BM-3252 MEDICAL PHYSICS

UNIT-1

1.3TISSUE AS A LEAKY DIELECTRIC

- If two electrodes are placed over the abdomen and the electrical impedance is measured between them over a wide range of frequencies then the results obtained might be as shown in figure 2.

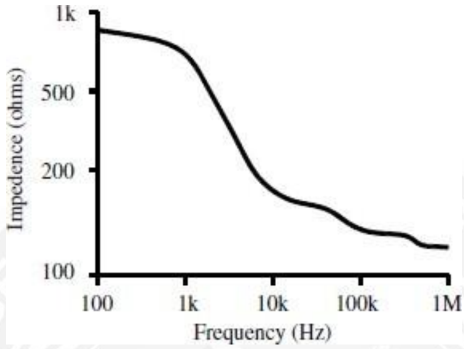

Figure 1.3. Electrical impedance as a function of frequency for two electrodes placed on the abdomen

- The results will depend somewhat upon the type and size of electrodes, particularly at the lowest frequencies, and exactly where the electrodes are placed.
- However, the result is mainly a function of the tissue properties. The impedance always drops with increasing frequency.
- Let us consider tissue as a lossy dielectric.
- We know that conductors, which have free charge carriers, and of insulators, which have dielectric properties as a result of the movement of bound charges under the influence of an applied electric field. An insulator cannot also be a conductor.
- Tissues though contain both free and bound charges, and thus exhibit simultaneously the properties of a conductor and a dielectric.
- If we consider tissue as a conductor, we have to include a term in the conductivity to account for the redistribution of bound charges in the dielectric.
- Conversely, if we consider the tissue as a dielectric, we have to include a term in the permittivity to account for the movement of free charges. The two approaches must,

of course, lead to identical results.

- Considering the interaction between electromagnetic waves and tissue by exploring the properties of dielectrics. zThe use of dielectrics which are insulators in cables and electronic components. A primary requirement of these dielectrics is that their conductivity is very low ($<10^{-10}$ S m^{-1}).
- Metals and alloys, in which the conduction is by free electrons, have high conductivities ($>10^{4}$ S m^{-1}).
- Intermediate between metals and insulators are semiconductors (conduction by excitation of holes and electrons) with conductivities in the range 10^{0}–10^{-4} S m^{-1}, and electrolytes (conduction by ions in solution) with conductivities of the order of 10^{0}– 10^{2} S m^{-1}.
- Tissue can be considered as a collection of electrolytes contained within membranes of assorted dimensions.
- None of the constituents of tissue can be considered to have 'pure' resistance or capacitance—the two properties are inseparable.
- Let us considering slabs of an ideal conductor and an ideal insulator, each with surface area A and thickness x (see figure 3).

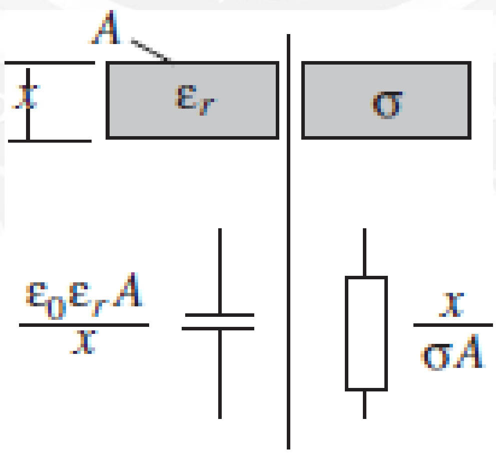

Figure1.3.2. Slabs of an insulator, on the left, and a conductor, on the right.

- If the dielectric has relative permittivity ε_r then the slab has a capacitance $C = \varepsilon_0\varepsilon_r A/x$.
- The conductance of the slab is $G = \sigma A/x$, where the conductivity is σ.

