Interactions of Electromagnetic Waves with Biological Tissue

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BIOE 200C

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Motivations

- Biological effects of electromagnetic waves are critical for:
  - Understanding potential health and safety risks in order to set safe standards for:
    - Cellular phones
    - Radio waves
    - Wireless networking
    - TV / Radio broadcasting
    - 60 Hz power lines
    - X-ray imaging
  - Developing and utilizing medical applications and therapies:
    - Ultrasound
    - Terahertz imaging
    - Tissue heating
    - Magnetic resonance imaging (MRI)
    - Ionophoresis
    - Non-invasive drug delivery
    - Bone healing

Goals for lecture

- Analyze biological effects of electromagnetic radiation at the cellular level from two different viewpoints
  - Macroscopically (Dosimetry)
    - Wave incidence
    - Parameters of medium
    - Penetration depth and frequency dependence
    - Human body resonance
    - Thermal heating
      - Cancer therapy
  - Microscopically (Biophysical interaction mechanisms)
    - Non-ionizing radiation
      - Low frequencies
        - » Signal transduction theory
        - » Direct interaction theory
      - Radio frequencies
        - » Low-level fields
        - » High-level fields
    - Ionizing radiation
      - Planck's equation and ionization energy
      - Cutoff between non-ionizing and ionizing radiation

Parameters of media

- Permeability, μ, is analogous to the permittivity in that it describes the relationship between the magnetic dipole vector and the magnetic field
  - Most of the cells and tissues that will be studied are non-magnetic
  - For these types of materials, μ is considered to be equivalent to μ_0, the permeability of free space
  - It is, therefore, much less critical to our analysis of EM interaction with biological tissue than permittivity and conductivity

$$\vec{B} = \mu \cdot \vec{H} \qquad (5)$$

- These three parameters fundamentally characterize any medium macroscopically
  - Parameters can be used to determine depth of penetration and absorbed power of an incident electromagnetic wave on the medium

Parameters of media

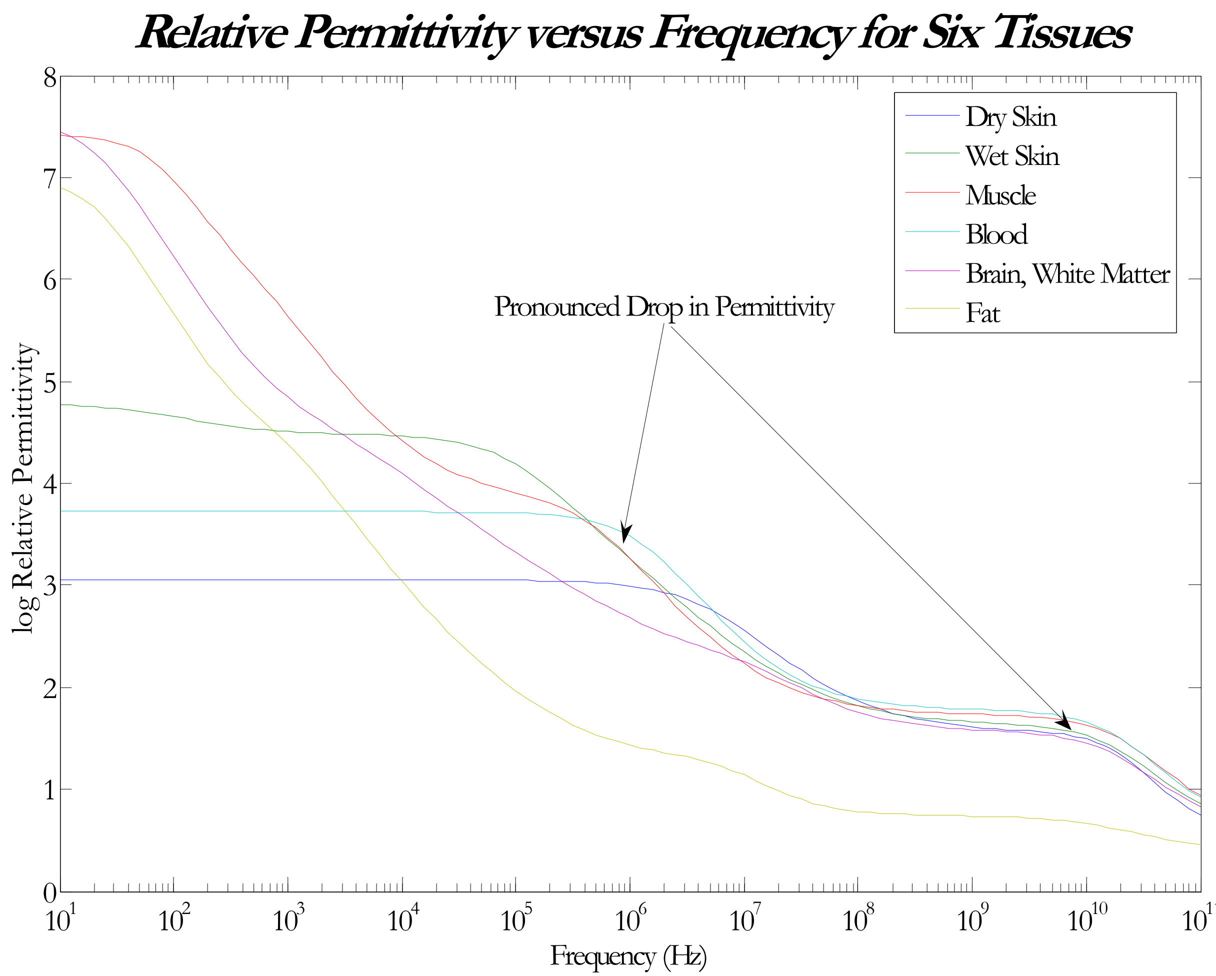
- Permittivity, ε, defines the *polarizability* of a material
  - Applied E-field gives rise to dipole moment distribution in atoms or molecules
  - Secondary fields are set up, thus net E-field is different
  - If dipole moment distribution is denoted by vector **P**, the relationship between applied electric field and **P** is:

$$\vec{P} = (\varepsilon - \varepsilon_0) \cdot \vec{E} \qquad (3)$$

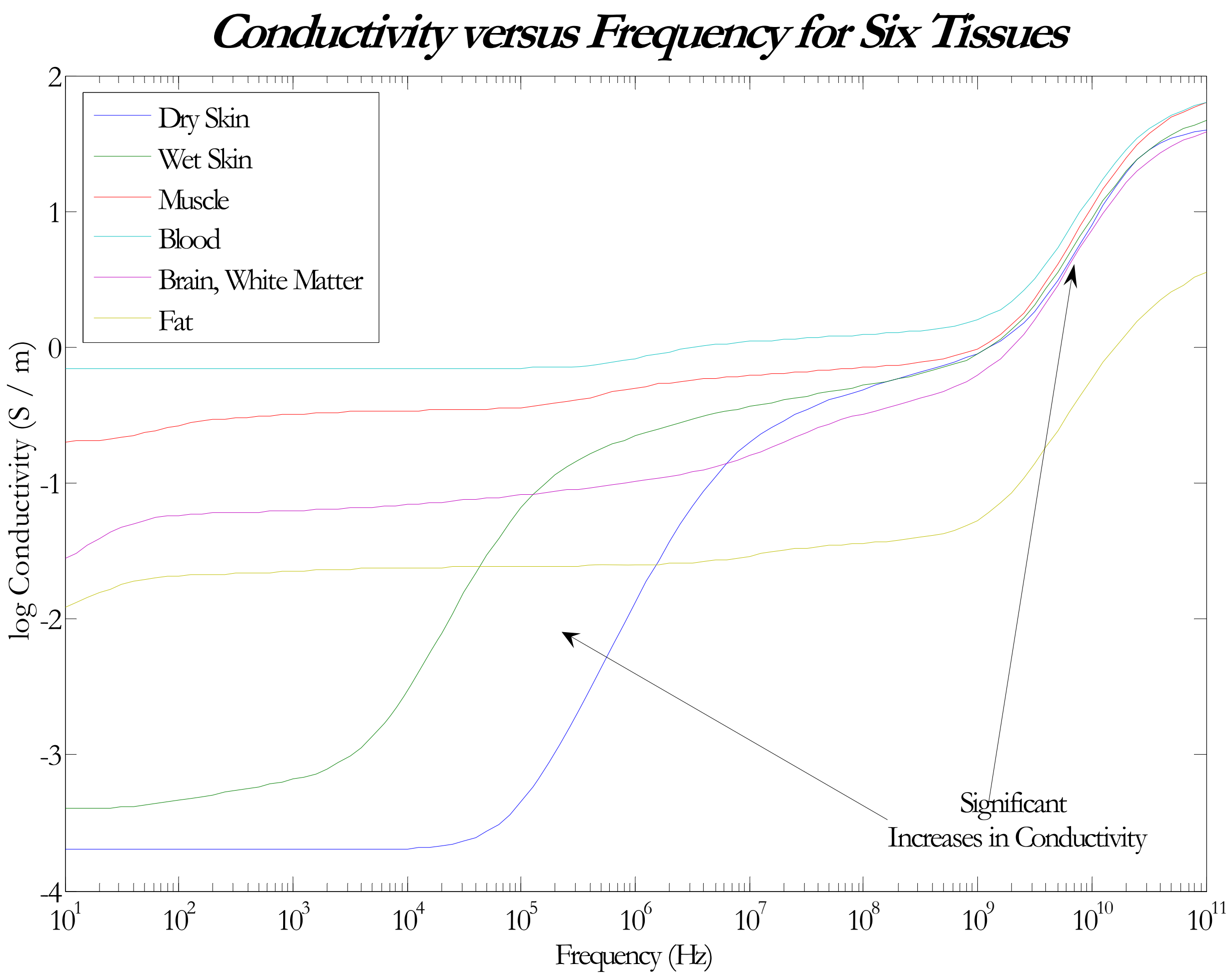
- Conductivity, σ, summarizes the microscopic behavior of conductors
  - Applied E-field gives rise to electron drift
  - This drift results in a current density in the direction of the E-field
  - Conductivity is the factor which relates the E-field to the drift current

