DEGREE OF CONFIDENCE IN CAUSALITY FOR POLICY ANALYSIS
Air Pollution Triggered Asthma Attacks (Example: Not EMF Related)	2	Human Risk	Virtually Cert.	
Particulate Air Pollution Triggered Deaths (Example: Not EMF Related)	2	Probable Risk	Highly Prob.	
Prior Confidence that EMFs Could Cause Epidemiologically Detectable Disease	1 2 3		<51% Possible Very Improb. <51% Possible	
Childhood Leukemia	1 2 3	Carcinogen Possible Probable	Virtually Cert. >50% Possible >50% Possible	

CONDITION	REVIEWER	IARC CLASS	CONFIDENCE IN CAUSALITY	DEGREE OF CONFIDENCE IN CAUSALITY FOR POLICY ANALYSIS
Adult Leukemia	1 2 3	Carcinogen Possible Possible	>50% Possible >50% Possible <51% Possible	
Childhood Brain Cancer	1 2 3	Inadequate Inadequate Inadequate	<51% Possible <51% Possible <51% Possible	
Adult Brain Cancer	1 2 3	Possible Possible Possible	Virtually Cert. >50% Possible >50% Possible	
Breast Cancer, Female	1 2 3	Inadequate Inadequate Inadequate	>50% Possible <51% Possible <51% Possible	
Breast Cancer, Male	1 2 3	Inadequate Inadequate Inadequate	<51% Possible <51% Possible <51% Possible	

CONDITION	REVIEWER	IARC CLASS	CONFIDENCE IN CAUSALITY	DEGREE OF CONFIDENCE IN CAUSALITY FOR POLICY ANALYSIS
EMF Universal Carcinogen?	1 2 3	Inadequate Inadequate Inadequate	Very Improb. Very Improb. Very Improb.	
Spontaneous Abortion	1 2 3	Possible Possible Possible	Highly Prob. > 50% Possible >50% Possible	
Other Reproductive	1 2 3	Inadequate Inadequate Inadequate	Very Improb. Very Improb. Very Improb.	
ALS	1 2 3	Possible Possible Possible	>50% Possible >50% Possible >50% Possible	
Alzheimer's	1 2 3	Inadequate Inadequate Inadequate	<51% Possible <51% Possible < 51% Possible	

CONDITION	REVIEWER	IARC CLASS	CONFIDENCE IN CAUSALITY	DEGREE OF CONFIDENCE IN CAUSALITY FOR POLICY ANALYSIS
Suicide	1 2 3	Inadequate Inadequate Inadequate	<51% Possible <51% Possible <51% Possible	
Heart	1 2 3	Inadequate Inadequate Inadequate	<51% Possible <51% Possible <51% Possible	

Selected Extracts from the Report

STATEMENT FOR THE GENERAL PUBLIC

Page 1, line 1 on. On behalf of the California Public Utilities Commission (PUC), three scientists who work for the California Department of Health Services (DHS) were asked to review the studies about possible health problems from electric and magnetic fields (EMFs) from power lines, wiring in buildings, certain jobs and appliances.

The following statements properly capture the range of their judgements:

It is "*more than 50% possible*" that EMFs at home or at work could cause a very small increased lifetime risk of childhood leukemia, adult brain cancer, and amyotrophic lateral sclerosis (ALS, Lou Gehrig's Disease).

It is "*more than 50% possible*" that EMFs at home or at work could cause a 5-10% added risk of miscarriage....

It is "*10-50% possible*" that residential or occupational EMFs could be responsible for a small increased lifetime risk of male breast cancer, childhood brain cancer, suicide, Alzheimer's disease, or sudden cardiac death.

It is *"very unlikely (2-10% possible) but not impossible"* that residential or occupational EMFs could be responsible for even a small fraction of birth defects, low birth weight, neonatal deaths or cancer generally.

As the above phrases imply there is also a chance that EMFs have no effect at all.

All of the three reviewers give a degree of confidence of at least "*10-50% possible*" that residential or occupational EMFs could be responsible for a small increased lifetime risk of adult leukemia or female breast cancer, and one gave a degree of confidence that was higher.

The reviewers compared the size of possible risks from EMFs to the size of possible risks from chemical and physical agents now being regulated. They agreed that:

Page 1, lines 21 – 23. If EMFs really contribute to the cause of these `[the above]` conditions, even these low individual risks and the low fractions of cases could be of concern to regulators. Indeed, when deemed real, **theoretical risks smaller than these have triggered regulatory evaluation and sometimes, regulatory control of chemical agents.**

Page 2, lines 1 – 6. [concerning miscarriage] While rodent and chicken egg studies provide little or no support, two new epidemiology studies in humans suggest that a substantial proportion of miscarriages might be caused by EMFs. Miscarriages are common in any case (about 10-15% of pregnancies) and the theoretical added risk for an EMF-exposed pregnant woman may be an additional **5 to 10% according to these two studies. If true, this would clearly be of concern to individuals and regulators**. However, the type of EMF exposures implicated by these two new epidemiological studies (short, very high exposures) probably come from being within a few inches of appliances and indoor wiring, and only rarely from power lines. It may not be possible to avoid all such exposures in modern life.

Page 2, lines 7 – 8. Even one exposure a day [short, very high exposures to magnetic fields] if typically experienced during pregnancy, seemed to increase the risk of miscarriage. Nonetheless, [the Report emphasises] the majority of pregnant women with such exposures did NOT miscarry.

SCIENTIFIC ABSTRACT OF EXECUTIVE SUMMARY

HOW THE EVALUATION WAS DONE

Page 3, lines 2 – 10. The three main reviewers examined epidemiological findings statistically linking EMFs and 13 health conditions and developed a degree of confidence that these statistical links might be causal in nature. .... They also provided a classification of the evidence using criteria developed by the International Agency of Research on Cancer (IARC).

Often these two evaluations were not consistent with each other. There are several reasons for this. The California Guidelines, which, unlike IARC require explicit pro and con justification for the classifications made, tend to consider emerging evidence that the more conservative IARC system discounts. The California Guidelines require the reviewers to provide a quantitative degree of confidence that is needed for the California program's policy projects. The IARC system is at base a *"quality of evidence"* classification, while the California Guidelines call for a *"degree of confidence"* classification.

Elsewhere in the Report a detailed description of how the review process was carried out is given. The extract below

is taken from Chapter 1, Introduction, Section 1.5 "THE DHS REVIEW PROCESS OF THE CORE EMF TEAMS RISK EVALUATION".

> A number of Epidemiologists and Toxicologists with the California Department of Health Services (DHS) and experienced in environmental health investigations, were asked to read parts of the literature reviewed for this evaluation. After the first draft of this document was completed, the scientists critically reviewed it .... They then participated in a 3-day workshop which included a training on probability elicitation [see Appendix 2 of the Report]. After this training, the core EMF Risk Evaluation Team [the three core Reviewers], who previously had received probability elicitation training, **presented and defended their evaluation**.
>
> The DHS scientists were encouraged to ask probing questions and to challenge both the comprehensiveness and the validity of the pro and con arguments and subsequent discussion ... After the workshop the core team conscientiously reviewed the comments received and modified the first draft.
>
> The second draft was sent to outside consultants and to members of the Department's Science Advisory Panel (see Appendix 1 of the Report for membership). Comments received after this second draft were incorporated to produce the present draft for public comment.

This summary now continues with extracts from the section "STATEMENT FOR THE GENERAL PUBLIC":

POTENTIAL POPULATION BURDEN OF ILL HEALTH AND THEORETICAL LIFETIME RISK FROM HIGH EMF EXPOSURE

Page 4, lines 22 – 27. Two recent review articles calculated the proportion of all childhood leukemia cases that might be attributed to the rare highest residential EMF exposures to be around 4%. This would translate to about four deaths in California per year. ... If the same 4% were applied to the 11 conditions listed above that were not *"very unlikely"* to be caused by EMFs, the numbers of attributable cases **could be in the hundreds or thousands and comparable to the theoretical burden of ill health that has motivated other environmental regulation**. This would be true even if one were only 20% sure that EMF was a contributory cause of these various conditions.

Page 5, lines 1 – 3. The theoretical lifetime individual risk that derives from any agent that has an epidemiologically detectable effect will by definition be greater than the lifetime risk of 1/100,000 that triggers many regulatory processes. This means **most** of the epidemiological associations examined in this document **would clearly be of regulatory concern if real.**

[The Report then emphasises that apart from miscarriage, the risk to \the individual is extremely small.]

Page 5, lines 8 - 10. Two new epidemiology studies suggest that a substantial proportion of miscarriages (40%) might be caused by EMFs. Miscarriages are common in any case (about 10-15% of pregnancies) and the theoretical added risk for an EMF-exposed pregnant woman may be 5 to 10% according to these two studies. If true, this would clearly be of regulatory concern.

EXECUTIVE SUMMARY

HOW THE EVALUATION WAS DONE

Page 5, lines 20 – 22. The reviewers also presented a judgement as to whether or not the epidemiological associations, if judged to be causal, suggested a magnitude of theoretical added risk above 1/100,000 or 1/1000 for highly exposed groups.

A SUMMARY OF WHAT HAS CHANGED SINCE THE CALIFORNIA EMF PROGRAM WAS FIRST PROPOSED IN THE EARLY 1990S

Page 5, lines 48 – 59. Biophysical arguments based on physical principles and simplified biological models have produced lower and lower predictions as to what magnetic field intensities theoretically would be capable of producing biological effects. Nevertheless, theory would still claim that most residential and occupational epidemiological results are *"impossible"*. It would also claim that bioeffects from magnetic field experiments using intensities less than 100 mG (10 μT) are "*impossible*". Those who adhere to these biophysical theories still discount the relevance of experimental results at higher intensities to epidemiological findings because of this "*impossibility*" threshold and would require robust bioeffect laboratory results from ambient levels of exposure. **This is an unusual burden of proof since ambient levels of other pollutants often do not produce effects large enough to see in the laboratory.**

Under Mechanistic Research:

Page 5, lines 66-67, page 6 lines 1-2. One laboratory published studies and three other labs reported, but have not published, on the effect of low intensity (12 mG [1.2 μT]) magnetic fields on the ability of melatonin to inhibit cancer cell proliferation *in vitro*.

Under Epidemiology:

Page 6, lines 12 – 15. Published statistical summaries of the body of epidemiological evidence have suggested that chance is an unlikely explanation for the associations seen for childhood leukaemia, adult leukaemia, adult brain cancer, male breast cancer and ALS.

Page 6, lines 19 – 23. The study of **Linet *et al.*, originally interpreted** as showing no effect has been shown to contribute **important support in pooled analyses that indicate that the association between the highest exposures to EMF and childhood leukaemia are unlikely to be due to chance.**

Page 6, lines 24 – 29. An epidemiological literature is developing that associates magnetic fields with **diseases and conditions that are more common, such as sudden cardiac death, dementia, suicide and spontaneous abortion.** From a **cost/benefit perspective,** the confirmation of the associations in these more-common diseases **would have greater policy implications than the confirmation of EMF associations with rare disease, such as childhood cancer or amyotropic lateral sclerosis.**

How Credible Was the EMF Hypothesis To Begin With?

Page 7, lines 8 – 10. They [the Reviewers] were not much swayed by theoretical biophysical arguments that such [EMF] influences were impossible.

The Weight Accorded to the Experimental Evidence on any Mechanisms By Which EMF Might Work

Page 7, lines 29 – 32. [The reviewers pointed out that initially for many disease-causing agents there was not a well-documented mechanistic chain of events to explain causality]. Thus: The absence of a clear mechanistic story, and the failure of many experiments with aspects of the EMF mixture to produce any mechanistic effects, did not pull confidence of causality much below what it was initially.

Page 7, lines 36 – 40. Thus, this line of evidence did not contribute much to the reviewers' judgements. This is because, generally, the **lack** of mechanistic understanding is **initially so common in harmful agents** that **the absence of mechanistic understanding** is **not** as strong an argument against causality **as the presence of such an understanding would be in favor of causality.**

WEIGHT ACCORDED TO ANIMAL PATHOLOGY EXPERIMENTS

Page 7, lines 50 – 52. ... they [the Reviewers] were also cognizant that there are known human carcinogens, such as cigarette smoke, alcoholic beverages, benzene and arsenic, for which no animal model existed for many decades.

CONSIDERING THE RANGE OF EXPOSURE IN THE GENERAL POPULATION HOW MUCH MORBIDITY AND MORTALITY MIGHT BE ATTRIBUTED TO EMFS?

Page 16, lines 23 – 58. Greenland et al (2000)[1] and Wartenberg (2000) estimated that residential EMF exposure might account for 0% to 12% of childhood leukemia, with a mid-point estimate around 4%. A reanalysis of the Greenland data, supplemented by those of the UK (1998) study described in the body of this document, narrowed the confidence interval but concurred with the 4% mid-range estimate. This translates to four deaths per year from childhood leukemia in California. The miscarriage studies of Li (2000) and Lee (2000b) suggested that around 40% of the estimated 60,000 miscarriages in California each year might be attributable to exposure to maximum fields. The reviewers have insufficient information to provide similar figures for other disease endpoints.