- The conductivity σ is the current density due to unit applied electric field (from **J** = σ**E**), and the permittivity of free space ε_0 is the charge density due to unit electricfield, from Gauss' law.
- The relative permittivity $\varepsilon_r = C_m/C_0$, where C_0 is the capacitance of a capacitor in vacuo, and C_m is the capacitance with a dielectric completely occupying the region containing the electric field.
- In tissue, both of these properties are present, so we take as a model a capacitor with a parallel conductance, as shown in figure 4.

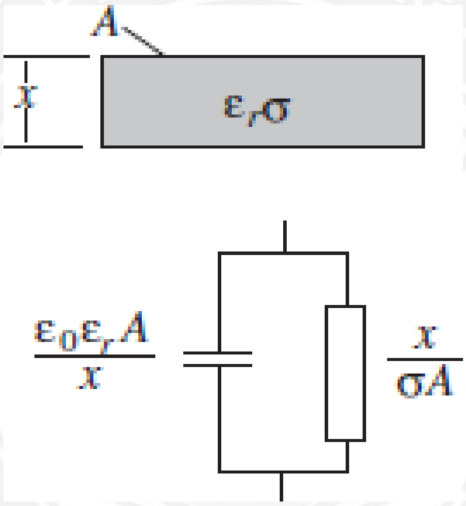

Figure 1.3.3. Tissue with both capacitive and resistive properties in parallel. The capacitance and resistance of the two arms are marked

- The equations $C = \varepsilon_0\varepsilon_r A/x$ and $G = \sigma A/x$ define the static capacitance and conductance of the dielectric, i.e. the capacitance and conductance at zero frequency.
- If we apply an alternating voltage to our real dielectric, the current will lead the voltage.
- Clearly, if G = 0, the phase angle θ = π/2, i.e. the current leads the voltage by π/2, as we would expect for a pure capacitance.
- If C = 0, current and voltage are in phase, as expected for a pure resistance.
- For our real dielectric, the admittance is given by $Y^* = G + j\omega C$, where the * convention has been used to denote a complex variable (this usage is conventional in dielectric theory).

- We can, as a matter of convenience, define a generalized permittivity $\varepsilon^* = \varepsilon' - j\varepsilon''$ which includes the effect of both the resistive and capacitive elements in our real dielectric. Where ε' is the real part and ε'' is the imaginary part.
- We can relate the generalized permittivity to the model of the real dielectric by considering the admittance,

$$Y^* = G + j\omega C = \frac{A}{x}(\sigma + j\omega\,\varepsilon_0\varepsilon_r).$$

- By analogy with an ideal capacitance C which has admittance jωC, we can define the complex capacitance C^* of the real dielectric,

$$C^* = \frac{Y^*}{j\omega} = \frac{A}{x}\left(-\frac{j\sigma}{\omega} + \varepsilon_0\varepsilon_r\right) = \frac{A}{x}\varepsilon_0\varepsilon^* = \varepsilon^* C$$

i.e.

$$\varepsilon^* = \varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}$$

thus

$$\varepsilon' = \varepsilon_r \quad \text{and} \quad \varepsilon'' = \frac{\sigma}{\omega\varepsilon_0}.$$

- From this it can be seen that we can consider the properties of our non-ideal capacitor as being the result of inserting a dielectric with a relative permittivity ε^* in an ideal capacitor C.
- The real part ε' is the relative permittivity ε_r of the ideal capacitor, and the imaginary part jε'' is associated with the resistive properties.
- We now have a means of handling real dielectrics which is analogous to that for ideal dielectrics.
- We can also consider the admittance in terms of a complex conductivity,

$$Y^* = G + j\omega C = \frac{A}{x}(\sigma + j\omega\varepsilon_0\varepsilon_r) = \frac{A}{x}\sigma^*$$

i.e.

$$\sigma^* = \sigma + j\omega\,\varepsilon_0\varepsilon_r.$$

- The complex permittivity and complex conductivity are related by

$$\sigma^* = j\omega\,\varepsilon^*\varepsilon_0.$$

- We are thus able to relate the behaviour of the conductivity and permittivity.
- Note that as the frequency tends to zero, the complex conductivity becomes purely real, and in the high-frequency limit, the complex permittivity becomes purely real.
- We would thus expect the conductivity to be dominant at low frequencies, and the permittivity to be dominant at high frequencies.

