Introduction

Imaging in Medical Sciences

- Imaging is an essential aspect of medical sciences for visualization of anatomical structures and functional or metabolic information of the human body.
- Structural and functional imaging of human body is important for understanding the human body anatomy, physiological processes, function of organs, and behavior of whole or a part of organ under the influence of abnormal physiological conditions or a disease.

Introduction

Medical Imaging

- Radiological sciences in the last two decades have witnessed a revolutionary progress in medical imaging and computerized medical image processing.
- Advances in multi-dimensional medical imaging modalities
  - **X-ray Mammography**
  - **X-ray Computed Tomography (CT)**
  - **Single Photon Computed Tomography (SPECT)**
  - **Positron Emission Tomography (PET)**
  - **Ultrasound**
  - **Magnetic Resonance Imaging (MRI)**
  - **functional Magnetic Resonance Imaging (fMRI)**

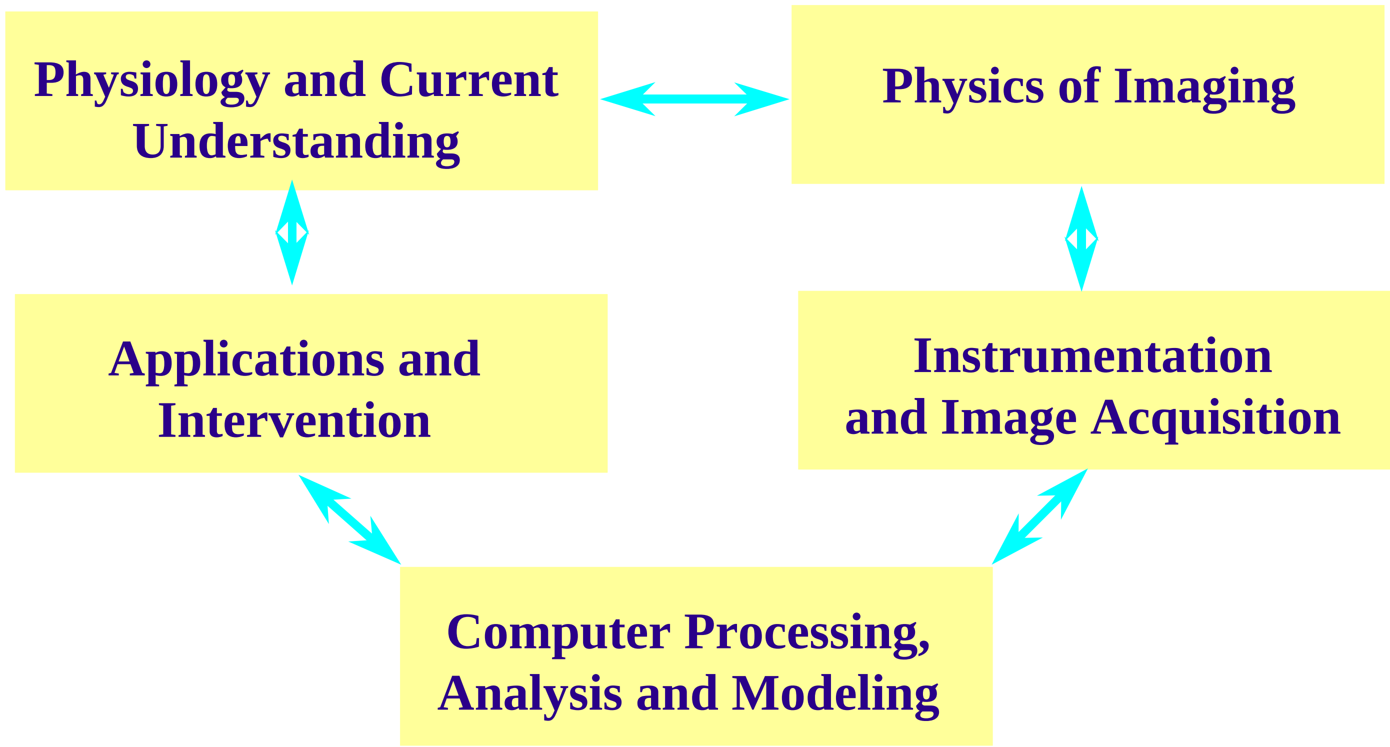
Introduction

Medical Imaging and Image Analysis

- The development of imaging instrumentation has inspired the evolution of new computerized image reconstruction, processing and analysis methods for better understanding and interpretation of medical images.
- The image processing and analysis methods have been used to help physicians to make important medical decision through physician-computer interaction.
- Recently, intelligent or model-based quantitative image analysis approaches have been explored for computer-aided diagnosis to improve the sensitivity and specificity of radiological tests involving medical images.

Medical Imaging:
A Collaborative Multidisciplinary Paradigm

A Collaborative Multidisciplinary Paradigm of Medical Imaging Research and Application



Medical Imaging:
From Physiology to Information Processing

1. **Understanding Imaging Medium**

   The imaged objects (organs, tissues and specific pathologies) and associated physiological properties that could be used for obtaining signals suitable for the formation of an image must be studied for the selection of imaging instrumentation

2. **Physics of Imaging**

   Considering the principle of imaging to be used for obtaining the data. The image formation from various modalities are different.