While 4% sounds like a low number, the annual numbers in California would not be trivial if applied to the base-line incidence or mortality rate of various conditions that received degrees of confidence greater than "*very improbable to be a cause*". Table 2 [in the Report] shows the mortality expected in about 9.6 million Californians younger than 20 and in the 23.4 million Californians over 20 years of age from these causes of death. Of these deaths, some fraction might be affected by EMFs. While the spontaneous abortions, ALS, and Alzheimer deaths are estimated using rates from special studies, the other deaths are derived from 1998 vital statistics. Even if the miscarriages are not treated as deaths, one is left with about 28,700 deaths. Four percent of this is about **1,150 deaths per year**. Forty percent of 60,000 miscarriages is **24,000**.

As a comparison, the California Comparative Risk Project (1994) (di Bartolomeis M, editor, *Toward the 21st Century: Planning for the Protection of California's Environment*. Final Report: California Comparative Risk Project, May 1994) estimated, from animal data, that there would be 49 cancers (not deaths) from chloroform in chlorinated drinking water, 100 cases of cancer (not deaths) from benzene in ambient air, and 124 cases of cancer (not deaths) from formaldehyde in indoor air (page 133). By extrapolating from occupational exposures to radon, they estimated 570 annual cases of cancer (not deaths) from naturally occurring indoor radon (page 427). **Thus, if one were certain that the epidemiological associations** [with magnetic fields] **were causal, the population burden of mortality would be more than that from many currently regulated**

[1] A bibliography is given in the California Health Department Report

environmental agents. If one were to adjust these numbers by one's degree of confidence in causality in order to derive an "*expected number*" and one used **20% as the degree of confidence of causality**, the above numbers would change from 1,148 to **229** and from 24,000 to **4,800**. **This is still not trivial in the regulatory framework**.

POLICY RELEVANT AREAS FOR FURTHER RESEARCH

Page 18, line 25 on. ...Deeply ingrained experimental research styles and an orientation to explaining mechanisms rather than describing phenomena has meant that investigator-initiated research and even programs which attempted to guide research have rarely been characterised by progressively refined descriptions of dose response relationships to produce stronger bioeffects.

This has been compounded by the expectation of a quick resolution of the question by those who fund the research, as was the case with the New York State program of the mid-1980s, the central California Program and the recent five year federal EMF program. As was discovered after President Nixon's "War on Cancer" in the early 1970s, research progresses slowly and in successive multi-year research cycles, with the results of each cycle governing the direction of the next.....

Line 37 on. This means that if one were serious about clarifying this issue, there would need to be a long-term commitment to steady research funding and funding for intermittent assessments of the state of the science and research directions.

Line 60 on. Such aspects include sudden exposures to the 60 Hz fields, such as micro shocks, stray ground currents and charged air pollutants. Such exposures would make it possible to reanalyse some of the existing worker cohorts to determine if these aspects are associated with diseases.

Rather than further pursuing new studies of rare diseases with long term incubation periods, further studies of the more common and policy-relevant conditions in which EMFs might have shorter incubation periods, such as spontaneous abortion, acute myocardial infarction and suicide, should be given priority.

The body of the Report

The body of the report deals with 13 health conditions: childhood leukaemia, adult leukaemia, childhood brain cancer, adult brain cancer, breast cancer (female), breast cancer (male), EMF as a universal carcinogen, spontaneous

abortion (miscarriage), other reproductive outcomes, ALS (Amyotrophic Lateral Sclerosis), Alzheimers disease, suicide and heart disease. For each condition the epidemiological evidence is reviewed and a level of risk attached to whether the incidence has any association with exposure to power frequency magnetic fields (as given in table 2 above). In each case the following arguments for or against causality are rigorously discussed: whether a given association is due to or influenced by chance, bias or confounding. Also considered is the strength of association, the consistency, homogeneity and dose response, the experimental evidence, the plausibility, analogy, temporality, specificity and relevance to other disease associations. These are the Hill (1965) criteria for causal inference of epidemiological associations.

It is this latter analysis for each of the 13 health outcomes that sets the California Health Report apart from any previous EMF health report. For each of the health outcomes, it gives the reader a clear explanation of the strengths and weaknesses of the epidemiological data considered and the rationale behind the conclusions reached by the Reviewers.

There are 6 appendices. Appendix 1 lists the Advisory Panel. Appendix 2 (67 pages) describes in detail the evaluation guidelines used by the Reviewers. The in-depth description is particularly valuable, especially the description of Bayesian analysis and its application to the evaluation of the evidence linking EMF exposure to the various health outcomes. Appendices 3 & 4 describe the (real but nevertheless rather meagre) evidence of hypersensitivity to electric and magnetic field exposures. Appendices 5 & 6 describe two major studies (in press) of miscarriage and exposure to magnetic fields.

Finally, a Policy Option document provides a cost-benefit analysis of the various options for reducing or avoiding exposure to power frequency electric and magnetic fields. This includes the burial of overhead high voltage powerlines (transmission lines).

What is not in the Report?

1. There is no detailed discussion of corona ion emission from high voltage powerlines and their action in charging

airborne pollutants. For separate evaluation see http://www.electric-fields.bris.ac.uk

2. The possible impact of exposure to magnetic fields and the effectiveness of the breast cancer inhibiting drug TAMOXIFEN.

3. There is no discussion on currently recommended exposure limits such as those of the International Commission on Non-ionising Radiation Protection, ICNIRP (100 μT), the

   UK National Radiological Protection Board, NRPB (1,600 μT) and that recently introduced by the Swiss Government for new installations (1 μT).

   In the pooled analyses of childhood leukaemia for example, a doubling of risk was associated with exposures above 0.4 μT. Most average domestic exposures in the UK are below 0.1 μT. Close to high voltage powerlines values up to 40 μT can be found. Elevated exposures also arise from underground high and low voltage distribution circuits. Short term exposures to elevated magnetic fields can occur near domestic appliances such as hair dryers. In a recent statement the UK Institution of Electrical Engineers, IEE (Factfile March 2001) has suggested that if people wish to avoid exposure to magnetic fields, some of the things which contribute to above-average exposures are:

   - Mains appliances such as clock-radios close to the bed;
   - Electric blankets left on overnight;
   - Homes close to high-voltage powerlines.

How to get hold of the Report: "*California Health Department Report on the Possible Health Risks Associated with Power Frequency Electric and Magnetic Fields (EMFs)*"

1. Access and download free from the web directly at:

http://www.dhs.ca.gov/ehib/emf/RiskEvaluation/riskeval.html

or via the Bristol University Website:

http://www.electric-fields.bris.ac.uk "California EMF Health Report"

2. A hard copy may be obtained from:

City Copy Center
580 14th Street
Oakland, CA 94612, USA
Phone: (510) 763-0193

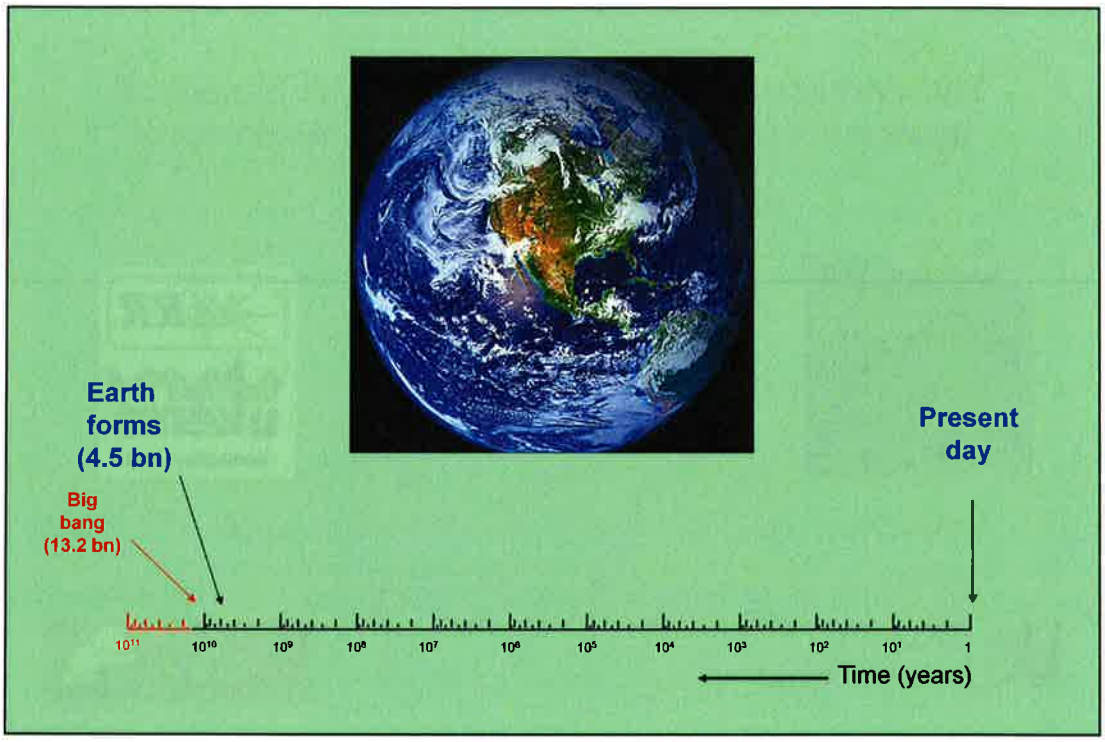
The interaction of magnetic fields with biological systems – trying to understand the diversity of reported health effects

Denis L Henshaw
School of Physics
University of Bristol
Tyndall Ave
Bristol BS8 1TL

ARR
ukems
Nottingham 2011

University of BRISTOL

CHILDREN with CANCER UK
Registered Charity No. 298405



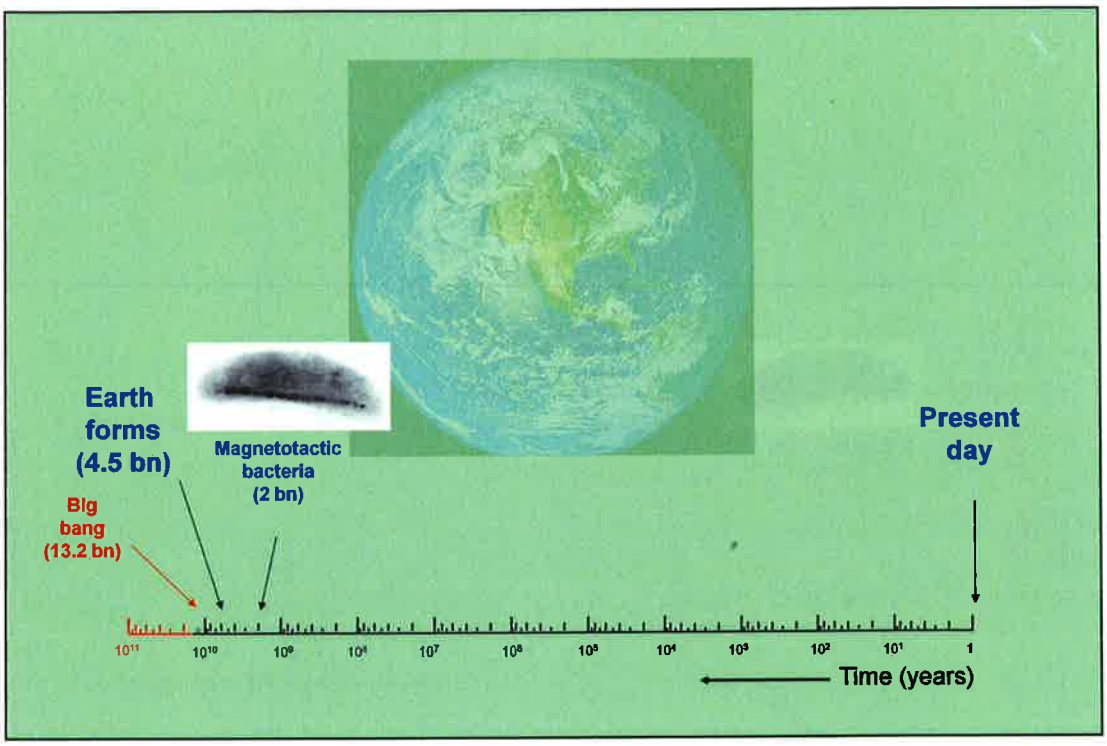
When the Earth was formed 4.5 billion years ago magnetic fields were already present, and had been since the Big Bang some 9 billion years earlier.

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 muT, 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 muT or 100 nT.

So, by the time electrification was introduced in Nottingham on 4th November 1878, 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.