$$\vec{J} = \sigma \cdot \vec{E} \qquad (4)$$

Permittivity of tissues

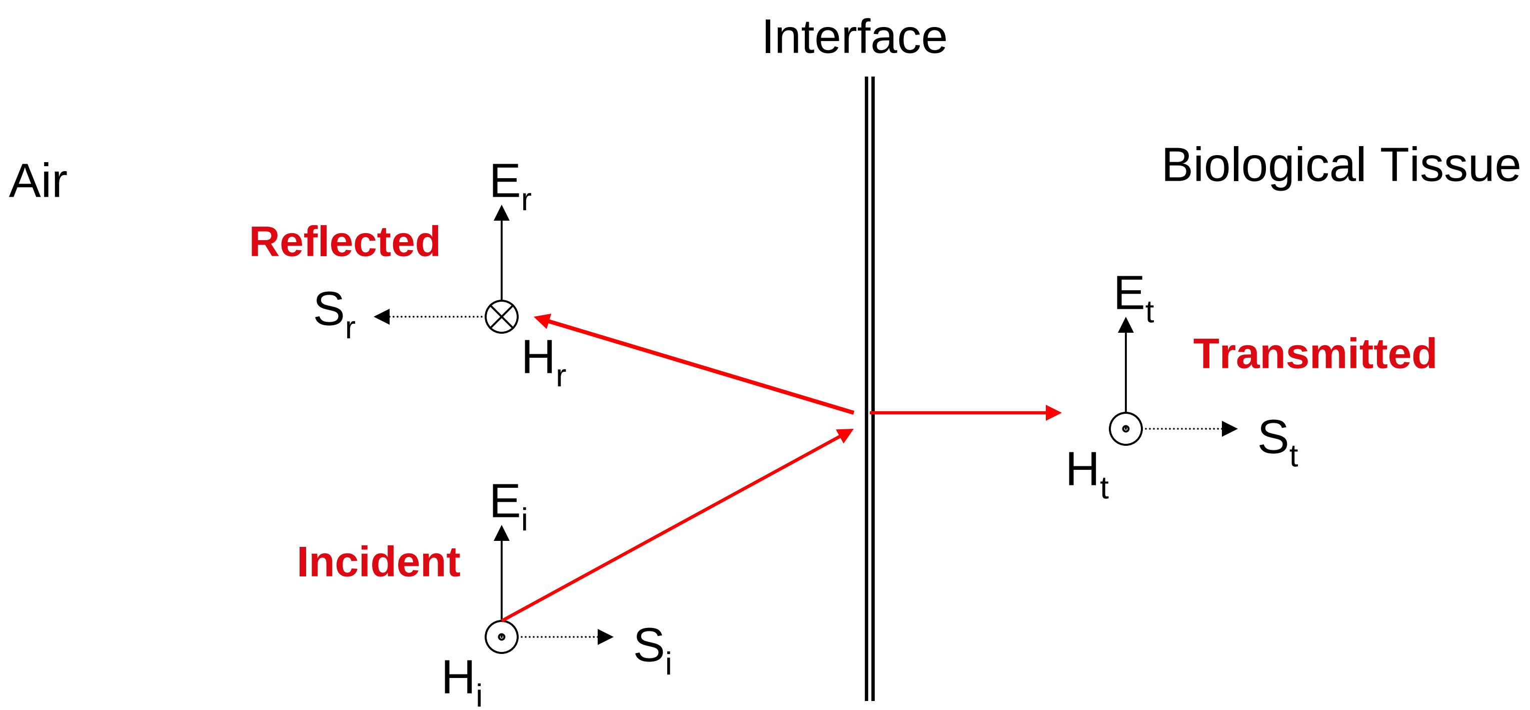


Conductivity of tissues



What happens macroscopically?

- Problem of electromagnetic wave incidence on a lossy medium (tissue)
- Incident EM energy is reflected and refracted at the interface of air and tissue
- Fundamental constants defining how much is reflected and refracted are parameters of the medium



Electromagnetic incidence

- Relative amplitudes of the reflected and transmitted components of the incident electric field wave are defined below:

$$E_r = \Gamma \cdot E_i \qquad \text{Reflected} \qquad (1a)$$

$$E_t = \tau \cdot E_i \qquad \text{Transmitted} \qquad (1b)$$

- Reflection coefficient, gamma, and, appropriately, transmission coefficient, tau, are determined purely by the parameters of the two media of conduction:

$$\Gamma = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \qquad \text{Reflected} \qquad (2a)$$

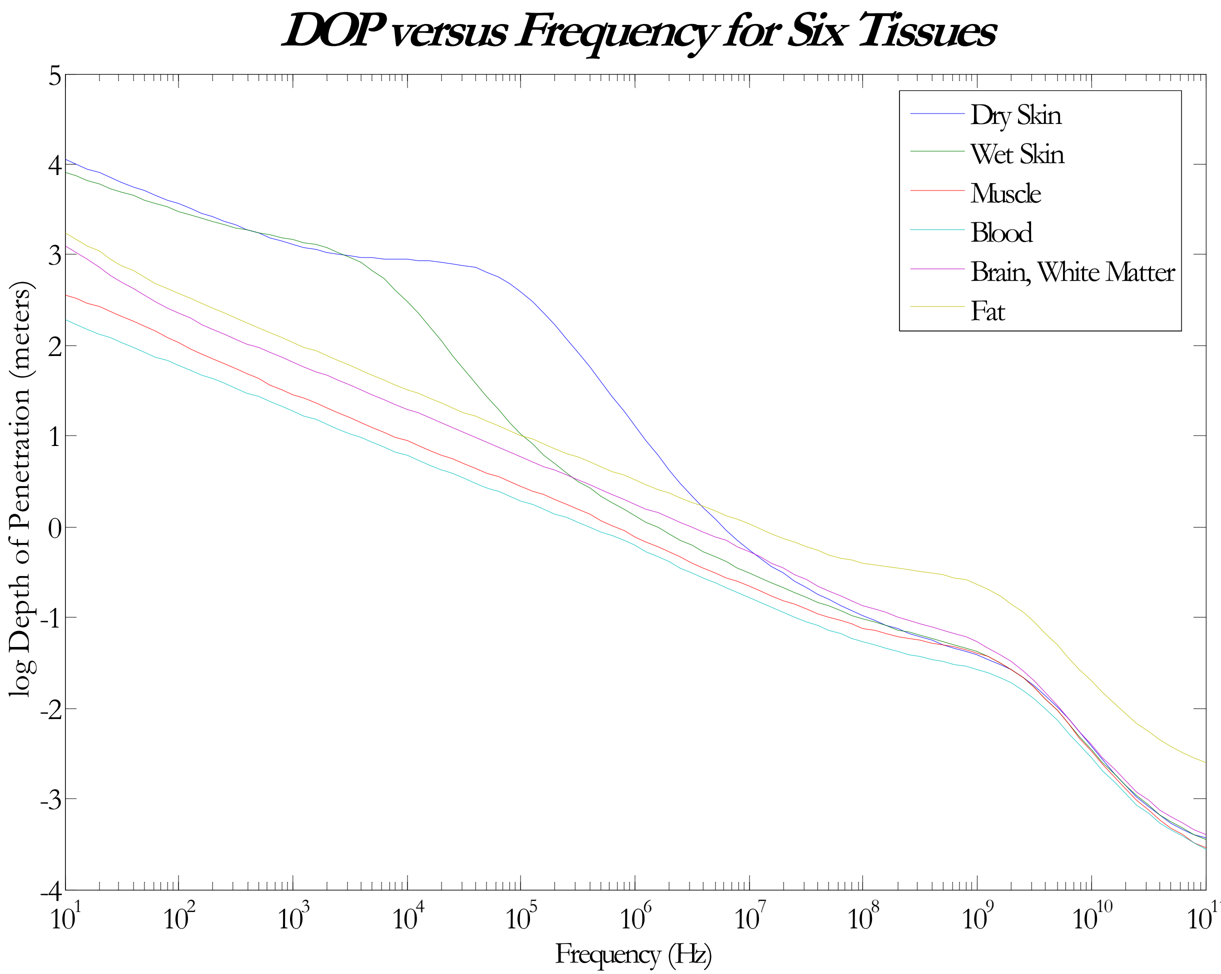
$$\tau = \frac{2\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \qquad \text{Transmitted} \qquad (2b)$$