   - CT : shaper image with high-resolution anatomical details.
   - PET: poor in contrast and anatomical details but representing metabolic condition
   - MR: high-resolution anatomical details with excellent soft-tissue contrast.

Medical Imaging:
From Physiology to Information Processing

3. Imaging Instrumentation

   Defining the image quality in terms of signal-to-noise ratio, resolution and ability to show diagnostic information

4. Data Acquisition Methods for Image Formation

   It is crucial in developing strategies to reduce image artifacts through active filtering or post-processing methods

5. Image Processing and Analysis

   Enhancing the diagnostic information to improve manual or computer-assisted interpretation of medical images

Medical Imaging:
A Collaborative Paradigm

- Medical imaging in diagnostic radiology has evolved as a result of the significant contributions of a number of different disciplines from basic sciences, engineering, and medicine.
- Computerized image reconstruction, processing and analysis methods have been developed for medical imaging applications
- The application-domain knowledge has been used in developing models for accurate analysis and interpretation.

Medical Imaging: A Collaborative Paradigm

- The requirements for Intelligent interpretation of medical images
  - Understanding of the interaction of the basic unit of imaging (such as protons in MRI, X-ray photons in X-ray CT) in a biological environment
  - Formation of a quantifiable signal representing the biological information
  - Detection and acquisition of the signal of interest
  - Appropriate image reconstruction

Medical Imaging Modalities

- **Radiation / Imaging Source**
- **External**
  - **X-ray Radiography**
  - **X-ray CT (Computed Tomography)**
  - **Ultrasound**
  - **Optical: Reflection, Transillumination**
- **Internal**
  - **SPECT (Single Photon Emission Computed Tomography)**
  - **PET (Positron Emission Tomography)**
- **Mixed**
  - **MRI, fMRI**
  - **Optical Fluorescence**
    - **External ultraviolet energy source stimulate the internal biological molecules to be a internal source of energy**
  - **Electrical Impedance**

Medical Imaging Modalities
-- CT (Computed Tomography)

