RF Interaction Mechanisms

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RF Mechanisms

- Qualitative description of interaction mechanisms, particularly those published in the last four years or so.

Thermal Effects

- All absorption mechanisms ultimately result in temperature rises.
- Biochemical reactions often strongly temperature dependent.
- “Thermal effects” normally attributed to temperature increases caused by current flow (Joule heating).
- Protected by guidelines.
- Age dependence of conductivity? Unlikely to be large enough to cause concern.
- Local Heating Effects??

Non-Thermal Effects

- Effects not directly caused by temperature rises.
- Electric fields
- Magnetic fields
- Energy quantum far too small to ionise DNA

Factors affecting RF coupling to biological components

1. At high frequencies, membrane resistance shorted out by its capacitance :
   - Decrease in voltage drop across membrane as frequency increases.
2. Velocity of light » sound velocity.
   - Hence wavevectors $k_{RF} \ll q_{vib}$.
   - So cannot conserve momentum : excitation of vibrations is “forbidden”.
3. RF changes should not be detectable if their energy « kT (there may be exceptions..)

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E-fields: changes in protein conformation

Bohr and Bohr (2000).

- Proteins consist of a chain of amino acids connected by peptide bonds.
- Conformation is geometrical arrangement of the chain in space.
- Biological properties of protein depend on its conformation.
- Shown that excitation of vibrational and torsional modes on protein leads to changes in conformation that occur as T changes.
- These dynamic modes have frequencies ~1GHz
- Model proposes these can be excited by RF.
- Some experimental evidence for SAR of 250 Wkg^{-1}
- Not possible to estimate strength of RF required

E-fields: changes in protein conformation

Laurence et al (2000,2003)

- Their analysis suggests conformational states are in thermal equilibrium.
- If so, conformational changes only produced by changing the *local* temperature (local heating).
- Laurence et al (2000) showed that significant changes could be produced by small RF fields.
- But Laurence et al (2003) noted the heat capacity they had assumed was incorrect-far too small!
- Temperature rises using correct heat capacity are too small to produce detectable effects.

E-fields: conformational changes in ion motive ATPases

Astumian (2003)

- ATPases are proteins that span membranes and act as ion pumps. Pump fuelled by ATP.
- Experiments by Xie et al (1997) at f < 1 MHz showed ions were moved across membranes by RF fields > guidelines
- RF pumping produced by ATPases? Astumian showed E-field coupling to dipole moment of ATPase could change its configuration and hence move ions.
- Since E in membrane falls at high frequencies (membrane resistance shorted by its capacitance) pumping unlikely to be significant at 1GHz for E<guidelines.

E-fields: resonant absorption of RF energy by vibrational states of biological components such as microtubules

Fröhlich (1968), Hyland (1998)

- Components such as microtubules have vibrational modes at frequencies up to ~1GHz. Suggested these could be excited by RF?.
- Interaction between these components could lead to bands of vibrational energies? cf. electronic bands in solids.
- Bands pumped by metabolic energy leading to the possibility of RF amplification as in a laser???.

E-fields: resonant absorption of RF energy by vibrational states

Foster and Baish (2000), Adair (2002)

- Microtubules immersed in relatively viscous fluid.
- Viscous damping of vibrations investigated theoretically by Foster and Baish and again by Adair.
- Damping so large that concept of bands is inappropriate: (band model breaks down if vibrations have a short lifetime)
- Adair also showed that power transferred to a vibration by RF of $100\ Wm^{-2} < kT$ by 10^9.
- Conclude : Fröhlich mechanism very unlikely to lead to biological effects

E-fields: changes in the binding of ligands such as Ca^{2+} to cell receptor proteins

Chiabrera et al (2000) and earlier papers

- Ligands, eg **Ca^{2+},** alter the conformation of proteins and hence control their receptor function.
- Bound ligand is held in a potential well.
- Well shape modulated by RF.
- RF exposure produces changes in binding probability of the ligand.
- However system will relax back to thermal equilibrium; are the resultant changes significant?

E-fields: changes in the binding of ligands such as Ca^{2+} to cell receptor proteins-cooperative model

Thompson et al (2000)

- Occupation of one protein site by a ligand changes its conformation
- Could this significantly affect the conformation of its neighbours? If so could it lead to an ordered array of empty and full ligand sites rather than a random one?
- The model suggests it could and that RF could trigger a transition from a random array to an ordered array-a phase transition.
- Uses statistical mechanics (Ising model) not a microscopic model.
- Not possible to calculate E-fields needed to produce effects.