Depth of penetration

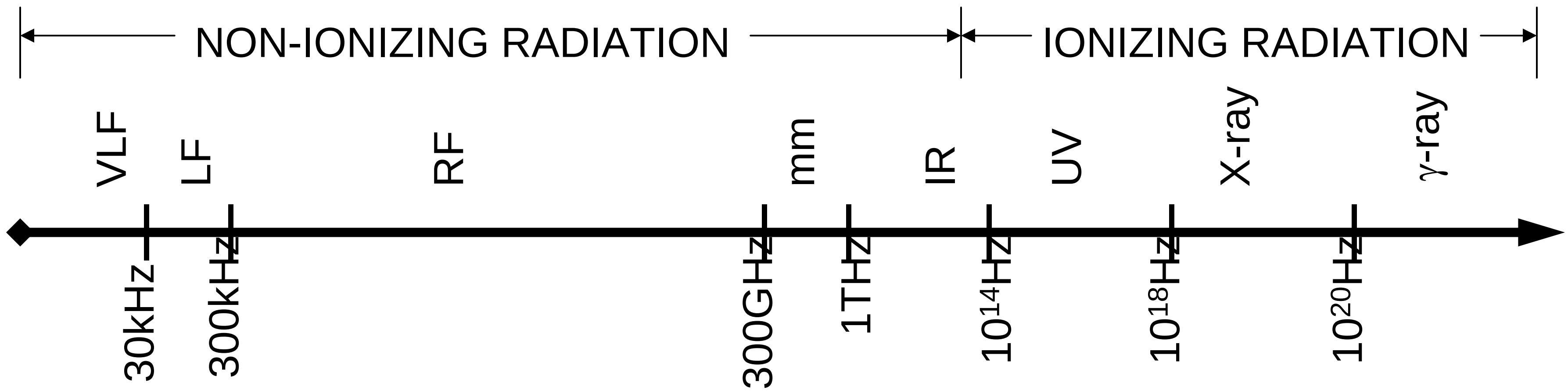
- Any wave that enters a lossy medium will be attenuated after some distance
- Depth of penetration (D.O.P.) characterizes the distance after which the field intensity is 1 / e of its incident value
- For a low-loss dielectric medium, the D.O.P. is described by the following equation, in which **tan(δ_c) is the loss tangent of the material**

$$D.O.P. = \frac{c\sqrt{2}}{\omega\sqrt{\mu_r \varepsilon_r'}[\sqrt{1+\tan^2\delta_c} - 1]^{1/2}} \quad (6)$$

DOP of tissues



Microscopic approach

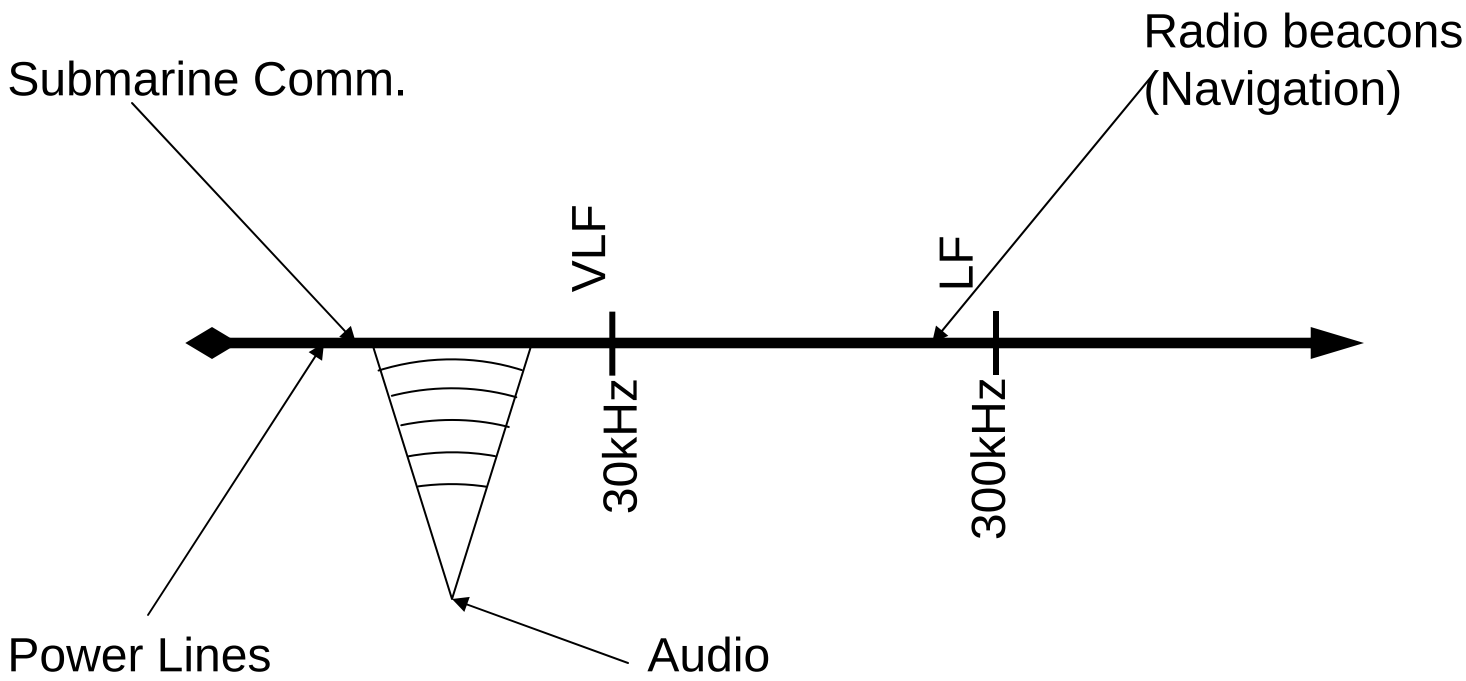


- We will consider two classifications of electromagnetic radiation separately because their effects on the human body are vastly different:
  - Non-ionizing Radiation
    - Frequency range: 0.1 - 10^{13} Hz
    - Designations: VLF, LF, RF, millimeter, submillimeter
    - Sources: Power lines, radio / TV broadcasting, radar, cellular phones
  - Ionizing Radiation
    - Frequency range: > 10^{13} Hz
    - Designations: IR, UV, X-rays, gamma rays
    - Sources: Optical communications, sunlight, cosmic radiation, medical applications

Non-ionizing radiation

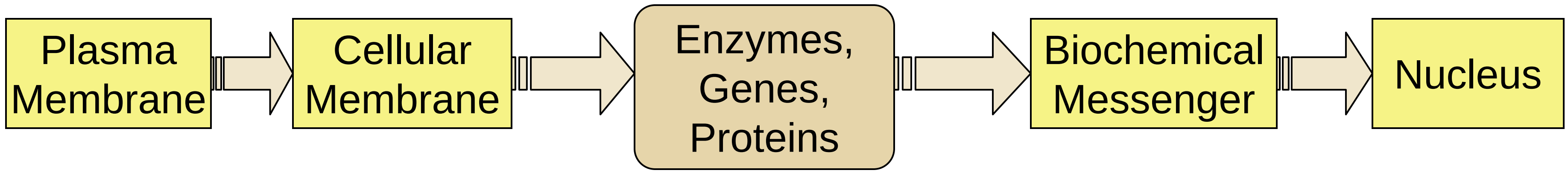
- Microscopic effects of non-ionizing EM energy have been studied extensively over the past few decades because we are exposed to these waves more often than ever before
- However, many mechanisms of interaction are still not well known nor are relevant results consistent
- In contrast, effects and health/safety standards are widely accepted in the science community
- Level of understanding of mechanisms of interaction decreases as we move from extracellular (membrane) to intracellular (enzyme, DNA) components
- We will consider these effects of non-ionizing radiation in two separate frequency bands, distinguished by the relative size of wavelength versus medium (human body)
  - Low frequency radiation: $\lambda >> D$
  - Radio frequency radiation: $\lambda \sim D$, $\lambda << D$

Lower frequencies



Low frequency EMF effects

- Prevailing theory is that interactions occur primarily in the plasma membrane, then a cascade of changes propagates from the membrane to the nucleus of the cell as shown below[2]:

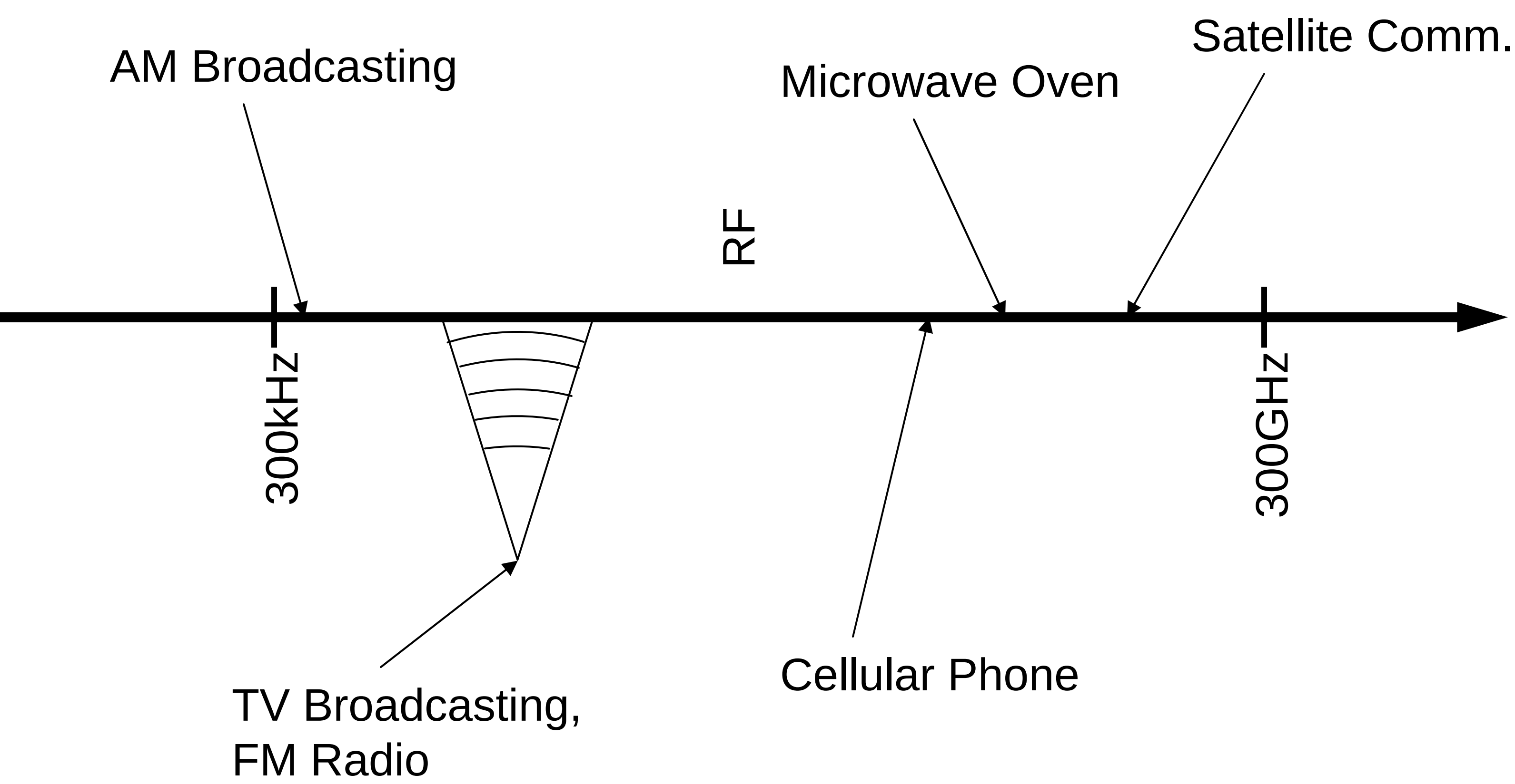


- An alternate theory suggests the possibility that EMF interacts directly with the nucleus and the DNA based on the following analysis
  - Membrane blocks low-level electric fields but not magnetic fields
  - Although cellular dimensions limit the induced electric field resulting from the penetrating magnetic field to very small values, the magnetic field itself may interact with cellular components
  - Recent studies by Blank and Goodman[3] show that the magnetic field may interact with enzymes and DNA within the cell through classical physics based mechanisms

[2] Behari, J., *Biological Effects and Health Implication of Radiofrequency and Microwave*, International Conference on Electromagnetic Interference and Compatibility'99, 6-8 Dec. 1999, New Delhi, India; p.449-52.

[3] Blank, M. and R. Goodman, *Do Electromagnetic Fields Interact Directly With DNA?*, Bioelectromagnetics; 1997; vol.18, no.2, p.111-15

Higher frequencies



Higher frequency effects

Mechanisms of interaction for RF radiation on the body are very different at low-levels of radiation versus higher levels

Low-level RF radiation causes predominantly non-thermal effects because the intensity is not high enough to significantly change tissue temperature

- Non-thermal effects are direct interactions of EMF with biological cells
- Very important because most common exposure is at low-levels
- Not as well understood: specifically, mechanisms are not fully explored nor consistently documented

High-level RF radiation causes thermal effects

- Thermal effects are indirect interactions: EMF -> heat -> biological effect
- RF energy and, specifically, Specific Absorption Rate (SAR), are high enough to significantly heat the tissue
- Hazards are well established, safety levels are well documented

Repacholi, *Low-Level Exposure to Radiofrequency Electromagnetic Fields: Health Effects and earch Needs*, Bioelectromagnetics, 19: 1 - 19, 1998

Non-thermal effects of RF

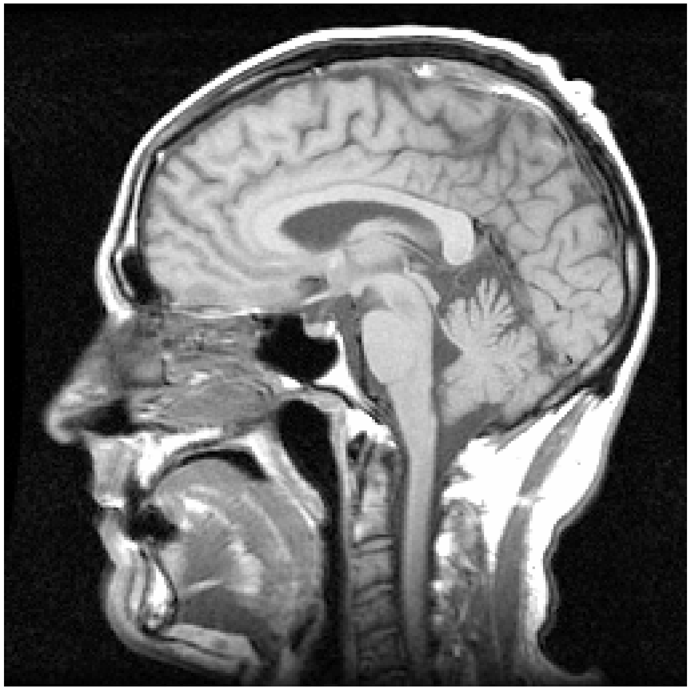
- RF fields induce torque on molecular dipoles which can result in ion displacement, vibrations in bound charges, and precession[5]
- This effect is characterized by the Bloch Equation which is fundamental to MR Imaging

$$\frac{d\vec{M}}{dt} = \vec{M} \times \gamma \vec{B} \qquad (9)$$

- With an applied magnetic field, the nuclear spins will precess in a left-hand direction around the field with angular frequency proportional to its amplitude
- No observable biological hazards have been noted as a result of these mechanisms because they are outweighed by random thermal agitation in low-level fields

hwan, HP, *Biological effects of non-ionizing radiation: Cellular properties and interactions,* Ann

MRI: Prof. John Pauly, EE



http://www.stanford.edu/~pauly/jmp_sag.jpg

Non-thermal effects of RF

In vitro research reports show that membrane structure and functionality may be altered in RF fields

The following have been reported[6] effects on membrane properties:

- Decreased rates of channel formation
- Decreased frequency of single-channel openings
- Increased rates of rapid firing

No mechanism that can be experimentally verified has been found to describe these effects, although some researchers have proposed possible methods of interaction (See Tarricone et al.)[7]

ctromagnetic Fields (300 Hz - 300 GHz). Environmental Health Criteria 137." (United Nations onment Programme, World Health Organization, International Radiation Protection Association.) va: World Health Organization.

icone L, Cito C, D'Inzeo G, *AGh receptor channel's interaction with MW fields*, Bioelectrochem

Influence on cancer promotion?

- Possibility of cancer promotion and progression by RF fields has been studied extensively because of the implications:
  - Cell phone usage -> tumor?
- Results from a few of these studies are provided below:
  - Exposure of glioma cells to RF fields leads to effects on transcription and cell proliferation[8] at high SAR values of 5 - 25 W / kg
  - Low-level 2.45 GHz fields produced cell-cycle alterations which may be associated with cancer promotion[9]
  - Studies conducted on lymphocyte transformation as a result of RF energy have mostly been negative

ary SF, Liu L-M, Merchant RE, *Glioma proliferation modulated in vitro by isothermal radiofrequency ion exposure*, Radiat Res 121: 38 - 45, 1990.