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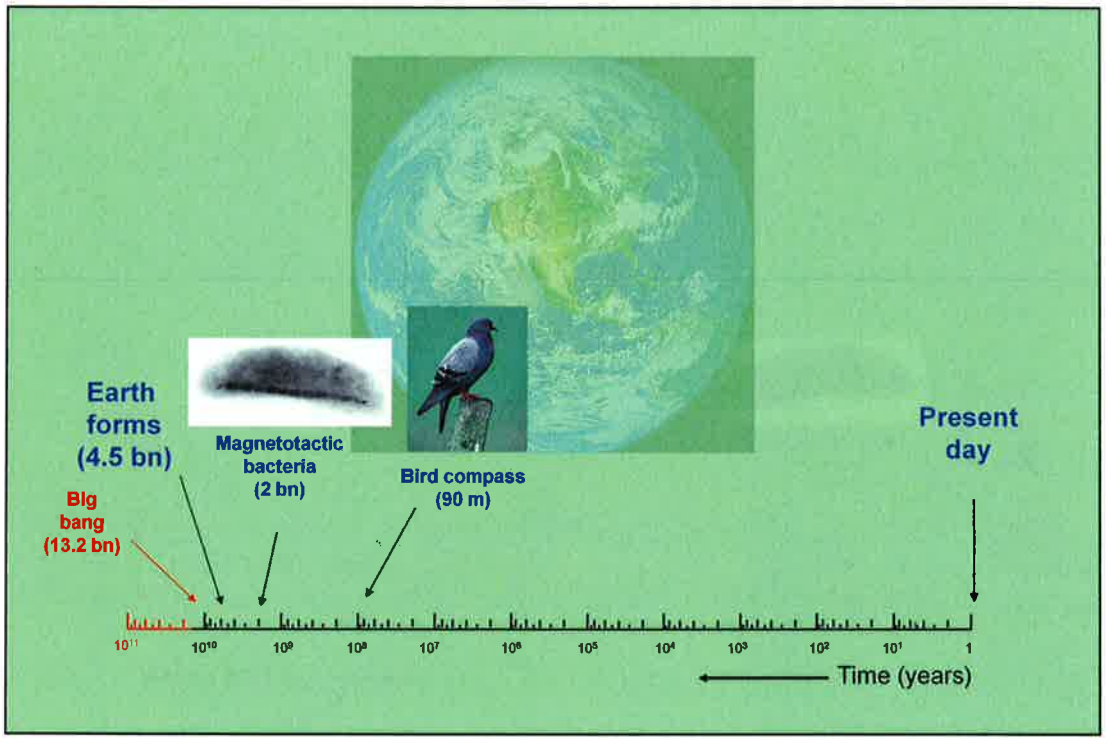

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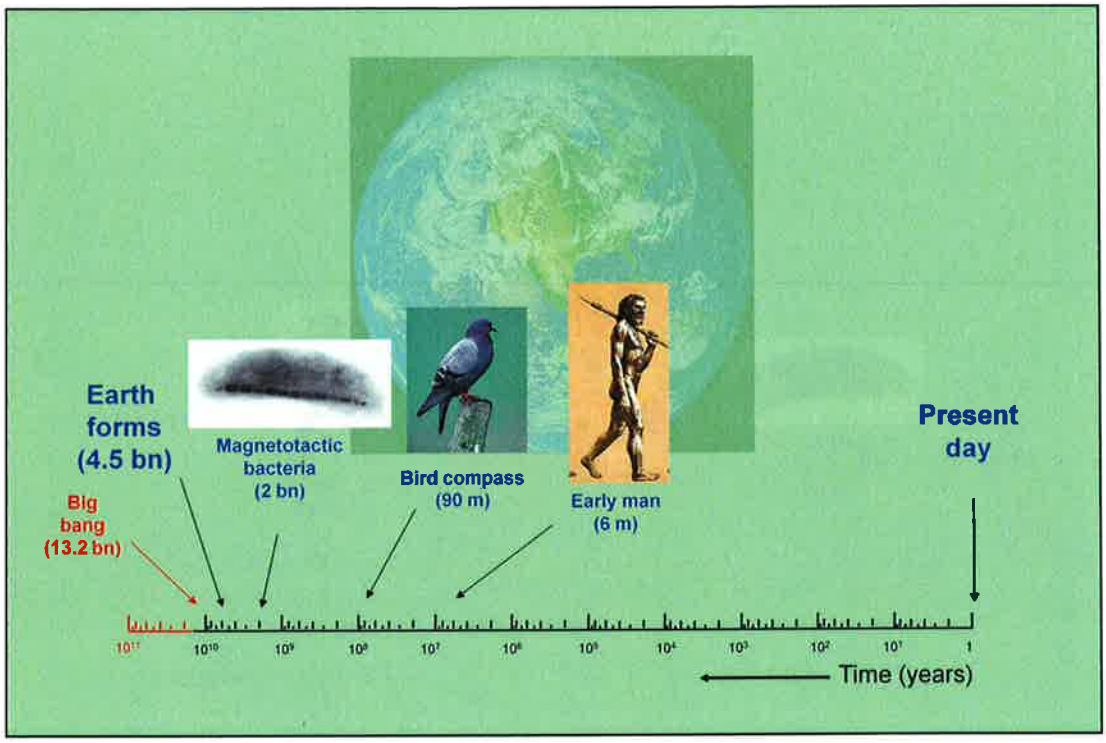

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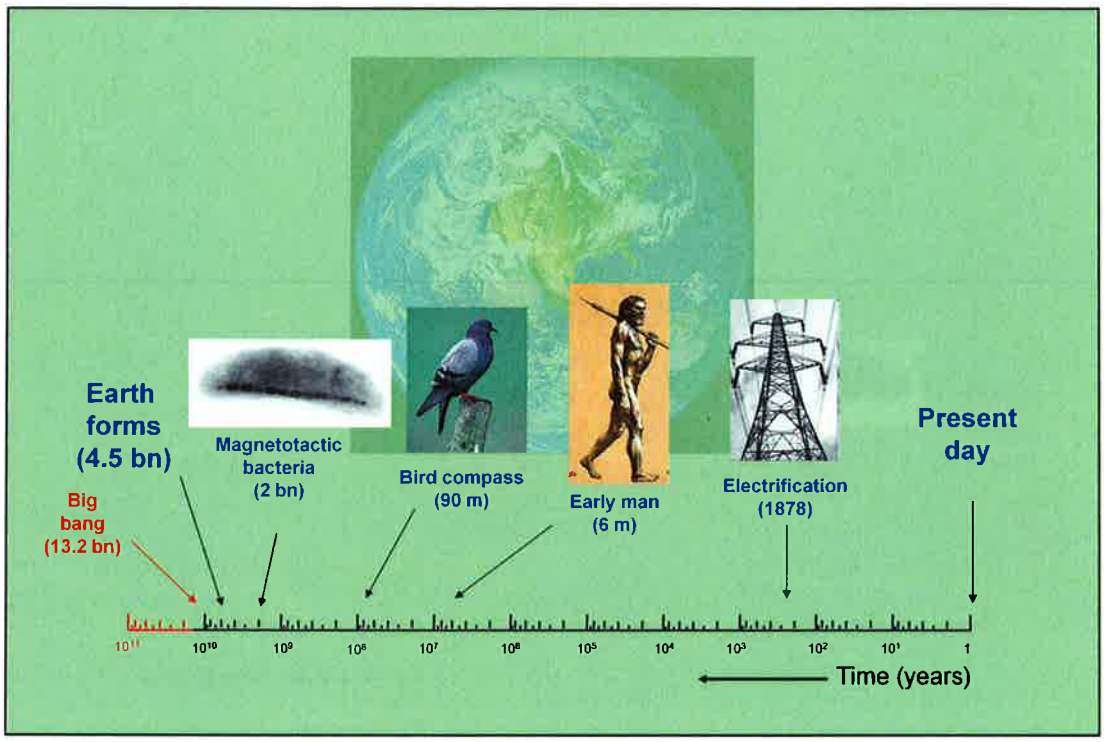


When the Earth was formed 4.5 billion years ago magnetic fields were already present, and had been since the Big Bang some 9 billion years earlier.

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 μυT, 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 muT or 100 nT.

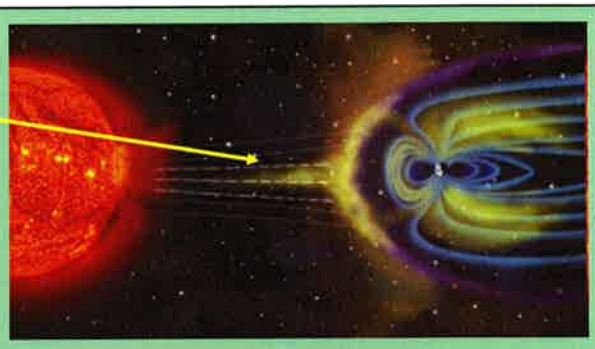
So, by the time electrification was introduced in Nottingham on 4th November 1878, it was already the case that wide sections of the animal kingdom had evolved to detect and exploit magnetic fields at levels below those associated with this new invention, and with hindsight, a hint that there might be adverse health effects in humans.

Notes only:

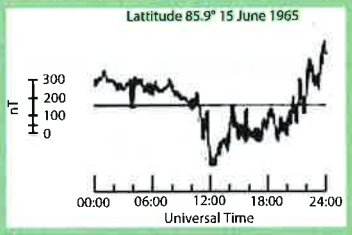
The species whose magnetic compass has been analyzed so far are not at all closely related. Chickens belong to an ancient line of birds, the Galloanseres, that separated from the remaining modern birds, the Neoaves, more than 90 million years ago in the beginning of the Late Creataceous Finding the same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

Geomagnetic Storms*

- Arising from charged particles from the sun



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



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

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

*Superimposed on the static GM field which in Nottingham is ~50 μT

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

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

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

So, start by taking as quick look at Geomagnetic storms

Superimposed on the Earth's static magnetic field of ~50 muT in Nottingham, 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.

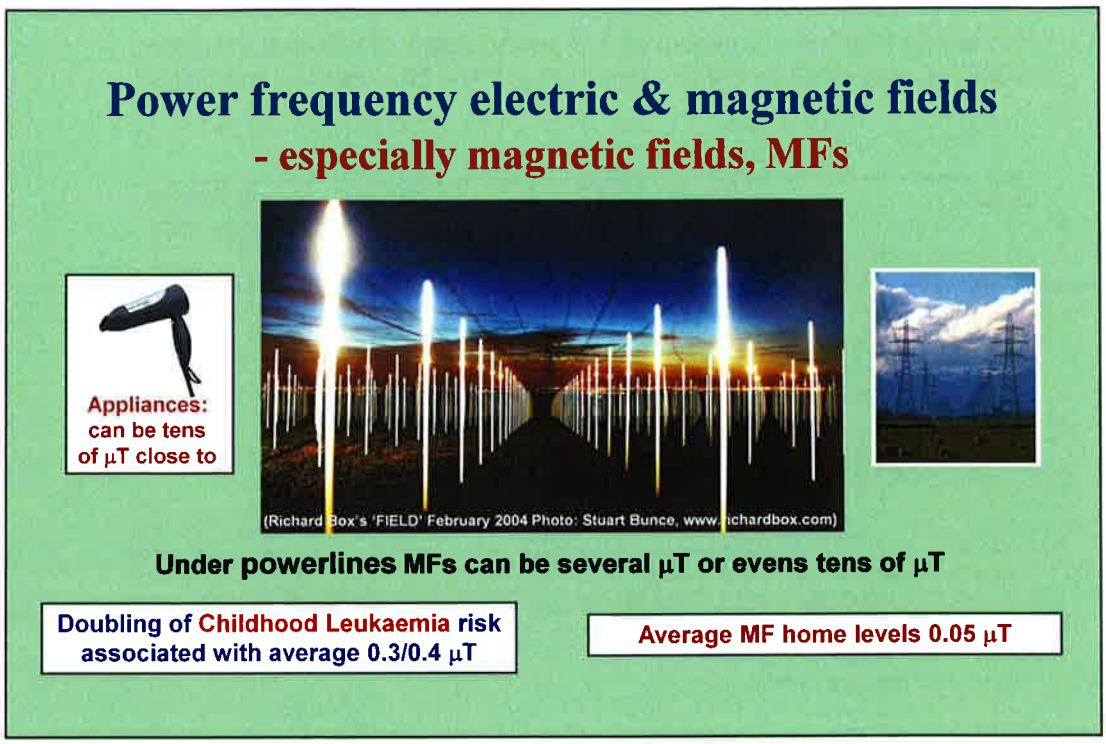
However, only 10-15% of the population seem affected