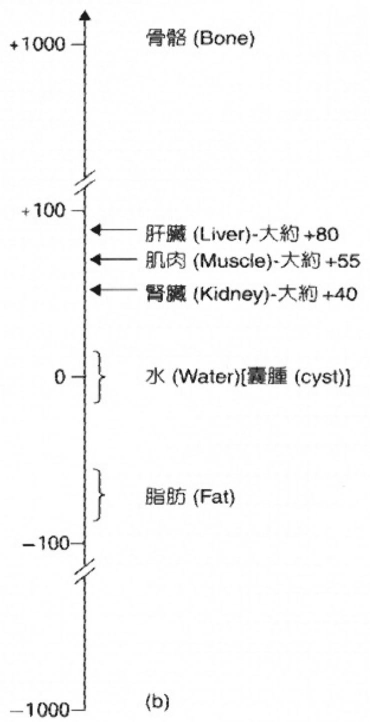


圖 1.4 各種正常身體組織的 CT 密度 (CT density)〔豪斯費爾單位 (Hounsfield units)〕的度量法。

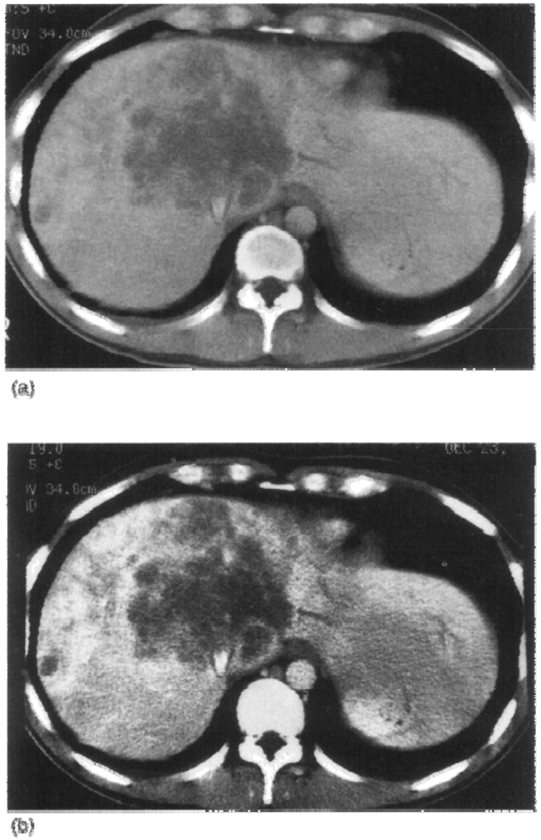


圖 1.5 改變窗寬 (window width) 的效果。(a) 和 (b) 的窗中心 (window center) 都固定在 65HU。在 (a) 的窗寬 (window width) 為 500HU；而 (b) 的窗寬只有 150HU。注意在窄窗寬影像 (b) 能比較清楚看到轉移病變，但肝臟以外的構造都在 (a) 中比較清楚。

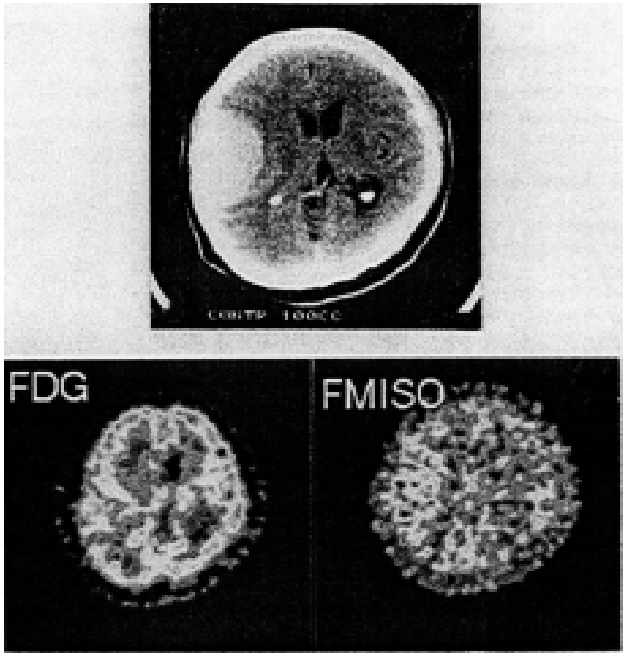
Medical Imaging Modalities
-- PET (Positron Emission Tomography)

➢FDG

產生 氟-18 正子同位素，進一步合成氟-18 去氧葡萄糖([F-18]-fluorodeoxyglucose, FDG)，評估腦細胞代謝情況，惡性度高的腦瘤，葡萄糖糖解反應(glycolysis) 愈高，FDG吸收也就愈多。