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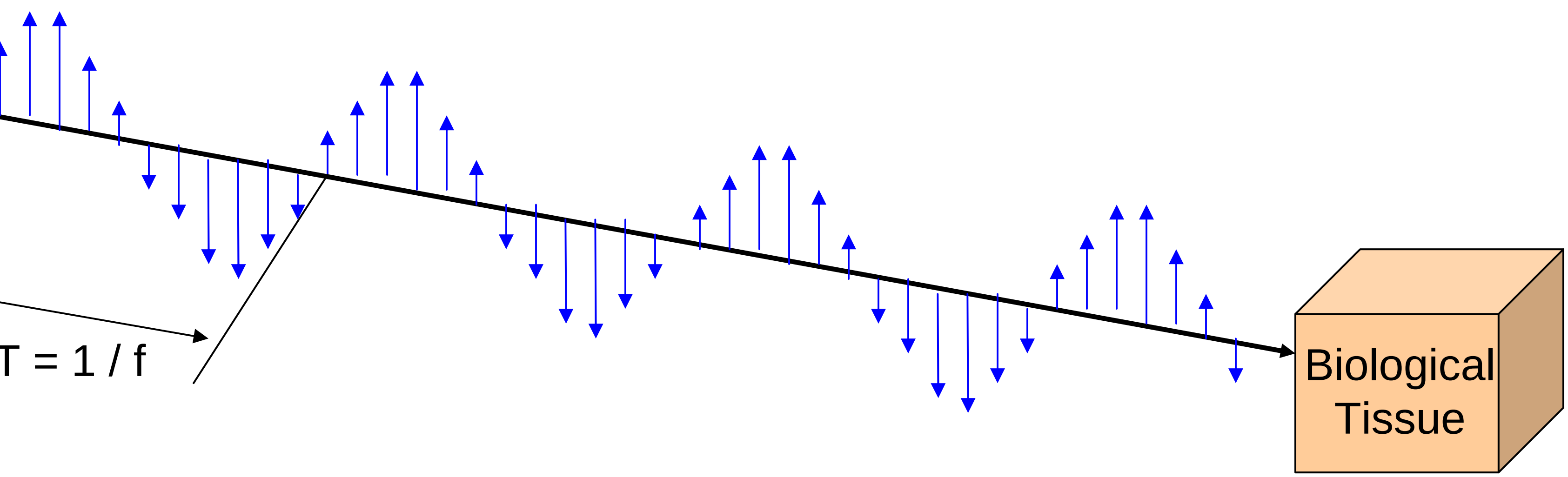
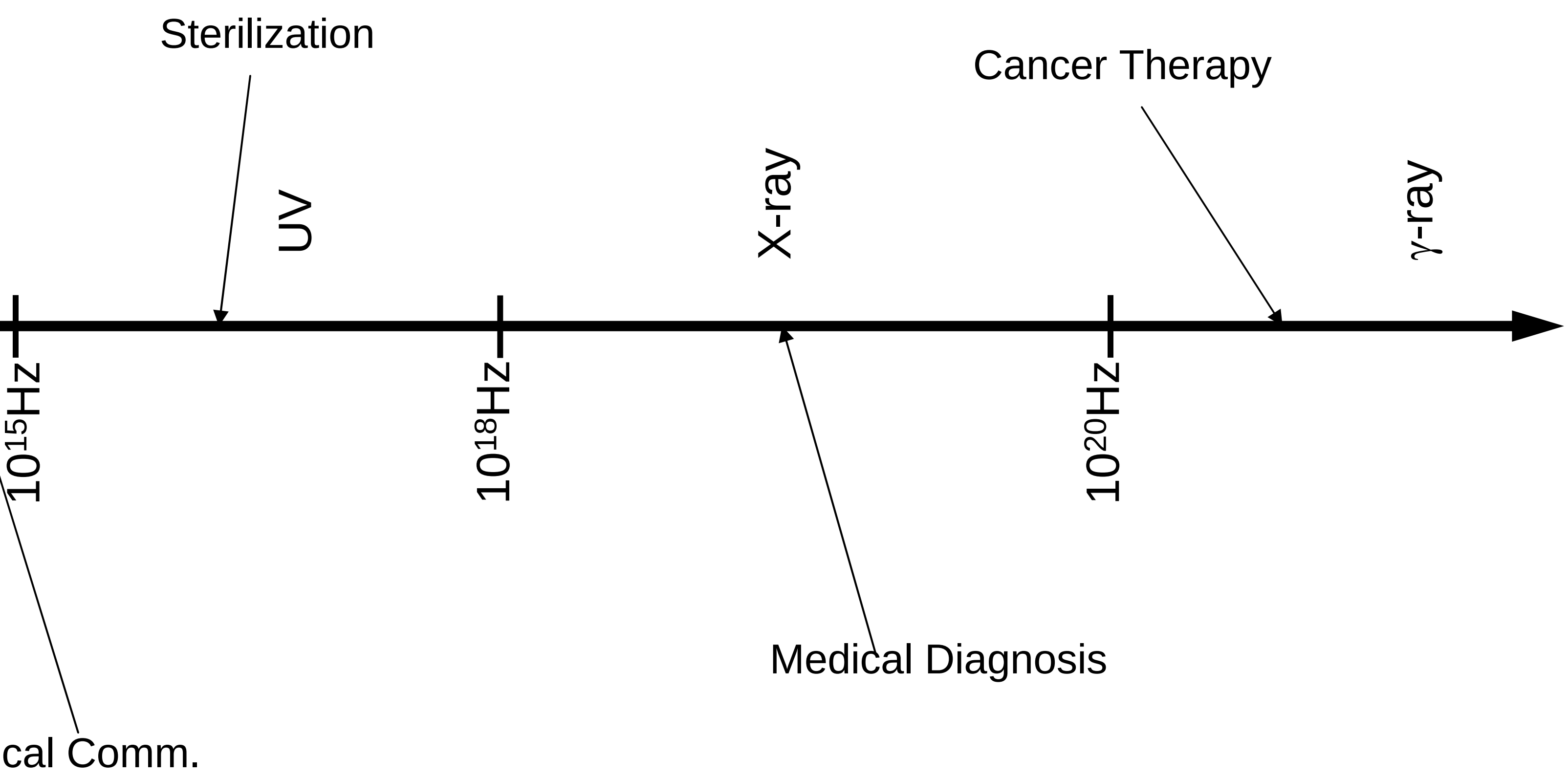
Thermal effects of RF



he above diagram depicts the electric field alternations, at a frequency f, of the ectromagnetic wave that is incident on biological tissue.

emember: For RF and microwave fields, this frequency is generally between 30 kHz nd 300 GHz

Ionizing radiation



Ionizing radiation: Energy

Electromagnetic waves are composed of discrete units of energy called *quanta* or *photons*

The energy of these photons can be found from Planck’s equation and is a direct function of the frequency of the EM wave (*h* is Planck’s constant and it is equivalent to 6.625×10^{-34} J s):

$$E = h \cdot f \qquad (10)$$

When these photons are incident on the molecules of cells in biological tissue at high energies (>10 eV), they can break bonds and ionize the molecules

- For example, the energy required to ionize H_2O is approximately 33 eV
- Using equation (9) we find that the lowest frequency wave that can ionize water molecules is then approximately 8×10^{15} Hz
- The lowest frequency that can ionize any molecule (E = 10 eV) is approximately the beginning of the ionizing radiation spectrum and it is 2.4×10^{15} Hz

Ionizing radiation effects

Unlike RF radiation where thermal heating is the only (proven) dangerous biological effect, ionizing radiation has many non-thermal effects which are potentially lethal

- A lethal dose of gamma radiation may only raise the body temperature by one-hundredth of a degree Celsius

Effects of ionizing radiation have been studied most extensively in two areas[10]:

- DNA damage and transcription / multiplicative dysfunction
- Membrane permeability changes leading to loss of barrier function

Health effects of hazardous doses of ionizing radiation include:

- Marrow stem cell damage
- Impairment of immune function
- Neurological syndrome
- Neuronal / capillary damage

nnig, J and RC Lee, *Structural Changes in Cell Membranes after Ionizing Electromagnetic Field*

Ionizing radiation mechanisms

- Ionization of water leads to the production of reactive oxygen intermediates (ROI) which can attack proteins, lipids, and carbohydrates
  - ROI are present in regular cellular metabolism but if their rate of induction exceeds normal capacity the result is cell damage
- ROI can disrupt covalent bonds in nuclear DNA, causing transcriptional and multiplicative errors and cell death during growth and repair
- Additionally, lipids in cell membranes can be susceptible to lipid peroxidation via these ROI leading to increased membrane permeability, increased ionic transport, and resulting cell death
  - Mutual diffusion of ions across the cell barrier exceeds the capacity of the ATP-fueled protein ionic pumps exhausting the metabolic energy of the cell and causing radiation necrosis

ig, J and RC Lee, *Structural Changes in Cell Membranes after Ionizing Electromagnetic Field*