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

Health effects of GMA

Zhadin MN. 2001. Review of Russian Literature on Biological Action of DC and Low-Frequency AC Magnetic Fields. Bioelectromagnetics 22:27-45.
Palmer SJ, Rycroft MJ, Cermack M. 2006. Solar and Geomagnetic Activity, Extremely Low Frequency Magnetic and Electric Fields and Human Health at the Earth's Surface. Survey Geophysics 27:557-595.
Burch JB, Reif JS, Yost MG. 1999. Geomagnetic disturbances are associated with reduced nocturnal excretion of a melatonin metabolite in humans. Neurosci Lett 266:209-212.
Burch JB, Reif JS, Yost MG. 2008. Geomagnetic activity and human melatonin metabolite excretion. Neuroscience Letters 438:76–79.
Weydahl A, Sothern RB, Cornélissen G, Wetterberg L. 2001. Geomagnetic activity influences the melatonin secretion at latitude 70° N. *Biomed. Pharmacother.* 55:57-62.
Bergiannaki J.-D, Paparrigopoulos TJ, Stefanis CN. 1996. Seasonal pattern of melatonin excretion in humans: relationship to day length variation rate and geomagnetic field fluctuations. Experientia 52:253-258.
Bartsch H, Bartsch C, Mecke D, Lippert TH. 1994. Seasonality of pineal melatonin production in the rat: Possible synchronization by the geomagnetic field. Chronobiology International 11:21-28.
Gordon C, Berk M. 2003. The effect of geomagnetic storms on suicide. South African Psychiatry Review 6:24-27.
Berk M, Dodd S, Henry M. 2006. Do ambient electromagnetic fields affect behaviour? A demonstration of the relationship between geomagnetic storm activity and suicide. Bioelectromagnetics 27:151-155.
Partonen T, Haukka J, Nevanlinna H, Lonnqvist J. 2004. Analysis of the seasonal pattern in suicide. Journal of Affective Disorders 81:133-139.
Kay RW. 1994. Geomagnetic Storms: Association with incidence of depression as measured by hospital admissions. British Journal of Psychiatry 164:403-409.
Kay RW. 2004. Schizophrenia and season of birth: relationship to geomagnetic storms. Schizophrenia Research 66:7-20.
Persinger MA. 1987. Geopsychology and geopsychopathology: Mental processes and disorders associated with geochemical & geophysical factors. Experientia 43:92-104.
Raps A, Stoupel E, Shimshani M. 1991. Solar Activity and admissions of psychiatric inpatients: relations and possible implications on seasonality. Israelis Journal of Psychiatry and Related Science. 28:50-59.
Biomedicine & Pharmacotherapy 56:247s–256s.
Belov DR, Kanunikov IE, Kisley BV. 1998. Dependence of Human EEG spatial synchronization on the Geomagnetic Activity on the Day of Experiment. [in Russian]. Ross Fiziol Zh Im I M Sechenova. 84:761-774.
Cernouss S, Vinogradov A, Vlassova E. 2001. Geophysical Hazard for Human Health in the Circumpolar Auroral Belt: Evidence of a Relationship between Heart Rate Variation and Electromagnetic Disturbances. Natural Hazards 23:121–135.
Ghione S, Mazzasalma L, Del Seppia C, Papi F. 1998. Do geomagnetic disturbances of solar origin affect arterial blood pressure? J Human Hypertension 12:749-754.
Dimitrova S, Stoilova I, Cholakov I. 2004. Influence of local Geomagnetic Storms on Arterial Blood Pressure. Bioelectromagnetics 25:408-414.
Gmitrov J, Gmitrov A. 2004. Geomagnetic field effect on cardiovascular regulation. Bioelectromagnetics 25:92–101.
Otto W, Hempel WE, Wagner CU, Best A. 1982. Various periodical and aperiodical variations of heart infarct mortality in the DRG – [In German]]. Z Gesamte Inn Med (Zeitschift für die Gesamte innere Medizin und ihre Grenzgebeite) 37:756-763.
Srivastava BJ, Saxena S. 1980. Geomagnetic-biological correlations – Some new results. Indian Journal of Radio and Space Physics 9:121-126.
O'Connor RP, Persinger MA. 1997. Geophysical variables and behavior: LXXXII. A strong association between sudden infant death syndrome and increments of global geomagnetic activity – possible support for the melatonin hypothesis. Perceptual and Motor Skills 84:395-402.
Dupont MJ, Parker G, Persinger MA. 2005. Brief Communication: reduced litter sizes following 48-h of prenatal exposure to 5 nT to 10 nT, 0.5 Hz magnetic fields: implications for sudden infant deaths. International Jl Neurosci 115:713-715.
Persinger, M. A., McKay, B. E., O'Donovan, C. A. and Koren, S. A., 2005. Sudden death in epileptic rats exposed to nocturnal magnetic fields that simulate the shape and the intensity of sudden changes in geomagnetic activity: an experiment in response to Schnabel, Beblo and May. International Journal of Biometeorology 49:256-261.
Sparks DL, Hunsaker JC. 1988. The pineal gland in sudden infant death syndrome: preliminary observations. Journal of Pineal Research. 5:111-118.
Sturner WQ, Lynch HJ, Deng MH, Gleason RE, Wurtman RJ. 1990. Melatonin concentrations in the sudden infant death syndrome. Forensic Sci International 45:171-180.

Here is a short list of some of the studies, the first two are reviews

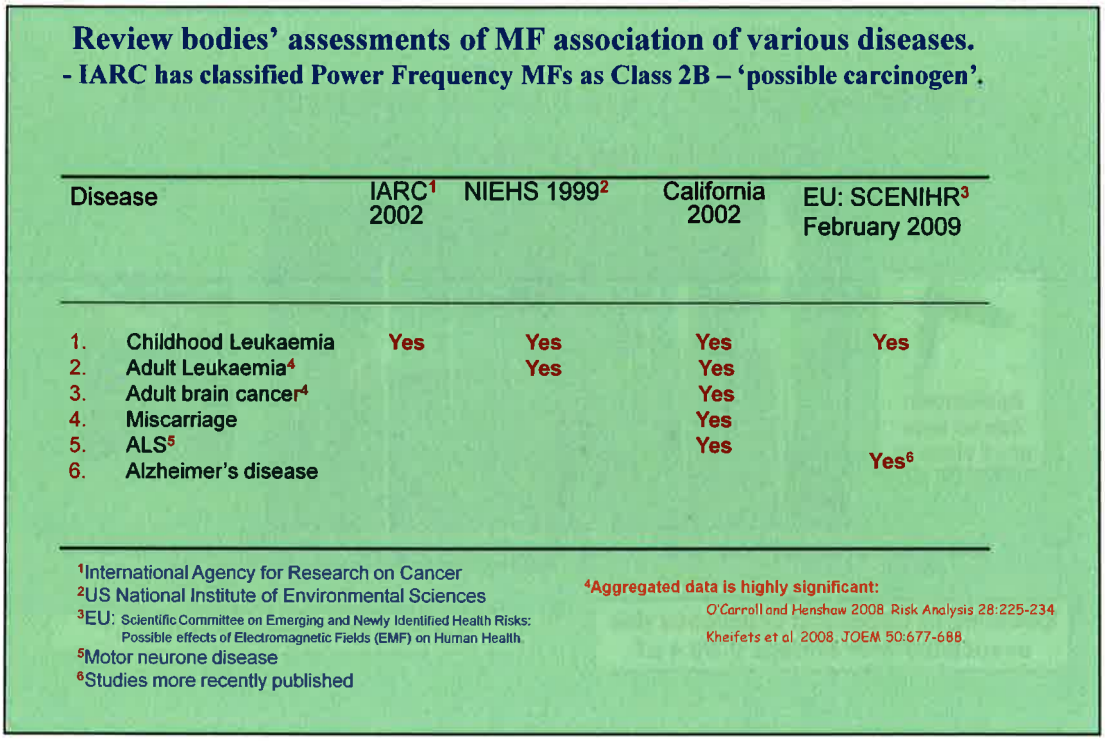


So, let's now look at power frequency magnetic fields

The average exposure to power frequency magnetic fields in the home is only 0.05 muT (50 nT). However, close to certain appliances, levels can be tens of muT.

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

Crucially a doubling of childhood Leukaemia risk is associated with average exposure of 0.3/0.4 muT



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

Disease	IARC[1] 2002	NIEHS 1999[2]	California 2002	EU: SCENIHR[3] February 2009
1. Childhood Leukaemia	Yes	Yes	Yes	Yes
2. Adult Leukaemia[4]		Yes	Yes	
3. Adult brain cancer[4]			Yes	
4. Miscarriage			Yes	
5. ALS[5]			Yes	
6. Alzheimer's disease				Yes[6]

[1]International Agency for Research on Cancer
[2]US National Institute of Environmental Sciences
[3]EU: Scientific Committee on Emerging and Newly Identified Health Risks: Possible effects of Electromagnetic Fields (EMF) on Human Health.
[5]Motor neurone disease
[6]Studies more recently published

[4]Aggregated data is highly significant:
O'Carroll and Henshaw 2008 Risk Analysis 28:225-234
Kheifets et al. 2008, JOEM 50:677-688.

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 Kheofets 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

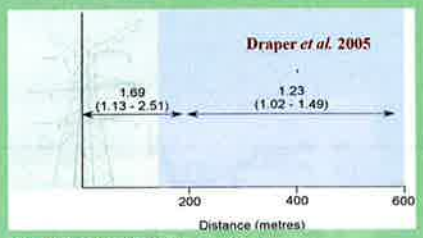
no significant-negative results in either list. Results for adult brain cancer gave a similar, but

less clear message.

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

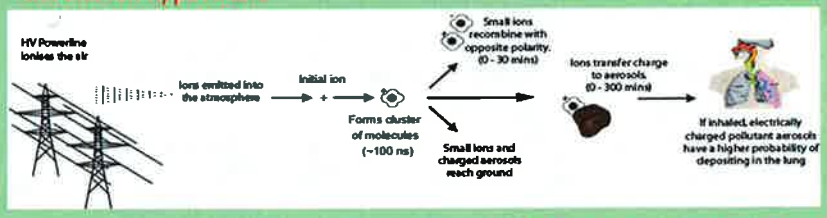
Study	Number of Cases	Increased risk to
Draper et al. 2005 BMJ 330:1290-3	322	600 m (1.23, 95% CI: 1.02 - 1.49)
Lowenthal et al 2007 Internal Med J 37:614-19	854	300 m (2.06, 95% CI: 0.87 – 4.91)[1] (4.74; 95% CI: 0.98–22.9)[2]
Feizi & Arabi 2007 Asian Pacific J Cancer Prev 8:69-72	60	500 m (8.67, 95%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

[1]Adults: Ever lived within 300 m; [2]0-5 years of life within 300 m



AC fields at background by ~100 m

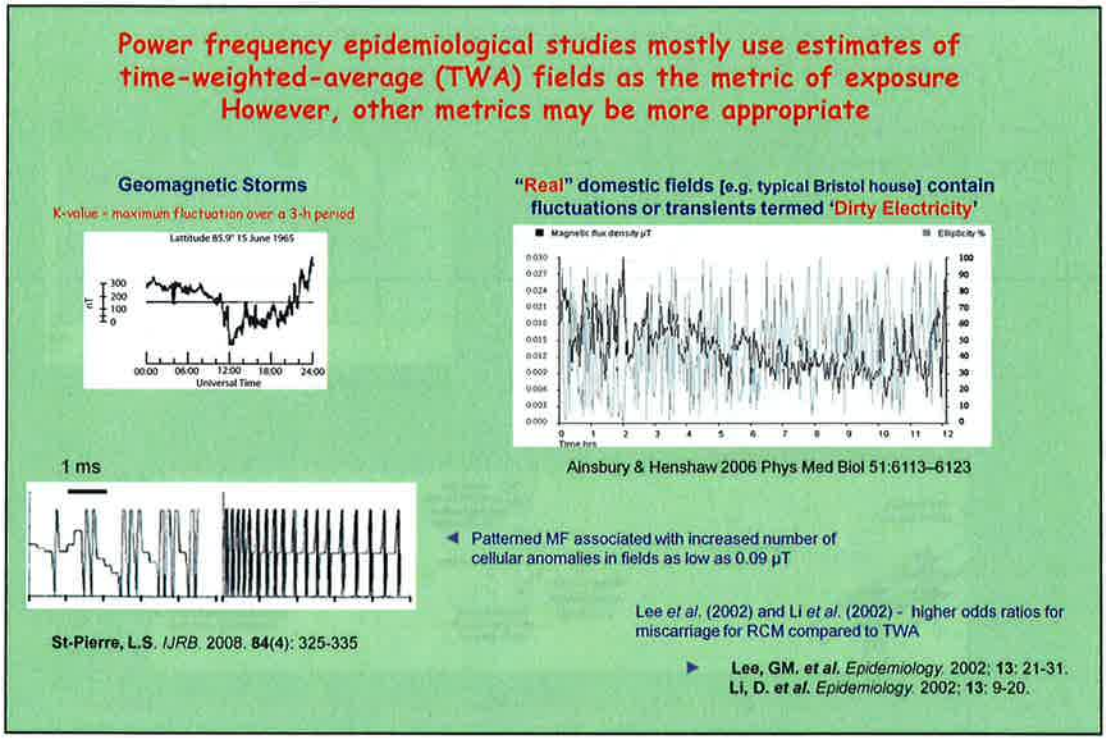
Corona ion hypothesis



Henshaw 2002 Med Hyp 59:39-51; Fews *et al* 1999 IJRB 75:1523-31; Fews *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 childhood 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

Don Jones originally asked me to talk about our corona ion hypothesis, but I am grateful to the ARR committee for agreeing to let me talk about where I think we are with the general issue of understanding the mechanisms of ELF MF interactions which may lead to adverse health effects