➢FMISO

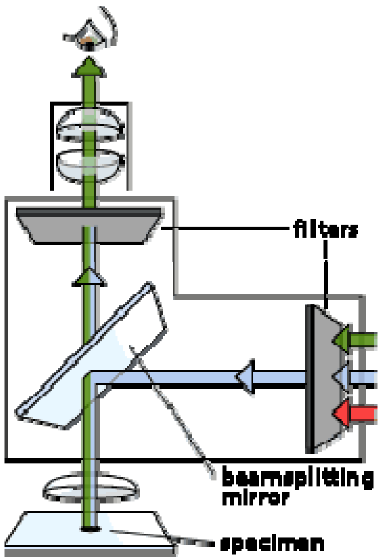
氟-18 標化之fluoromisonidazole (簡稱FMISO)，在缺氧細胞中經氮還原成胺類化合物停留在細胞中，便可利用正子斷層造影(positron emission tomography,PET)，偵測FMISO在腫瘤內之分布，從而了解腫瘤缺氧的程度。



A. 位於右側額ー頂葉的腦膜瘤；
B. FDG 葡萄糖代謝正子斷層掃描時，腫瘤呈現低代謝；
C. FMISO缺氧造影發現該腫瘤吸收較多的缺氧造影劑，缺氧指數為2.2，表示腫瘤呈缺氧現象。

（劉仁賢, 科學發展月刊第29卷第11期）

Medical Imaging Modalities
-- Optical Fluorescence



Excitation Balancer Performance with Dual Excitation Filters

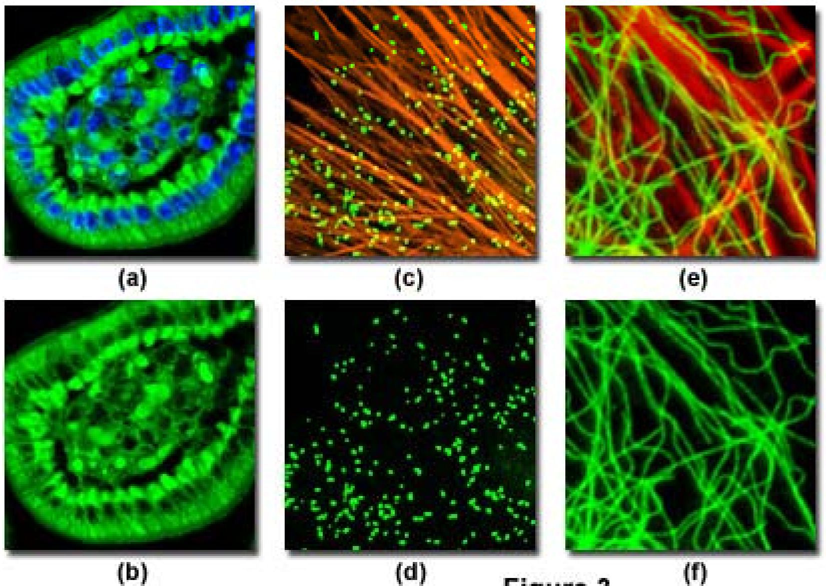
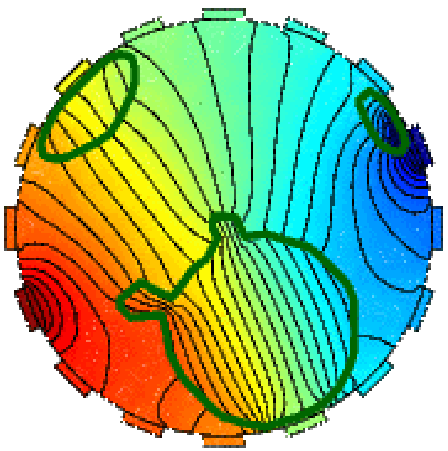
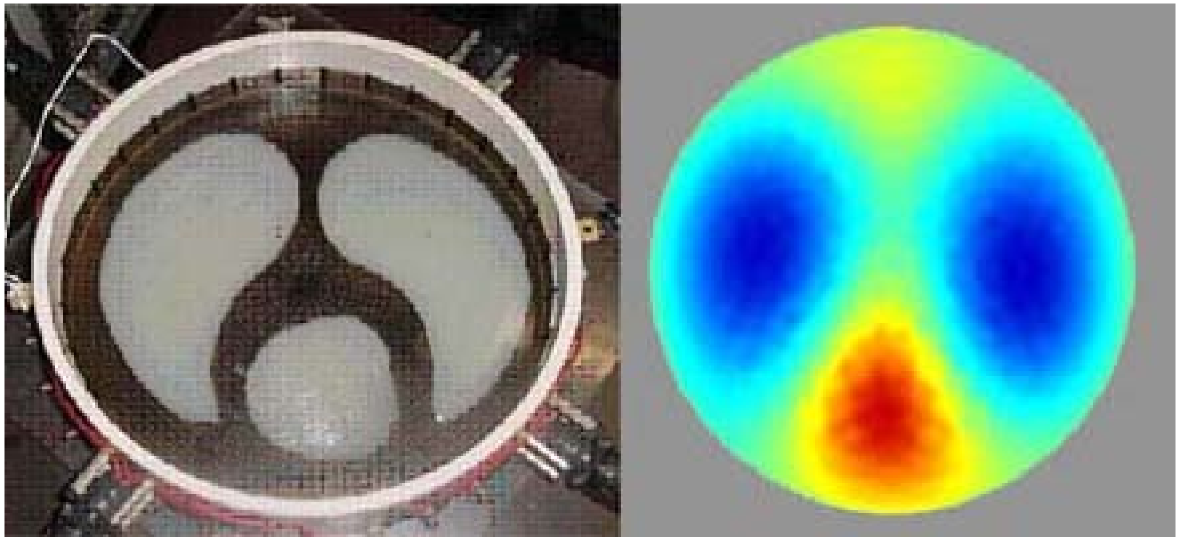