Wireless Issues
Radio Frequency Emissions

ONSUMER INFORMATION ABOUT RADIO FREQUENCY EMISSIONS
our wireless phone, which contains a radio transmitter and receiver, emits radio frequency energy during use. he following consumer information addresses commonly asked questions about the health effects of wireless hones.

re Wireless Phones Safe?
cientific research on the subject of wireless phones and radio frequency ("RF") energy has been conducted orldwide for many years, and continues. In the United States, the Food and Drug Administration ("FDA") and the ederal Communications Commission ("FCC") set policies and procedures for wireless phones. The FDA and the CC have created a joint website, "Cell Phone Facts - Consumer Information on Wireless Phones," which states at "[t]he available scientific evidence does not show that any health problems are associated with using wireless hones," while noting that "[t]here is no proof, however, that wireless phones are absolutely safe." You can ccess the joint FDA/FCC website at http://www.fda.gov/cellphones. You can also contact the FDA toll-free at 88) 463-6332 or (888) INFO-FDA. In June 2000, the FDA entered into a cooperative research and development greement through which additional scientific research will be conducted. The FCC issued its own website ublication stating that "[t]here is no scientific evidence that proves that wireless phone usage can lead to cancer a variety of other problems, including headaches, dizziness or memory loss." This publication is available at tp://www.fcc.gov/cgb/consumerfacts/mobilephone.html or through the FCC at (888) 225-5322 or (888) CALL-CC.

Wireless Issues
Radio Frequency Emissions (cont).

t Does "SAR" Mean?
96, the FCC, working with the FDA, the U.S. Environmental Protection Agency, and other agencies, established RF sure safety guidelines for wireless phones in the United States. Before a wireless phone model is available for sale e public, it must be tested by the manufacturer and certified to the FCC that it does not exceed limits established by CC. One of these limits is expressed as a Specific Absorption Rate, or "SAR". SAR is a measure of the rate of rption of RF energy in the body. Tests for SAR are conducted with the phone transmitting at its highest power level tested frequency bands. Since 1996, the FCC has required that the SAR of handheld wireless phones not exceed atts per kilogram, averaged over one gram of tissue. Although the SAR is determined at the highest power level, ctual SAR value of a wireless phone while operating can be less than the reported SAR value. This is because the value may vary from call to call, depending on factors such as proximity to a cell site, the proximity of the phone to ody while in use, and the use of hands-free devices. For more information about SARs, see the FCC's OET tins 56 and 65 at http://www.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins and /www.fcc.gov/oet/fccid, or visit the Cellular Telecommunications Industry Association website at /www.ctia.org/wireless_consumers/health_and_safety/index.cfm/AID/152. You may also wish to contact the facturer of your phone.

Minimize My RF Exposure?
are concerned about RF, there are several simple steps you can take to minimize your RF exposure. You can, of e, reduce your talk time. You can place more distance between your body and the source of the RF, as the sure level drops off dramatically with distance. The FDA/FCC website states that "[h]ands-free kits can be used with ess phones for convenience and comfort. These systems reduce the absorption of RF energy in the head because hone, which is the source of the RF emissions, will not be placed against the head. On the other hand, if the phone unted against the waist or other part of the body during use, then that part of the body will absorb more RF energy. ess phones marketed in the U.S. are required to meet safety requirements regardless of whether they are used st the head or against the body. Either configuration should result in compliance with the safety limit." Also, if you our wireless phone while in a car, you can use a phone with an antenna on the outside of the vehicle. You should

Wireless Issues
Radio Frequency Emissions (cont).

Wireless Phones Pose Any Special Risks to Children?

FDA/FCC website states that "[t]he scientific evidence does not show a danger to users of wireless communication ces including children." The FDA/FCC website further states that "[s]ome groups sponsored by other national ernments have advised that children be discouraged from using wireless phones at all. For example, the government e United Kingdom ["UK"] distributed leaflets containing such a recommendation in December 2000. [The UK] noted no evidence exists that using a wireless phone causes brain tumors or other ill effects. [The UK's] recommendation mit wireless phone use by children was strictly precautionary; it was not based on scientific evidence that any health ard exists." A copy of the UK's leaflet is available at http://www.dh.gov.uk (search "mobile"), or you can write to: PB, Chilton, Didcot, Oxon OX11 0RQ, United Kingdom. Copies of UK's annual reports on mobile phones and RF are lable online at http://www.iegmp.org.uk and http://www.hpa.org.uk/radiation/ (search "mobile"). Parents who wish to ice their children's RF exposure may choose to restrict their children's wireless phone use.

Wireless Issues
Radio Frequency Emissions (cont).

re Can I Obtain Further Information?

urther information, see the following additional resources:

Food and Drug Administration
Consumer magazine
mber-December 2000
hone: (888) INFO-FDA
/www.fda.gov/fdac/features/2000/600_phone.html

Federal Communications Commission
2th St. S.W.
ington, D.C. 20554
hone: (888) 225-5322
/www.fcc.gov/oet/rfsafety

pendent Expert Group on Mobile Phones
/www.iegmp.org.uk

l Society of Canada
rt Panel on Potential Health Risks of Radiofrequency Fields from Wireless Telecommunications Devices
Sparks Street
va, Ontario K1R 7X9
da
hone: (613) 991-6990
/www.rsc.ca/index.php?page=expert_panels_rf&lang_id=1&page_id=120

Wireless Issues
Radio Frequency Emissions (cont).

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national Commission on Non-Ionizing Radiation Protection
undesamt fur Strahlenschutz
staedter Landstr.1
4 Oberschleissheim
nany
hone: 011 49 1888 333 2156
/www.icnirp.de
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/www.ansi.org
onal Council on Radiation Protection and Measurements
Woodmont Avenue, Suite 800
esda, MD 20814-3095
hone: (301) 657-2652
/www.ncrponline.org
neering in Medicine and Biology Society, Committee on Man and Radiation (COMAR), of the Institute of rical and Electronics Engineers
/http://ewh.ieee.org/soc/embs/comar/

Questions?

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leary SF, Liu L-M, Merchant RE, *Glioma proliferation modulated in vitro by isothermal radiofrequency radiation exposure*, Radiat Res 121: 38 - 45, 1990.

leary SF, Cao G, Liu L-M, *Effects of isothermal 2.45 GHz microwave radiation on the mammalian cell cycle: Comparison with effects of isothermal 27 MHz radiofrequency radiation exposure*. Bioelectrochem Bioenerg 39: 167 - 173, 1996.

Hannig, J and RC Lee, *Structural Changes in Cell Membranes after Ionizing Electromagnetic Field Exposure*, IEEE Transactions on Plasma Science, Vol. 28, No. 1, Feb. 2000.

Other resources

Baranski and P Czerski, *Biological effects of microwaves,* Dowden, Hutchinson and Ross Inc., Stroudsburg, PA, 1976.

H Brown, RH Smallwood, DC Barber, PV Lawford, DR Hose, *Medical Physics and Biomedical Engineering: Medical Science Series,* Institute of Physics Publishing, 1999.