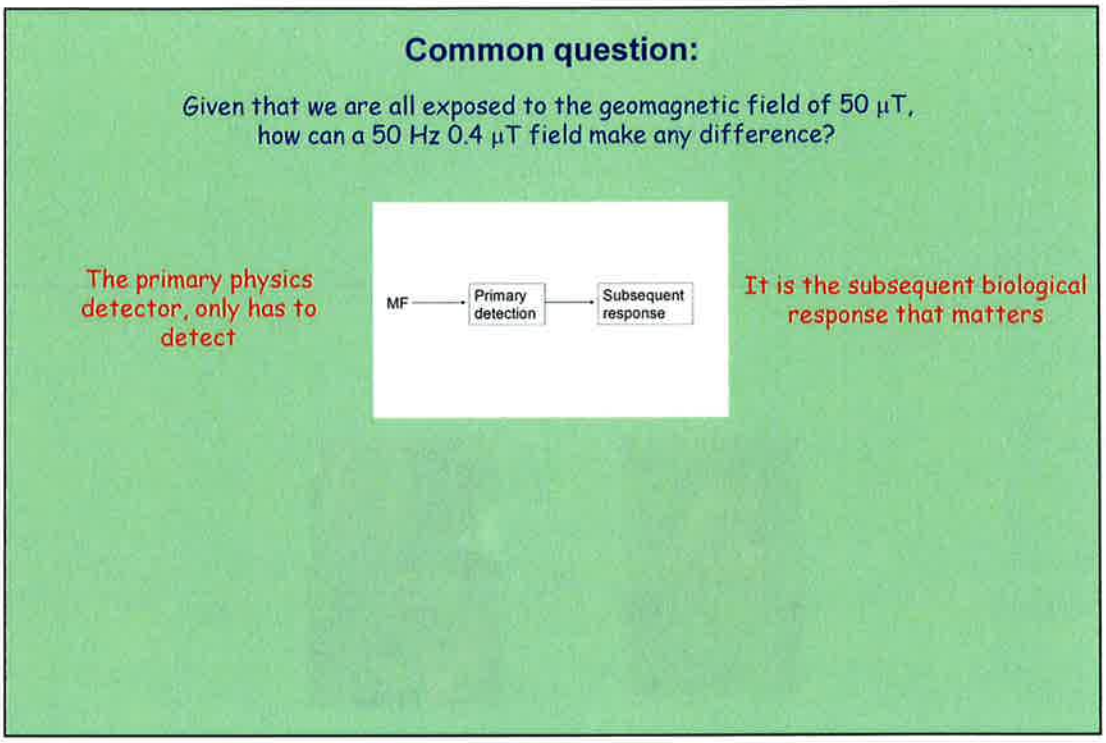
I just want to make the point here that whereas the bulk of epidemiological studies use time-weighted-average fields as the metric of exposure, "real" fields contain transients which evidence suggest is more biologically active.

Notes:

In the example from one of our papers, the average MF exposure is only 0.015 muT, but look at the much larger transient fluctuations

This is the case for Geomagnetic Storms, some laboratory studies and some human studies, and 'real' MFs contain transients dubbed 'Dirty Electricity'

Ainsbury EA, Henshaw DL. 2006. Observations on the relationship between magnetic field characteristics and exposure conditions. Phys Med Biol 51:6113–6123.



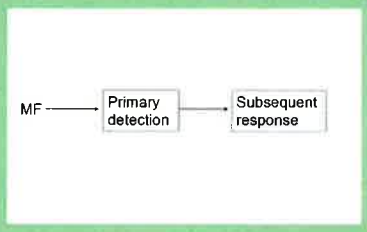
Now a common question that physicists ask is how can a field of 0.4 muT (at ELF frequency) make any difference alongside the existing DC field from the Earth?

The answer is that the physical detector need only detect the signal. It is the biological response that matters.

Common question:

Given that we are all exposed to the geomagnetic field of 50 μT, how can a 50 Hz 0.4 μT field make any difference?

The primary physics detector, only has to detect



It is the subsequent biological response that matters

Biological responses can vary with the same input data – some people like tarantulas !

To try to understand the epidemiological findings, lets consider three physical interaction mechanisms and some biology

- So-called Ion Cyclotron Resonance (ICR) models
  and Ca^{2+} efflux from cells
- Circadian rhythm and melatonin disruption
  could potentially explain many of the health effects
- Biogenic Magnetite
  in animals & humans
- Radical Pair Mechanism (RPM) at low fields
  Mechanisms
  Cryptochromes in birds and in man

I want to talk very briefly about calcium efflux from cells and the so-called ion cyclotron resonance models

A quick summary of circadian rhythm and melatonin disruption

Something about biomagnetite

And then the real "Hot Topic", the radical pair mechanism and cryptochromes

Ca^{2+} efflux and Ion Cyclotron Resonance (ICR) models

Background:

Increased Ca^{2+} efflux from brain tissues with **ELF modulated RF EMFs** (Bawin et al. 1975, Blackman et al. 1979, 1980a, b, Adey et al. 1982), and with **ELF electric fields** without an RF carrier (Bawin & Adey 1976).

Observations:

Increased Ca^{2+} efflux from brain tissue at particular frequencies of an applied **magnetic field** in the same vector direction as Earth's natural DC field (Blackman et al 1985).

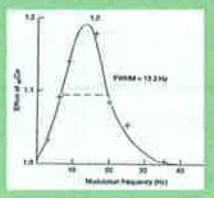
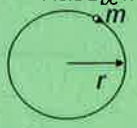


FIGURE 9.2
Comparison of shape of "window" data for Ca-efflux results [13] (seven points) with predicted resonance curve [18] (smooth curve). The best fit is for the charge-to-mass ratio for K^+, a magneto-static field of 35.0 μT_s and a collision time of 0.026 sec.

Field B_{DC} x



$$F = Bqv = mv^2/r$$

$$v/r = 2\pi f$$

$$f = \frac{1}{2\pi}\frac{q}{m}B_{DC}$$

For Ca^{2+}, q=2, m = mass of Ca ion
e.g. at B_{DC} = 50 μT, f = 40 Hz

Overall findings:

Liboff (2006)[1] cites **71 papers**, on this apparent **'window'** or **'resonance'** phenomenon' with only **11** reporting negative findings.

Today **>150** papers in model systems: bone, cell culture, rat behaviour, neural cell culture, diatom motility, complex biological systems, plants, cell-free systems.

Explanation:

In a magnetic field, Ca^{2+} and other ions behave like a physics cyclotron and so response can be 'tuned' to the cyclotron frequency – hence 'ICR'.

Status:

However, ICR may be an inappropriate analogy → unlike a real cyclotron, Ca^{2+} ions are not in a vacuum.

Bawin et al. 1975 PNAS 247:74-81; Bawin & Adey 1976 PNAS 73:1999-2003 [10 - 15 V/m in air; 0.1 mV/cm in tissue]
Gavalas-Medici & Day-Magdaleno 1976 Nature 261:256-259, Blackman et al. 1985 Bioelectromagnetics 6:327-37

[1]Liboff 2006 Chapter 9: In Bioengineering and biophysical aspects of EMFs p261-292, Eds Barnes & Greenebaum. 1 edition (7 Nov 2006) CRC Press

So, first to the so-called Ion Cyclotron Resonance or ICR

Blackman et al (1985) observed increased Ca^{2+} efflux from brain tissue at **particular low frequencies** (e.g. 40 Hz) of a magnetic field applied in the same vector direction as the Earth's natural DC field

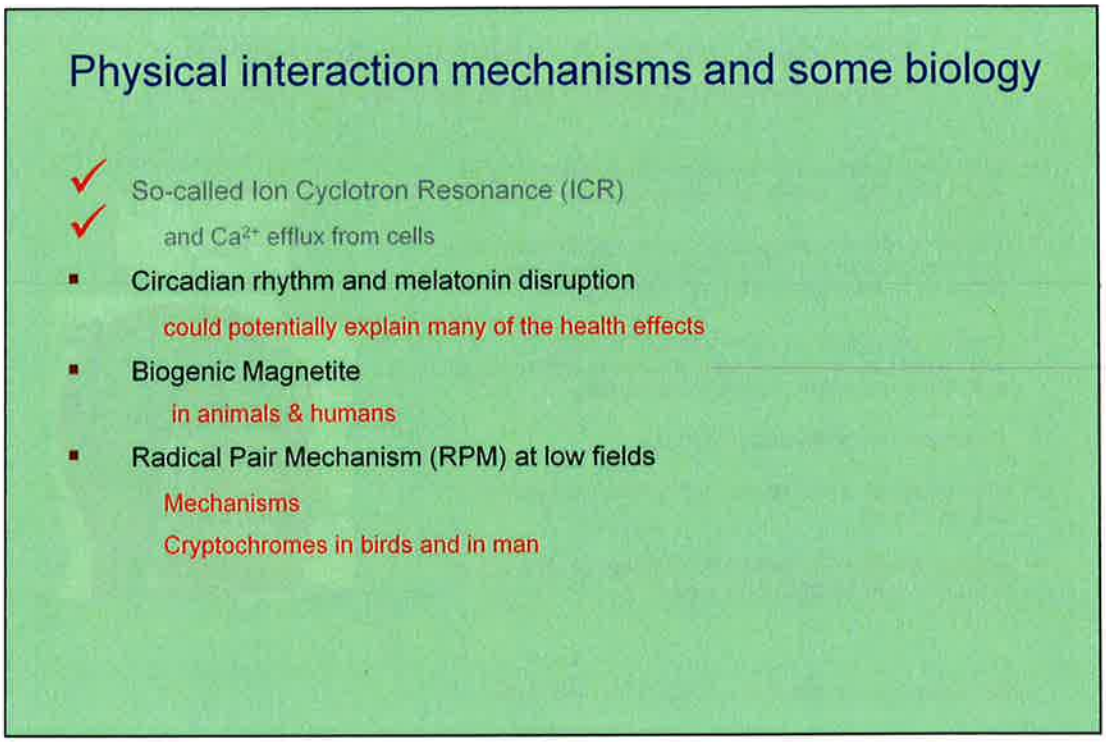
This has since been much researched experimentally and today we have counted over 150 papers reporting similar "resonance-type" phenomena in various biological systems

The explanation was that Ca2+ was somehow behaving like a cyclotron in physics, going round in circles in the Earth's field at a particular frequency, which could then be made to "resonate" by application of an appropriate AC magnetic field.

However, Ca ions in biology are not in a vacuum – it is not like a real cyclotron, so the analogy just doesn't fit

So, it remains the case **today** that we have a body of experimental findings that lack a proper explanation of the physics of the primary interaction

Notes:



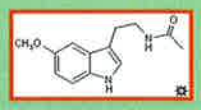
So now a few words about circadian rhythms and melatonin disruption

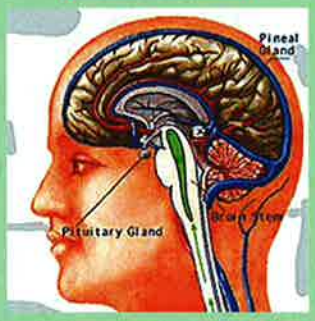
Circadian rhythm & melatonin disruption

- could potentially explain many of the EMF health effects

- Melatonin 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 system[1]
- Disruption by light-at-night associated with (i) increased cancer risk in animals and in humans, (ii) with depression and possibly miscarriage
- A component of circadian rhythms
- 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

N-acetyl-5-methoxytryptamine





[1]Vijayalaxmi et al 1996 Mutation Research 371:221-228

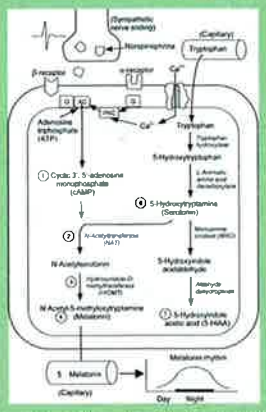
SAY ALL HEALTH MF EFFECTS COULD BE EXPLAINED BY CIRCADIAN RHYTHYM DISRUPTION

Broad-spectrum, ubiquitously-acting antioxidant and anti-cancer agent.

also reduces growth of human myeloid leukemia cells and whose disruption by light-at-night is associated with increased cancer risk.

Magnetic field effects on 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" EMFs[1] - down to 0.2 μT
- **in animals**
  - Most effects observed with non-smooth AC MFs
  - Strong findings in cows and sheep with "real" EMFs
- **on pineal cells**
  - Small but detailed literature - action in synthesising melatonin disrupted. Some animals have MF compass in the pineal gland
- **human light detection threshold**
  - Dependent on MF exposure (Cremer-Bartels et al. 1983, Partonen 1998, Thoss et al. 1999, 2000, 2002, Thoss & Bartsch 2003)
- **clock genes**
  - Cryptochrome[2] controls the mammalian circadian clock and acts as the magnetic compass in animals



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 Fields[1].

[1]Henshaw & Reiter 2005 BEMs Suppl 7:S86-S97 [2]Evolved ~2.5 bn years (Gu 1997 Mol Biol Evol 14:861-866)

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 muT

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**.