Non-Ionizing Radiation:

Non-ionizing (or **non-ionising**) **radiation** refers to any type of electromagnetic radiation that does notcarry enough energy per quantum (photon energy) to ionize atoms or molecules—that is, to completely remove an electron from an atom or molecule.

- **Examples:**

Radio waves, microwaves, infrared, (visible) light, ultraviolet.

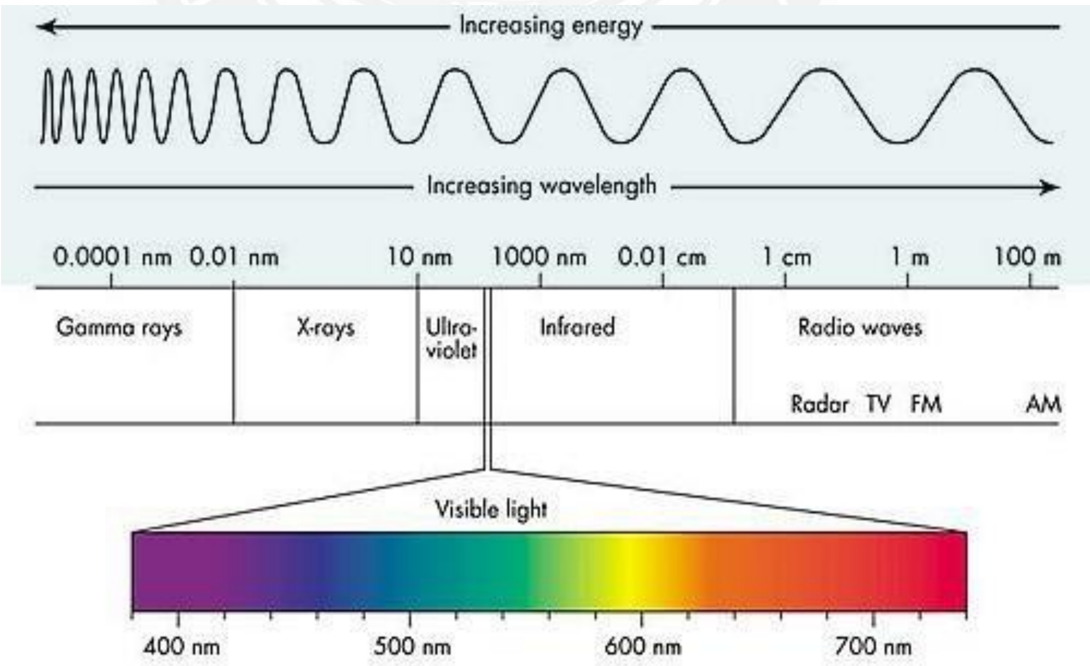

Figure 1 (a). Electromagnetic Spectrum

Table 8.3. *Some sources of electromagnetic fields.*

Source	Frequency range	Intensity range
Lightning	1 Hz–1 kHz	10 kV m^{-1}
Short-wave and microwave diathermy	27 MHz 2.450 GHz	>2 kV m^{-1} (in air)
Surgical diathermy/ electrosurgery	0.4–2.4 MHz	>1 kV m^{-1} (in air)
Home appliances	50–60 Hz	250 V m^{-1} max. 10 μT max.
Microwave ovens	2.45 GHz	50 W m^{-2} max.
RF transmissions	<300 MHz	1 W m^{-2} max.
Radar	0.3–100 GHz	100 W m^{-2} max.
High-voltage cables	50–60 Hz	>10 kV m^{-1}
Portable phones	500 MHz typical	>1 W m^{-2}