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Further reading

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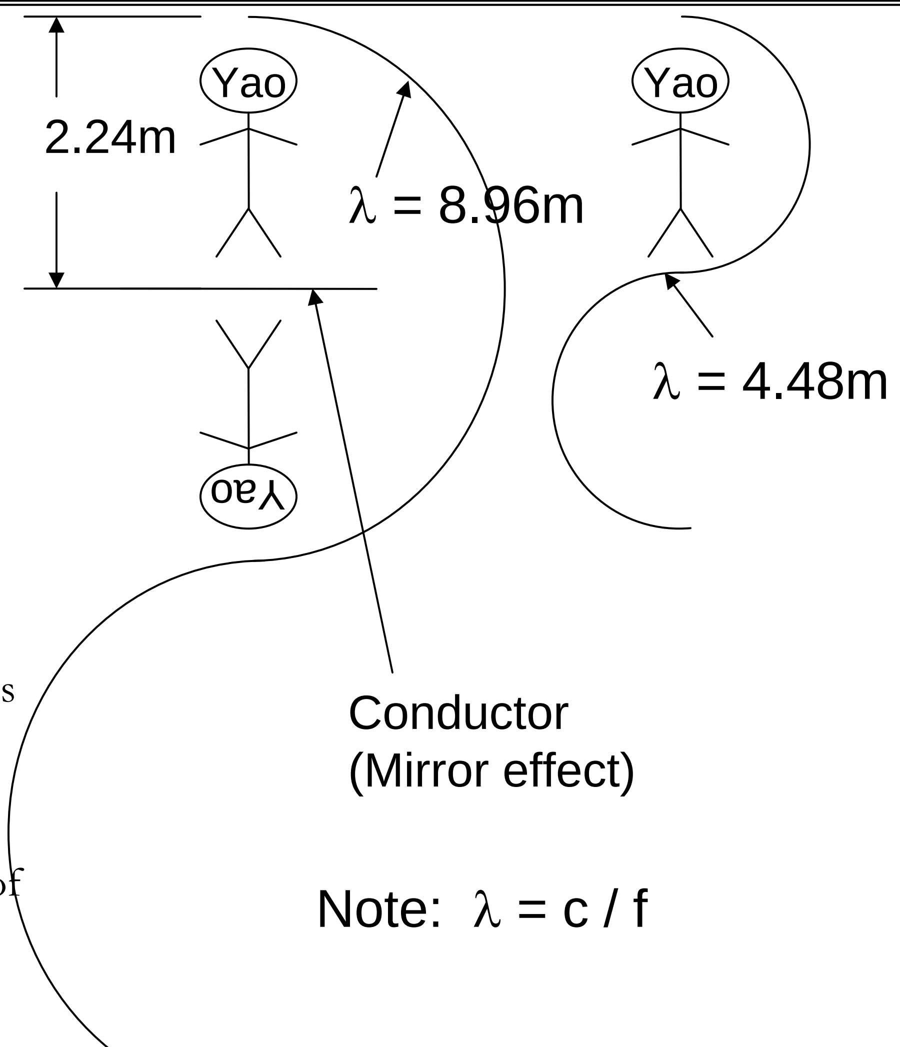
V Smye, JM Chamberlain, AJ Fitzgerald and E Berry, *The Interaction between Terahertz radiation and biological tissue*, Physics in Medicine and Biology, 46, R101 - R112, 2001.

R Black and LN Heynick, *Radiofrequency (RF) Effects on Blood Cells, Cardiac, Endocrine and Immunological Functions,* Bioelectromagnetics Supplement, 6: S187 - S195, 2003.

References

Resonance and mirror effect

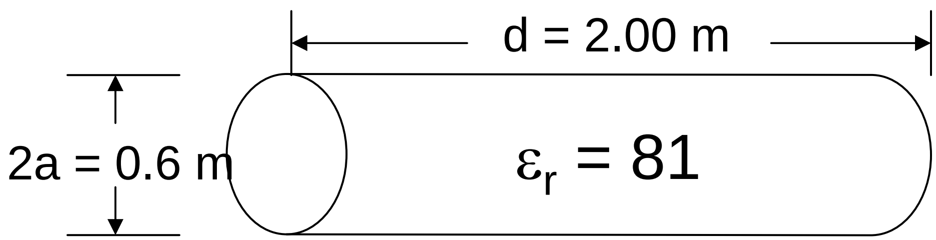
- Transmitted component of the incident wave adds energy to the tissue, resulting in heating
- The change in tissue temperature for a given wave intensity is strongly dependent on frequency of the wave:
  - Human body absorbs waves at frequencies that are close to its resonant frequency much more strongly than others
  - Resonance is approximately 35 MHz (λ = 8.56m) for a human that is grounded and 70 MHz (λ = 4.28m) for one who is insulated (figure describes why)
  - RF waves, for example, are much closer to this resonant frequency of the body than 60 Hz power lines or other forms of LF energy thus they are absorbed much more efficiently



Note: $\lambda = c / f$

Human body resonance

- In order to understand why the human body is resonant at frequencies in the megahertz and gigahertz, we must look at the problem from an electromagnetics viewpoint as in the following simple example
  - Consider the body as a *cylindrical cavity resonator* (for simplification purposes) with dimensions as shown below filled with water:



  - Boundary conditions and Maxwell’s equations can be used to derive an expression for different modes of wave propagation inside the medium
  - Consequent to these calculations is that there will be discrete frequencies at which resonance will occur
  - The following calculation is for the smallest of these frequencies for a water filled cavity of above dimensions (insulated):

$$f_{101} = \frac{1}{2\pi\sqrt{\mu\varepsilon}} \cdot \sqrt{\left(\frac{\pi}{d}\right)^2 + \left(\frac{3.832}{a}\right)^2} \approx 64\ MHz$$

Microwave thermotherapy

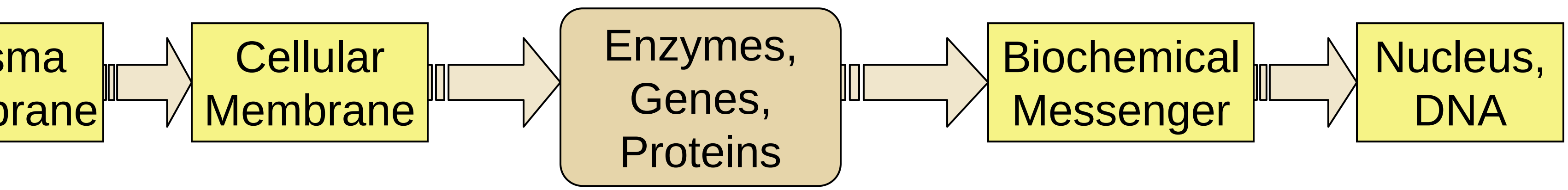
Microwave thermotherapy (.4 - 2.5 GHz)[1]

- Tissue is heated with microwaves because of the efficiency of energy absorption unique to this frequency band shown previously
- Additionally, higher frequencies (than human body resonance) are used to reduce depth of penetration and effectively focus the energy of the wave to a shallow region (tumor)
- Cancerous cells are killed by the heating since healthy cells can survive at higher temperatures due to greater blood flow (45 degrees Celsius for healthy cells, 41 for cancerous)
- Vrba et al. state that they have treated over 500 patients with tumors ranging up to 4 cm in depth using these methods
- Their results show, in the long run:
  - Complete response of tumor: 53%
  - Partial response of tumor: 31%
  - No response of tumor: 16%

a, J. et al., *Microwave Thermotherapy in the Czech Republic: Technical and Clinical Aspects.* www2.elec.qmul.ac.uk/iop/files/HTinCR.pdf

Theory of signal transduction

First, consider the signal transduction theory in which an enzymatic cascade is responsible for changes in biosynthesis



The following is a step by step account (from Behari 1999) of how the signal reaches the DNA in order for changes in biosynthesis to occur:

- Faraday induction creates currents in the ionic aqueous solution of the plasma membrane
- These currents are blocked by the strong dielectric barrier of the cell membrane; however, they cause changes in the cell surface involving counter ion layer, ion channel permeability, glycoproteins, and ligand receptors
- Consequently, there is enzyme activation, gene induction, protein synthesis, and mitogenesis / cell proliferation
- Secondary biochemical messengers then pass this signal to the nucleus and the DNA of the cell

Direct interaction theory

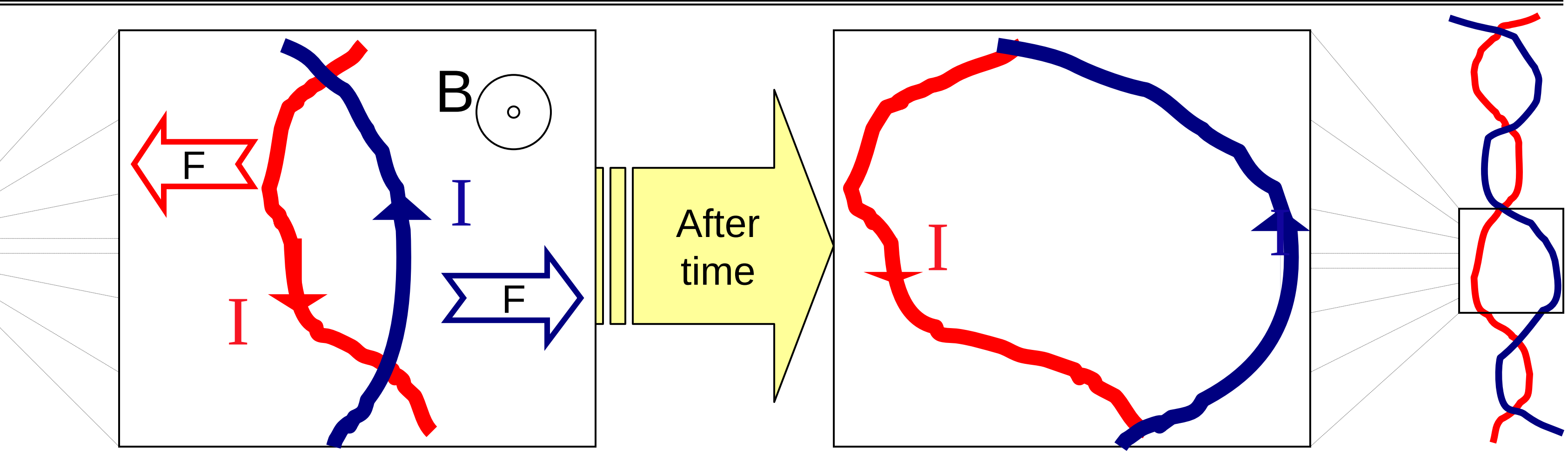
Many current studies present possible direct EM interaction mechanisms with DNA to explain changes in biosynthesis of the cell exposed to EMF