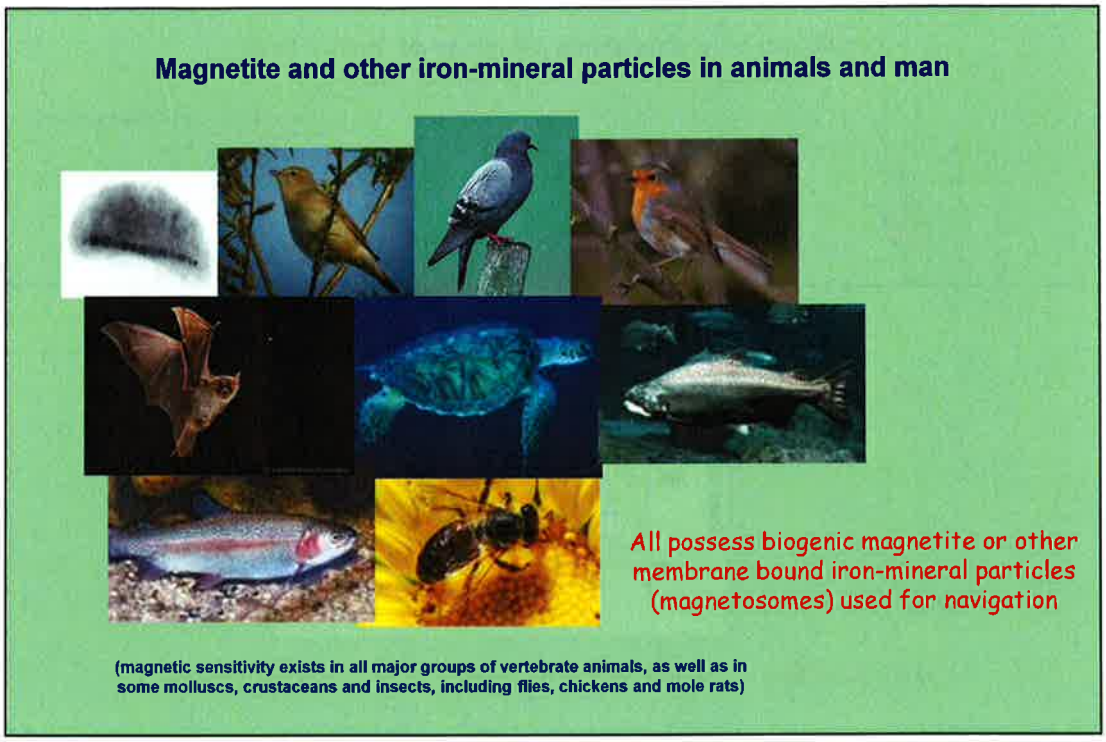
And I will be saying more about that later.

Physical interaction mechanisms and some biology

- ✓ So-called Ion Cyclotron Resonance (ICR)
- ✓ and Ca^{2+} efflux from cells
- ✓ Circadian rhythm and melatonin disruption
- ✓ could potentially explain many of the health effects
- Biogenic Magnetite
  - in animals & humans
- Radical Pair Mechanism (RPM) at low fields
  - Mechanisms
  - Cryptochromes in birds and in man

WILL TALK BOUT CRYPTOCHROMES ETC

Repeat this slide



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

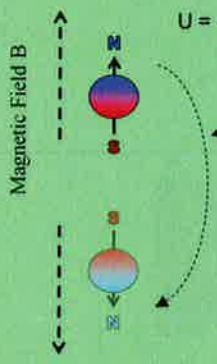
Should use iron-mineral based, rather than magnetite based.

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.

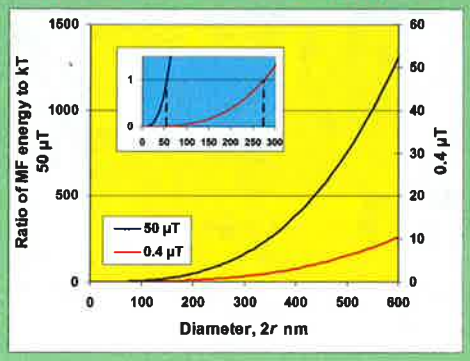
Potential energy of magnetic particle in the Earth's field
- Compare this with the thermal energy *k*T

$U = -\mu.B$ where $\mu = v\,M$

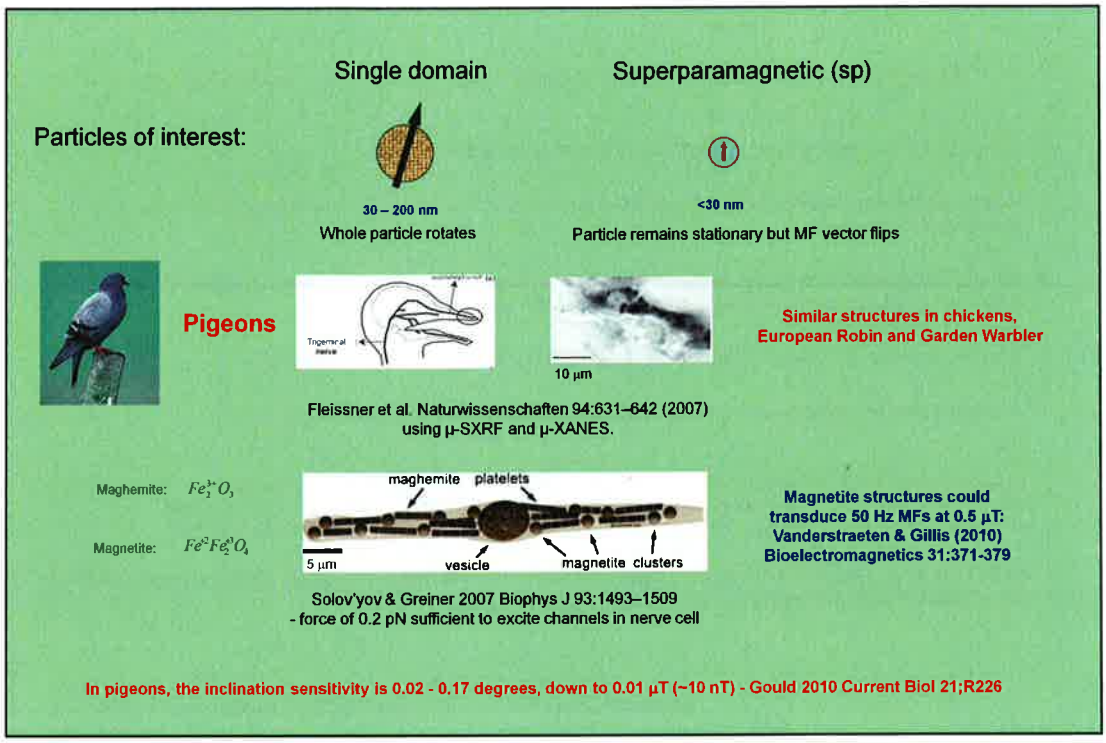
U = potential energy of dipole magnet in field B
μ = magnetic moment
v = particle volume; r = radius
M = 4.8×10^5 J T^{-1} m^{-3}
k = Boltzmann's constant, 1.3807×10^{-23} J K^{-1},
and *T* the absolute temperature.



The energy required to rotate the particle 180° is 2U, compare this to the thermal energy *k*T at 300° K



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



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

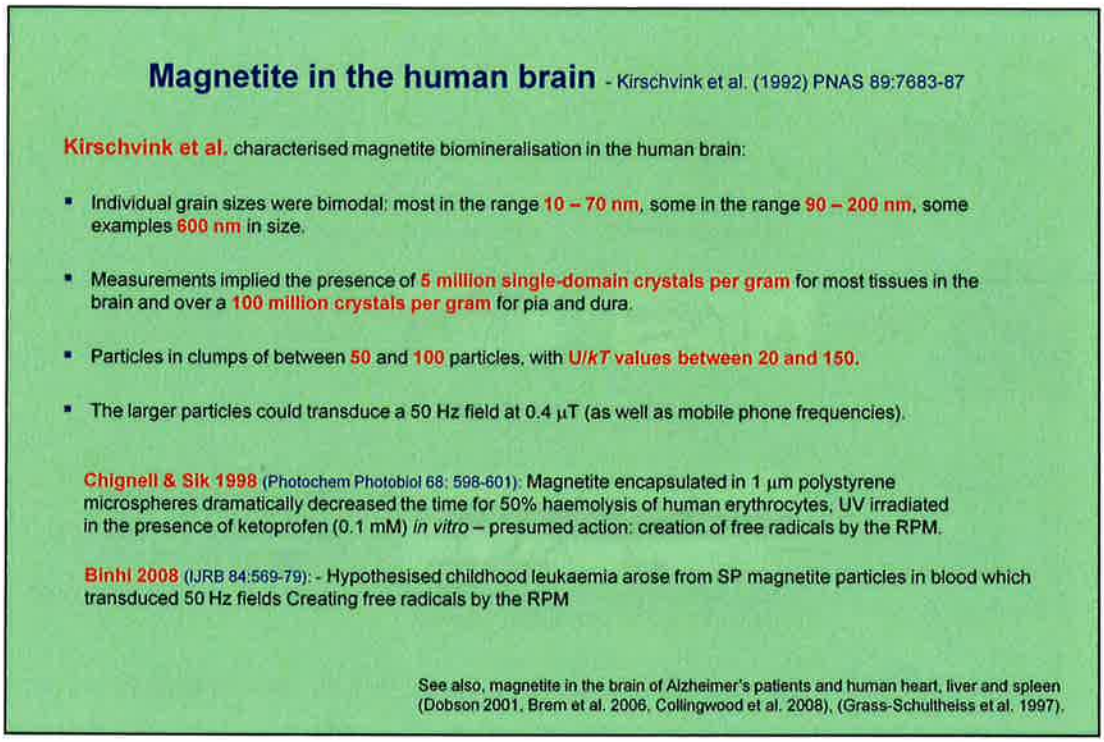
And

Superparamagnetic particles which remains stationary but the MF vector quantum flips

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

Falkenberg G, Fleissner G, Schuchardt K, Kuehbacher M, Thalau P, et al. (2010)



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

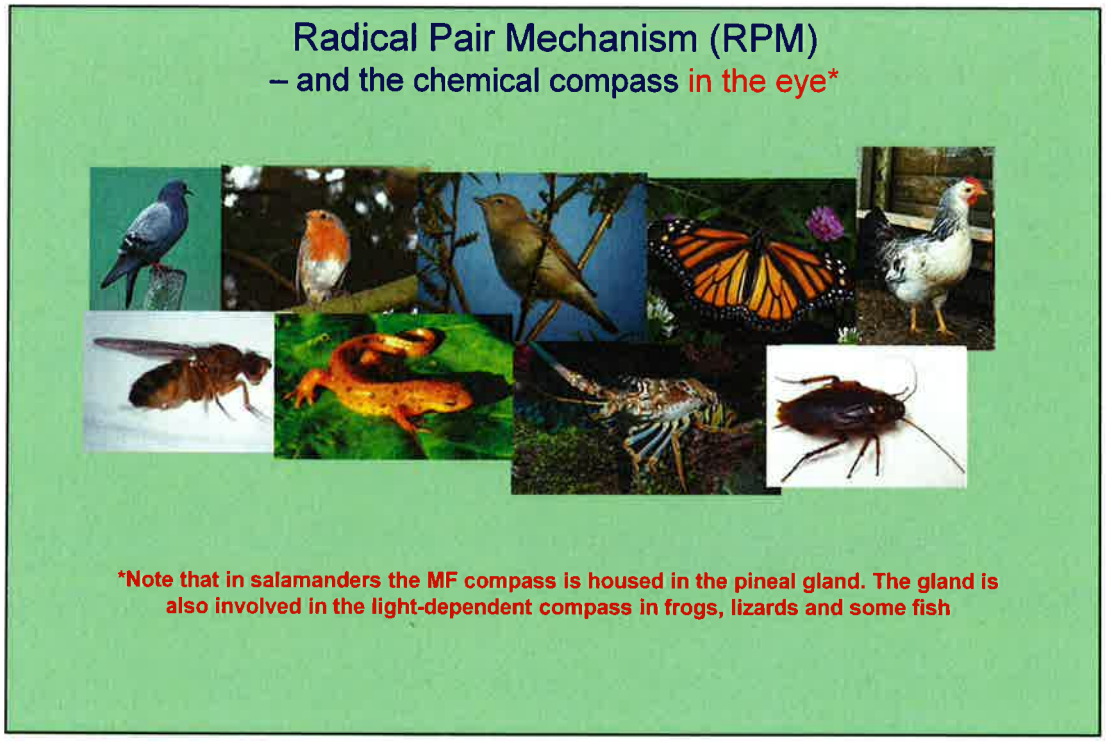
Joseph L. Kirschvink 1996. Microwave Absorption by Magnetite: A Possible Mechanism for Coupling Nonthermal Levels of Radiation to Biological Systems. Bioelectromagnetics 17:187-194 (1 996) CITE ON SLIDE

Physical interaction mechanisms and some biology

- ✓ So-called Ion Cyclotron Resonance (ICR)
- ✓ and Ca^{2+} efflux from cells
- ✓ Circadian rhythm and melatonin disruption
- ✓ could potentially explain many of the health effects
- ✓ Biogenic Magnetite
- ✓ in animals & humans
- **Radical Pair Mechanism (RPM) at low fields**
  - Mechanisms
  - Cryptochromes in birds and in man