Enhanced attraction between cells (Pearl-Chain Effect)

(Schwan 1985, Adair 1994)

- Van der Waals forces:
  - –Cells have dipole moments because of motion of electrons.
  - –Average value of moment is zero; instantaneous value is non-zero.
  - –E- field due to dipole moment on one cell produces attractive force on dipole moment of another. Average value is non-zero.
  - –Cells attract each other= Van der Waals force
- RF E-fields produce oscillating dipoles in cells. Are these big enough to enhance significantly the attraction between cells causing them to aggregate –pearl chain effect??

Enhanced attraction between cells (Pearl-Chain Effect)

- Adair (1994) : for typical cells and at 100 MHz, showed that energies~kT for E=300 Vm^{-1}. So could be significant.
- Effects decrease with frequency but depend on biological structure so cannot exclude possibility of biological effects at these E-fields and ~ 1GHz.
- More recent studies have been made by Krasil'nikov (1999) and Sernelius (2004). Comment on 2nd by Adair has been submitted for publication.

E-fields: resonant excitation of plasmons in quasi-2D ion layers at membrane surfaces

(Krasil'nikov 1999)

- Hydrogen ions attached to inner and outer surfaces of membranes move freely around the surfaces. (20 times higher than in water)
- These 2D "metals" can support longitudinal sound waves or plasma-like modes (plasmons) with f~ 1GHz..
- RF waves can excite simultaneously 2 plasmons, one on inside surface and one on outside.
- If wavevectors approximately equal to $+q_{vib}$ and $-q_{vib}$ can overcome the problem that $k_{RF} \ll q_{vib}$
- Results in enhancement of Van der Waals attraction between cells or vesicles .
- No comparison made between enhanced potential energy and kT

E-fields: RF enhancement of the attractive forces between cells

Sernelius (2004)- comment by Adair

- Sernelius first compares the size of an RF field to that of the endogenous E-fields around the cell.
- He then assumes the forces scale according to this comparison.
- Argument not easy to follow.
- Adair shows his method overestimates the enhancement by 10^{11}!

E-fields: interaction of low frequency electrical fields arising from the demodulation of pulsed RF

- Maximum RF E-fields in tissue from phones ~100 Vm^{-1}
- Guidelines: ELF E-fields in tissues should be < 5 Vm^{-1}
- Demodulation of pulsed RF leads to ELF E-fields eg ~217 Hz for GSM, 17.6 Hz TETRA (plus "white noise" from digital signals ~ 10 kHz).
- Demodulation requires non-linear dielectric properties eg conductivity $\sigma = \sigma_0 + \sigma_1 E$
- In nearly all dielectrics $\sigma_1 E \ll \sigma_0$ for E-fields ~ 100 Vm^{-1}
- Are any biological components sufficiently non-linear to produce ELF E-fields > 5 Vm^{-1}?

E-fields: interaction of low frequency electrical fields arising from the demodulation of pulsed RF

- Only biological component known to be non-linear is a cell membrane.
- Non-linearity only observable < 500 kHz. (E-field in membrane falls when f > 500 kHz because membrane capacitance shorts out resistance)
- So membranes could not demodulate ~1 GHz signals.
- Are any other biological components non-linear at ~1 GHz??
- Proposed experiment by Balzano (2002, 2003) exposes tissues at frequency f and looks for a signal at 2 f.

B-fields:RF interaction with a bacterium containing particles of magnetite (Fe_3O_4)

(Cranfield et al 2003 a and b)

- Tentative experimental evidence for interaction with magnetite:
  - RF alone SARs up to 2 Wkg^{-1} does not cause cell deaths but exposure to mobile phone (which of course includes ELF B-fields) does.
- Result needs to be confirmed.
- Ferromagnetic resonance? Interaction might however be suppressed by slow orientation of particles?

B-fields:radical pairs.
(Woodward et al 2001)

- Free radicals are molecules with an unpaired electron
- Usually extremely reactive and hence short-lived.
- Role in disease, including cancer, is well-established.
- Produced in pairs as intermediates in chemical reactions.
- Free radicals produced if radical pair dissociates before the two radicals recombine.
- Experiments (<80 MHz) show concentration of free radicals can be increased by low intensity RF.

B-fields:radical pairs.

(Woodward et al 2001)

- Could this happen at microwave frequencies?
- Pairs produced with spins antiparallel (S) or parallel (T) but oscillate between S and T at a rate determined by hyperfine coupling.
- Radicals less likely to recombine within the pair if in T state.
- RF at hyperfine frequency can increase the proportion in the T state and so concentration of free radicals.
- Hyperfine splittings mostly <100 Mhz.
- So less likely to be a significant mechanism at ~1 GHz?
- More work needed though

Summary

- Variety of mechanisms proposed. Some seem unlikely to lead to biological effects for f~1 GHz. For others the position is less clear.
- Thermal effects could be age dependent although still unlikely to be significant below guidelines. (local heating??)