- Blank suggests Mobile Charge Interaction (MCI) model from a variety of experiments[4]
  - Magnetic fields interact with moving charges via the classical electromagnetics relation:

$$\vec{F} = q\vec{v} \times \vec{B} \qquad (7)$$

  - In the case of intracellular flowing charges, such as enzymes, this force will result in a change in velocity and a resulting alteration in intended biological function (demonstrated in Na, K-ATPase and cytochrome oxidase reactions)
  - In addition, moving electrons in DNA helices will begin to experience forces which may repel them from each other and bend, or even break, the chain, resulting in increased DNA multiplication

DNA chain bending



A direct result of equation (7) is the relationship between flowing charge (current), magnetic field, and induced force shown in equation (8) below

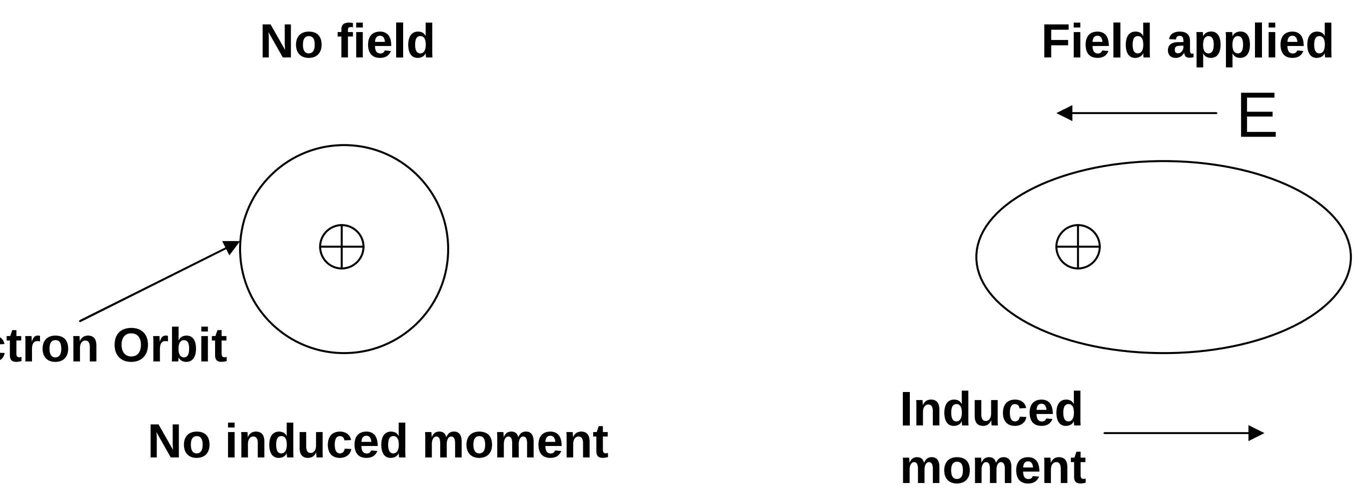
$$F = I \cdot d\vec{l} \times \vec{B} \qquad (8)$$

When two wires have currents flowing in opposite directions, an applied magnetic field will cause repulsion

Expanding this idea by thinking about the DNA helix simply as two "wires" which may carry charge through electron transport in opposing directions, we

Thermal effects: Heat generation

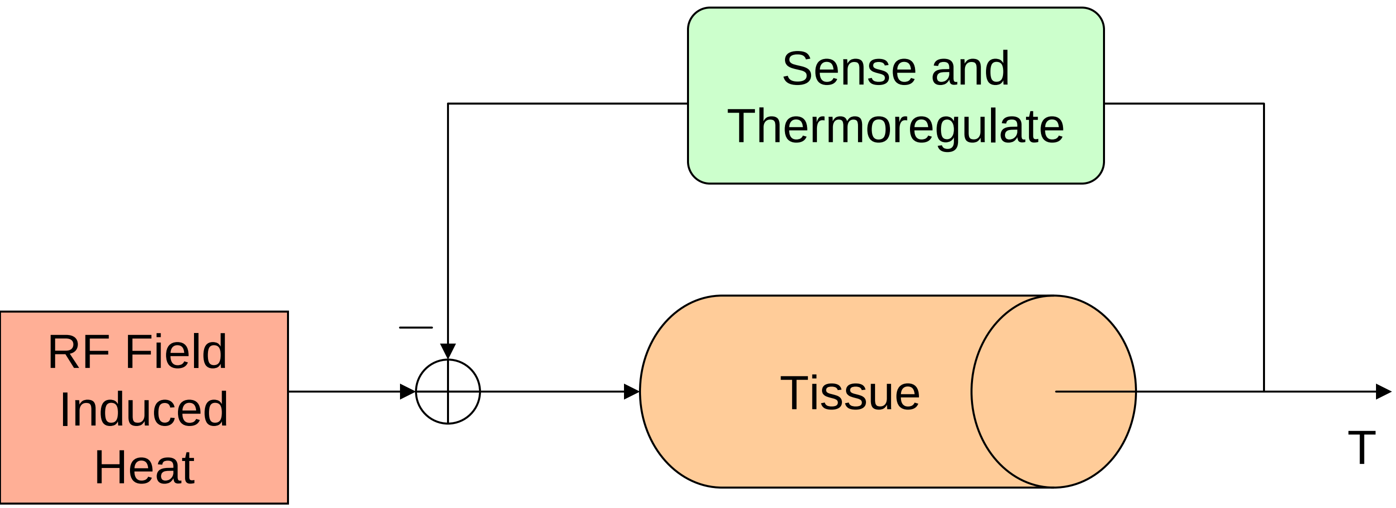
- Ionic conduction and vibration of dipole molecules following alternations of the field lead to an increase of kinetic energy which is converted to heat
- The simplistic model below elucidates this phenomenon by first demonstrating induction of dipole moments by an applied electric field (electronic polarization)



- These dipole moments are internally induced electric fields that oppose the externally applied field
- They try to (unsuccessfully) follow the alterations of the electric field at RF and microwave frequencies but instead lag behind the transmitted wave, thus energy is gained

tuchly, "Fundamentals of the Interactions of Radio-frequency and Microwave Energies with Matter," In: *Biological ts and dosimetry of nonionizing radiation, radiofrequency and microwave energies: NATO advanced study*

Thermoregulation



If T exceeds a certain threshold value (usually determined based on the Basal Metabolic Rate), the thermoregulation feedback system will break down and the tissue temperature will rise beyond control

Biological damage and, possibly, tissue death will result if the RF field continues to be applied especially if the tissue is of a control organ

Thermoregulation

Whenever heat is generated within the body, neuroendocrine thermoregulatory control mechanisms take effect

Body has both passive and active thermoregulatory mechanisms:

- Passive:
  - Heat radiation
  - Evaporation cooling
  - Conduction / convection
- Active
  - Internal fluids (such as blood) transfer heat to external parts of the body
  - In humans, heat is transferred to skin where it can be radiated or convected away (*cutaneous vasodilation*)

To maintain homeostasis, these control mechanisms respond to the stimuli or stressors from the outside environment

If the body temperature keeps rising regardless of the efforts of these mechanisms, they breakdown and temperature is no longer stable

ichaelson, "Biological effects and health hazards of RF and MW energy: Fundamentals and overall omenology", In: *Biological effects and dosimetry of nonionizing radiation, radiofrequency and*

Thermoregulatory breakdown

After this breakdown, localized tissue damage can occur, resulting from insufficient heat diffusion by the active processes

Other possible results include hyperthermia, or heat exhaustion, accompanied by irreversible damage once the human tissue exceeds temperatures of approximately 43 degrees Celsius, and heat stress via the induction of the relevant gene (heat shock protein, hsp70)

Health and safety standards are developed given these potentially hazardous effects and specific absorption rate (SAR in W / kg) limits are set for various frequencies of radiation

In general, these levels are set such that the bulk body temperature does not rise more than 1 degree Celsius

A common standard is also the approximate Basal Metabolic Rate (BMR) that should, in general, not be exceeded by the SAR

:hen, *RF and Microwave Radiation Safety Handbook*, Newnes, Oxford, 2001.

At risk?

- Tissues which are at highest risk are those with lower blood concentration:
  - Eyes
  - Gall bladder
  - Testes
- These tissues are least able to dissipate heat through the active thermoregulatory mechanism of blood flow

- CAVEAT:
  - Although thermal effects are by far those which carry the greatest potential for biological hazard, it is perhaps more critical to study and bring to light the non-thermal effects of RF radiation
  - This is because the thermal effects are generally not encountered at lower-level radiations since the body can effectively dissipate the generated heat at these levels
  - And it is these lower levels of RF radiation to which we are most often exposed