WILL TALK BOUT CRYPTOCHROMES ETC

Repeat this slide

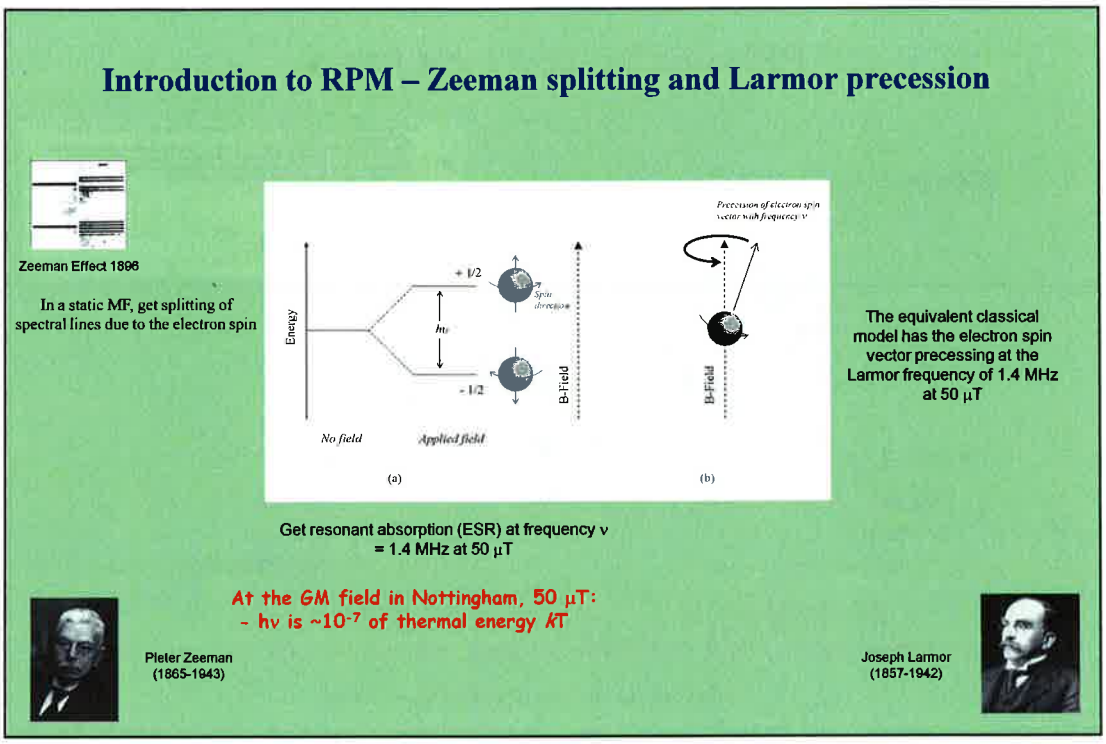


These species all have a light-dependent compass with evidence that it is based on the RPM. Notice that in some cases, this is in addition to magnetite. Notice also the involvement of the pineal gland in some species

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.



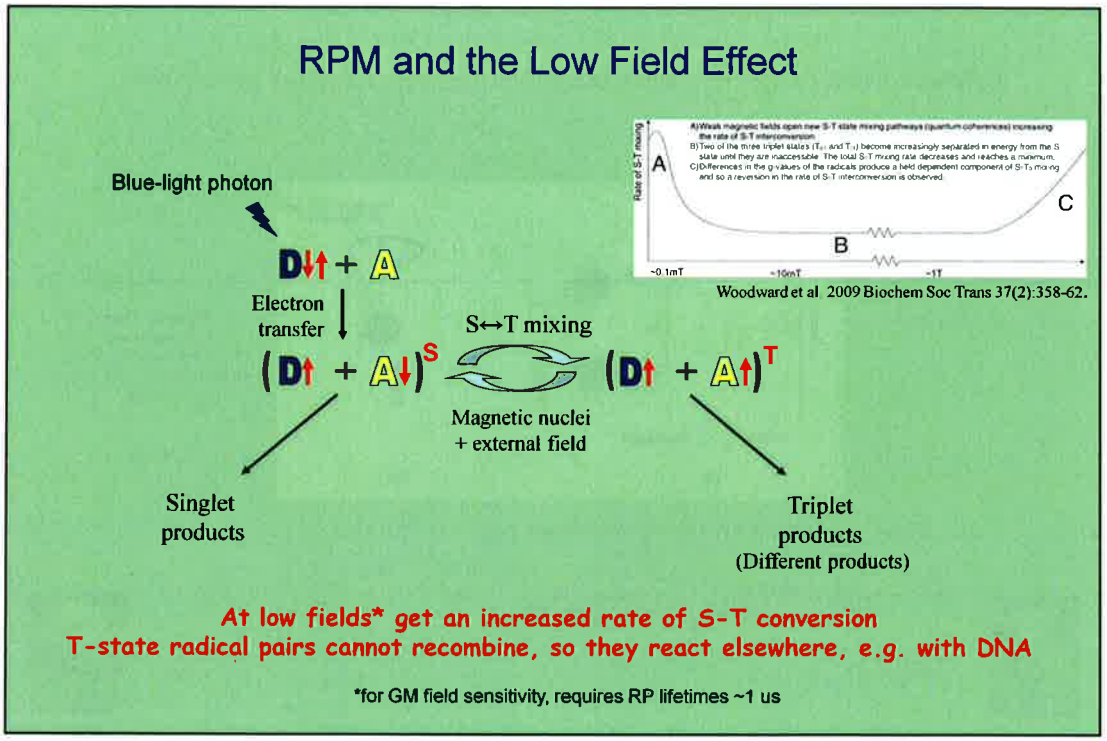
As an introduction to the RPM this slide goes back to basics

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 hnu where h is Planck's Constant and nu is the photon frequency. A spectroscopic transition can be induced between these energy states by applying radiation at the correct frequency. At 50 muT, nu = 1.4 MHZ.

I am showing this to point out that the energy difference is ~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 nu, 1.4 MHz, the so-called Larmor frequency. I will be using this model in a moment.



Opens up new S-T mixing pathways increasing thee 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-dibromonaphthalen, anthracene; Table 5: e.g.s of photochemical reactions in the gas phase

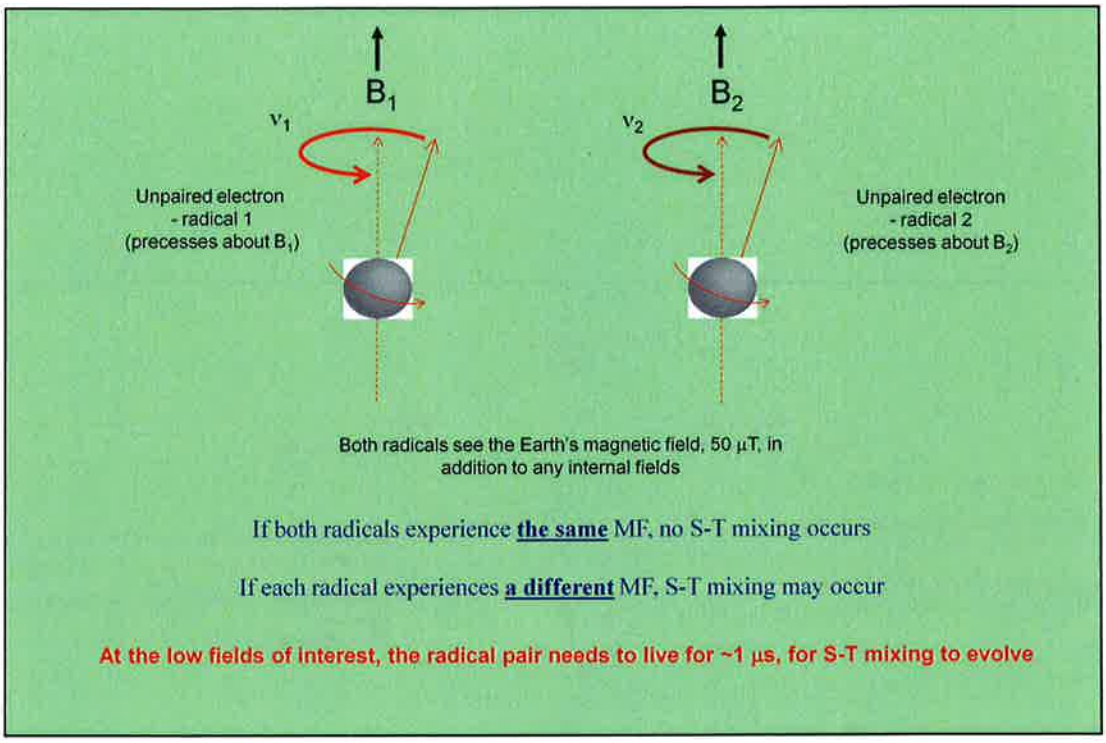
Brocklehurst & McLauchlan 1996: benzaldehyde (PhCHO, Ph = C6H5) in tetrachloromethane; RPs created from UV irradiation of the condensed ring aromatic hydrocarbon pyrene (Py) in solution with 1,3-dicyanobenzene (DCB)

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

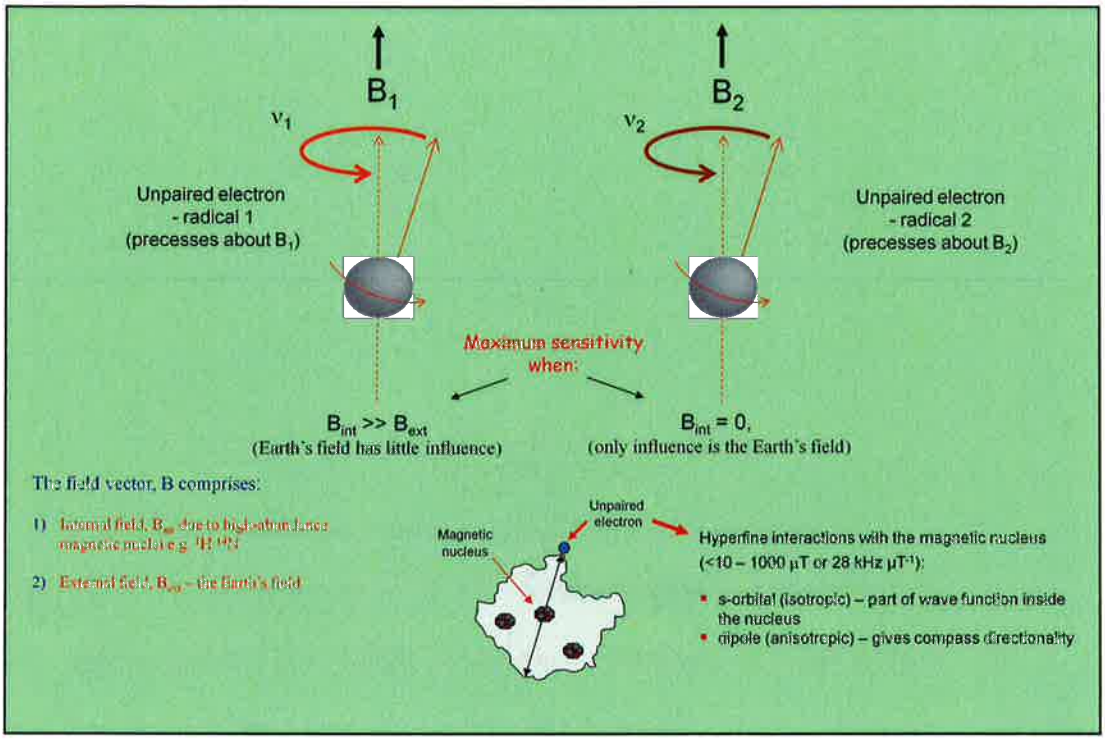
Woodward et al 2002: Pyrene with isomers of dicyanobenzene

References:

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



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 14N, 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.

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

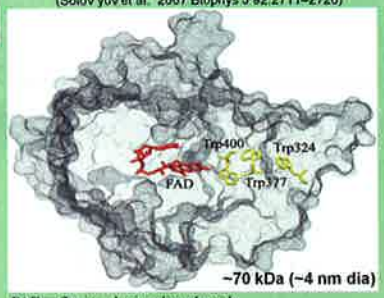
-50-90 kDa blue-light photoreceptor; flavoproteins - **best known for their role in controlling circadian rhythms**. High sequence-homology to DNA photolyases.

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 ~1 μs or longer[1]
- ✓ Has an anisotropic response
- ✓ Can be anchored (in the eye)[2]

Ritz proposed that RF fields ~1 MHz might interfere with the MF compass

Schematic view of cryptochrome
(Solov'yov et al. 2007 Biophys J 92:2711–2726)



FAD = flavin-adenine dinucleotide

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

[1]Liedvogel et al. 2007 *PLos One* 2(10): e1106, [2]Cry1a 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 cry[tochrome molecules in the eye and that as an experimental test, this might be interferred with by application of an approprite RF field

1: Lifetimes of up to 20 ms – five orders of magnitude higher than 1 muS required: 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

2: 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

Radical pair scheme in cryptochrome

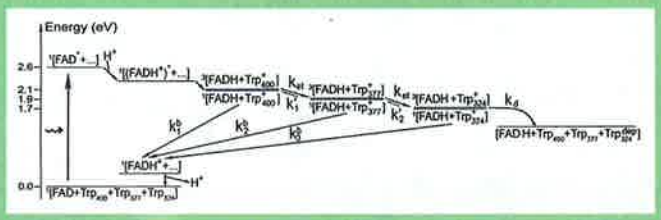


Figure 2. Schematic presentation of the radical-pair reaction pathway in cryptochrome.

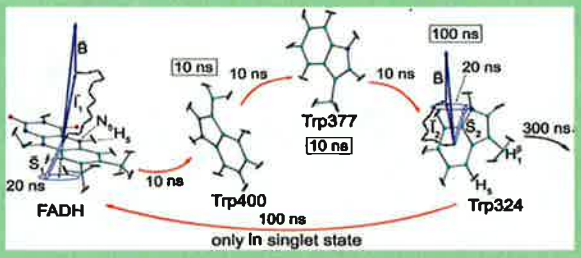


Figure 4 Schematic illustration of electron hole transfer and electron spin dynamics in the FADH cofactor and tryptophan chain.

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

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

Ritz et al 2000 reported…..

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, *Erithacus rubecula*; 12 individually tested in spring migration season	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	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 μT, 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**
Wiltschko et al. 2007: Domestic chickens, *Gallus gallus*; 36 in total, between 12 and 22 days old	Local GMF 55.9 μT, 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 μT and 83.8 μT and (iii) 25%, weaker and stronger: 41.9 μT and 69.9 μT	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, *Erithacus rubecula*; 12-16 per test	Local GMF 46 μT, inclination 66° and 565 nm green light or total darkness, alone (control) or plus 1.315 MHz at 0.48 μT, 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, *Taeniopygia guttata*; 10 for MF orientation; 7 for visual perception	Local GMF 43 μT, inclination 67° daylight. Local Larmor frequency 1.156 MHz at 0.47 μT, 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. Wiltschko *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, Wiltschko R, Wiltschko W. 2004. Resonance effects indicate a radical-pair mechanism for avian magnetic compass. Nature 429:177-180.

Thalau P, Ritz T, Stapput K, Wiltschko R, Wiltschko 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, Wiltschko R, Hore PJ, Rodgers CT, Stapput K, Thalau P, Timmel CR, Wiltschko 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)

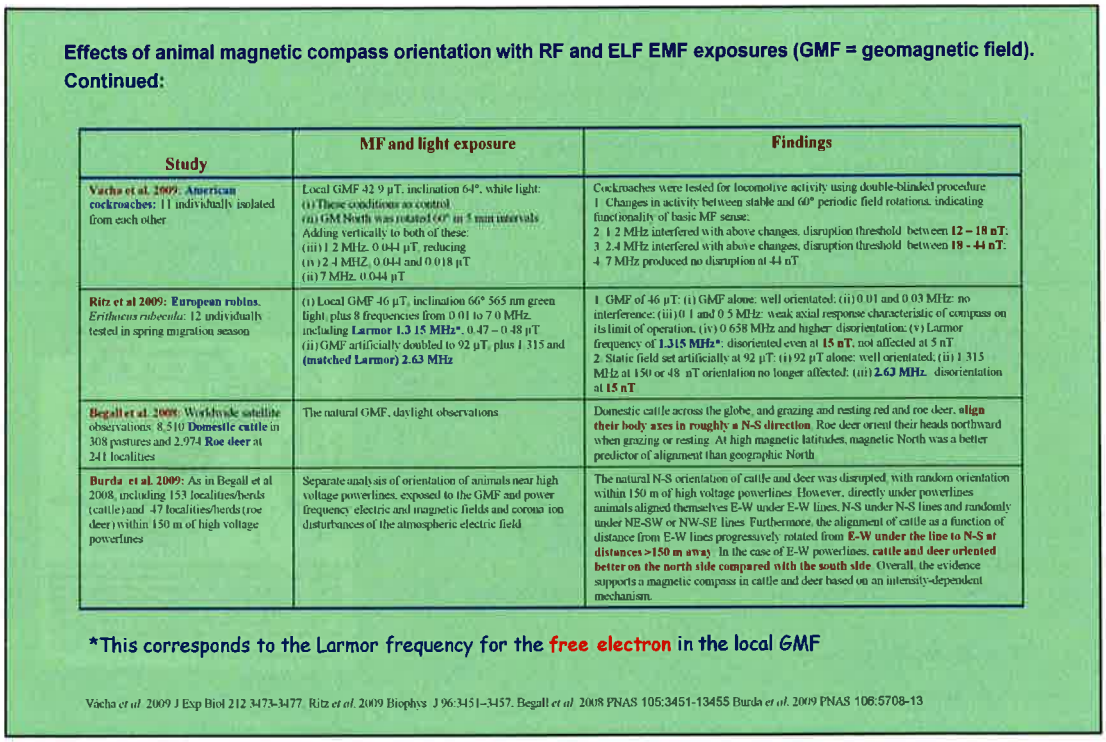
Stapput K, Thalau P, Wiltschko R, Wiltschko W. 2008. Orientation of Birds in Total Darkness. Current Biology 18:602–606. (DOI 10.1016/j.cub.2008.03.046)

Wiltschko W, Freire R, Munro U, Ritz T, Rogers L, Thalau P, Wiltschko R. 2007c. The magnetic compass of domestic chickens, *Gallus gallus*. The Journal of Experimental Biology 210, 2300-2310.

Keary N, Ruploh T, Voss J, Thalau P, Wiltschko R, Wiltschko W, Bischof H-J 2009. Oscillating magnetic field disrupts magnetic orientation in Zebra finches, *Taeniopygia guttata*. Frontiers in Zoology 2009, 6:25.

Vácha M, Půžová T,and Markéta Kvičalová M. 2009. Radio frequency magnetic fields disrupt magnetoreception in American cockroach. The Journal of Experimental Biology 212;3473-3477.

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.



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 μT, 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 μT, reducing (iv) 2.4 MHZ, 0.044 and 0.018 μT (ii) 7 MHz, 0.044 μT	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. *Erithacus rubecula*: 12 individually tested in spring migration season	(i) Local GMF 46 μT, inclination 66° 565 nm green light, plus 8 frequencies from 0.01 to 7.0 MHz, including **Larmor 1.315 MHz***, 0.47 – 0.48 μT (ii) GMF artificially doubled to 92 μT, plus 1.315 and **(matched Larmor) 2.63 MHz**	1. GMF of 46 μT: (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 μT: (i) 92 μT 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

Vácha *et al.* 2009 J Exp Biol 212:3473-3477. Ritz *et al.* 2009 Biophys J 96:3451–3457. Begall *et al.* 2008 PNAS 105:3451-13455 Burda *et al.* 2009 PNAS 106:5708-13

Point also to the findings of Begall et al 2008 and Burda et al 2009

ICNIRP Limit:

0.92 muT at 1 MHz
0.092 muT between 10 – 400 MHZ
0.2 muT at 2 GHz

Ritz T, Wiltschko R, Hore PJ, Rodgers CT, Stapput K, Thalau P, Timmel CR, Wiltschko 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)

Stapput K, Thalau P, Wiltschko R, Wiltschko W. 2008. Orientation of Birds in Total Darkness. Current Biology 18:602–606. (DOI 10.1016/j.cub.2008.03.046)

Wiltschko W, Freire R, Munro U, Ritz T, Rogers L, Thalau P, Wiltschko R. 2007c. The magnetic compass of domestic chickens, *Gallus gallus*. The Journal of Experimental Biology 210, 2300-2310.

Keary N, Ruploh T, Voss J, Thalau P, Wiltschko R, Wiltschko W, Bischof H-J 2009. Oscillating magnetic field disrupts magnetic orientation in Zebra finches, *Taeniopygia guttata*. Frontiers in Zoology 2009, 6:25.

Vácha M, Půžová T,and Markéta Kvičalová M. 2009. Radio frequency magnetic fields disrupt magnetoreception in American cockroach. The Journal of Experimental Biology 212;3473-3477.

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. CHECK !!!!!

Burda H, Begall S, Cerveny J, Neef J, Nemec P. 2009. Extremely low-frequency electromagnetic fields disrupt magnetic alignment of ruminants. Proceedings of the National

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 μT, red light, then 0, 150, 300, 500 μT, 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 μT and (i) *cryb*: no MF effect; (ii) *cryOUT*: no MF effect and (iii) *tim-gal4 uas-cry*: at 300 μT, 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. Volunteerss were immediately entrained to the external signal. Effect lasted for a few days, indicating E-fields acting as zeitgebers

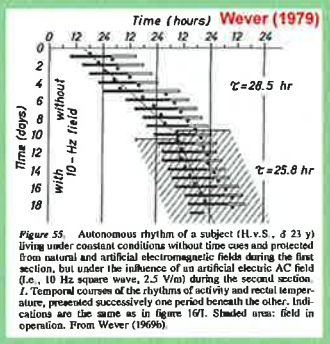


Figure 55. Autonomous rhythm of a subject (H.v.S., ♂ 23 y) living under constant conditions without time cues and protected from natural and artificial electromagnetic fields during the first section, but under the influence of an artificial electric AC field (i.e., 10 Hz square wave, 2.5 V/m) during the second section. *1.* Temporal courses of the rhythms of activity and rectal temperature, presented successively one period beneath the other. Indications are the same as in figure 16f1. Shaded area: field in operation. From Wever (1969b).

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

Talk through the significance that cryptochromes control circadian rhythms

FAD = flavin-adenine dinucleotide

Are human cryptochromes magnetosensitive?

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 μT 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.

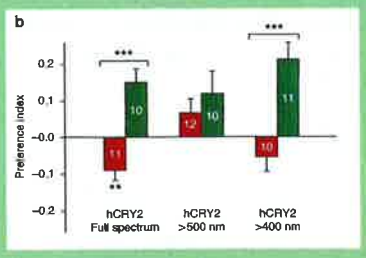
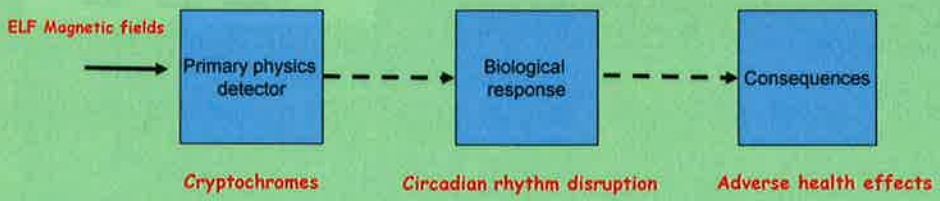


Figure 1b

Summary

- Many life forms evolved to detect MFs and use them for navigation; acute adverse health effects are associated with GM storms
  - all below some levels from the electricity supply
- Both magnetite clusters and the RPM can transduce power frequency MFs at common public exposure levels
- The demonstration that human cryptochromes are magneto-receptive, has implications for circadian rhythm disruption in humans and one possible model to explain health effects associated with ELF MF exposure



Acknowledgements

Illia Solov'yov (Frankfurt)
Jonathan Woodward (Tokyo)
Mike O'Carroll

and

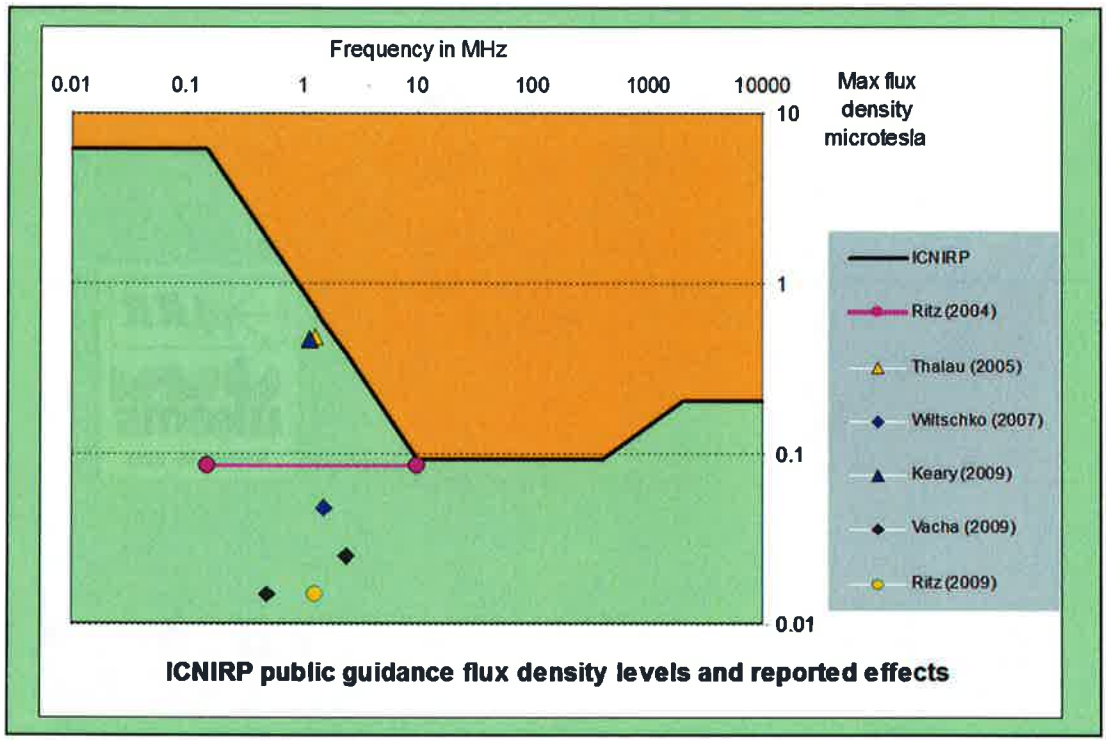
Children with Cancer UK

ARR
ukems
Nottingham 2011

University of BRISTOL

CHILDREN with CANCER UK
Registered Charity No. 298405

Last slide



ICNIRP public guidance flux density levels and reported effects