Figure 3

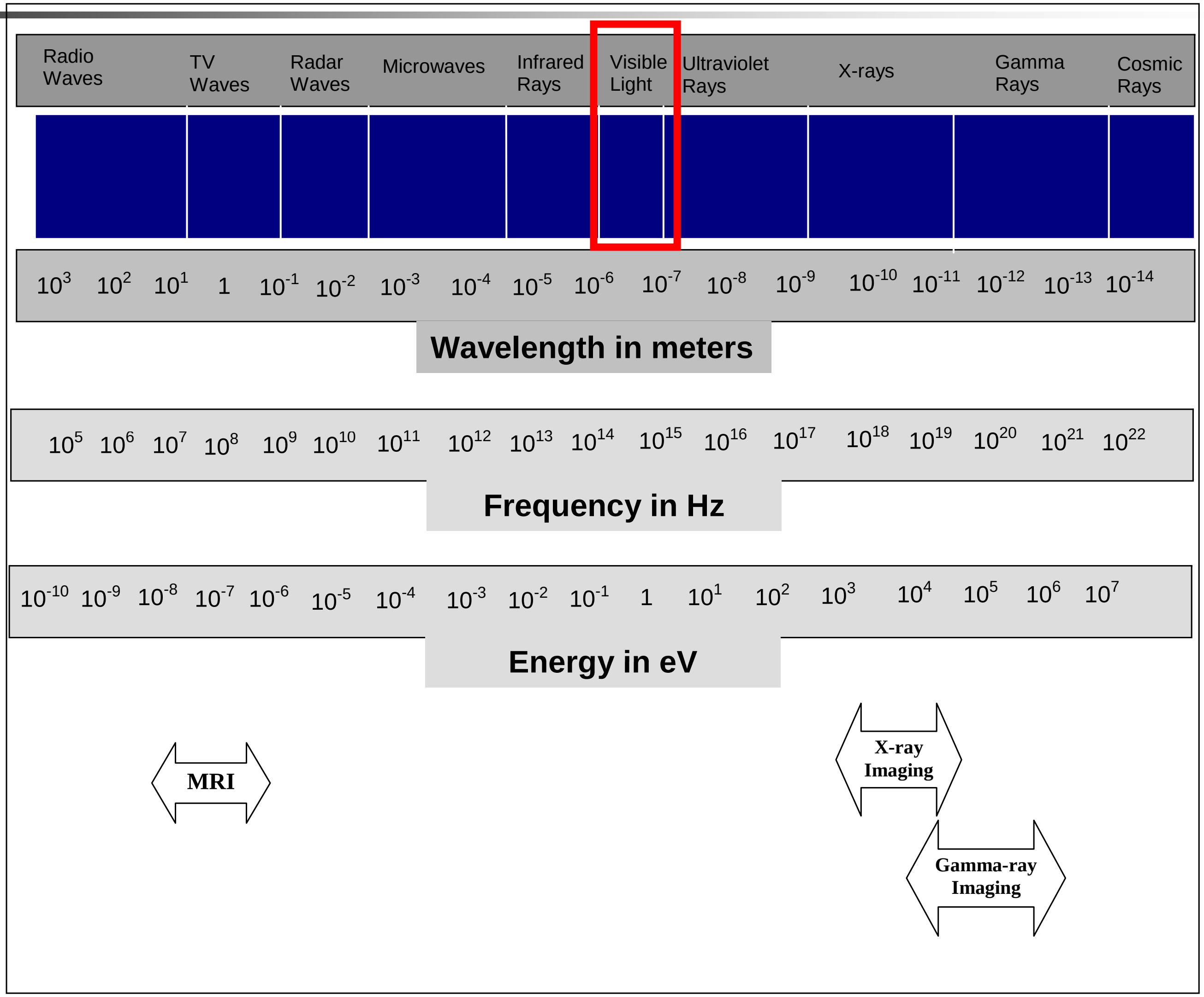
Medical Imaging Modalities

-- Electrical Impedance Tomography





Electromagnetic Radiation Spectrum



Medical Imaging Information

- **Anatomical**
  - **X-Ray Radiography**
  - **X-Ray CT**
  - **MRI**
  - **Ultrasound**
  - **Optical**
- **Functional / Metabolic**
  - **SPECT**
  - **PET**
  - **fMRI, pMRI**
  - **Ultrasound**
  - **Optical Fluorescence**
  - **Electrical Impedance**

The Type of Energy Source of Medical Imaging Modalities

- Medical Imaging Modalities
  - Source of Energy
    - External
      - X-ray Imaging:
        - Radiographs
        - Mommography
        - CT
      - Ultrasound Imaging and Tomography
    - Internal
      - Nuclear Medicine: SPECT (Single Photon Emission Tomography)
      - Nuclear Medicine: PET (Position Emission Tomography)
    - Combination: External + Internal
      - Magnetic Resonance Imaging: MRI, PMRI, FMRI
      - Optical Fluorescence Imaging
      - Electrical Impedance Imaging

The Type of Energy Source of Medical Imaging Modalities

External	Based on the attenuation coefficient of radiation passing through the body	**X-ray, Ultrasound**	Anatomical structure
Internal	Radioactive pharmaceuticals are injected into the body to interactive with selected body matter or tissue to form an internal source of radioactive energy	**Signal Photon Emission Computed Tomography (SPECT)** **Positron Emission Tomography (PET)**	Physiological function (Metabolic information)
Combination	Be used to acquire accurate information about the tissue material and physiological responses and functions	**MRI** External energy : magnetic energy Internal energy : stimulated atomic nuclei such as hydrogen protons)	Anatomical & Physiological

General Performance Measures

- The measures in the evaluation of a medical imaging or diagnostic test for detecting an object
  - Observation
    - Positive: The object was observed in the test.
    - Negative: The object was not observed in the test.
  - Condition
    - True: The actual true.
    - False: The condition is false (Wrong result).

General Performance Measures

A conditional matrix for defining four basic performance measures as defined in the text

True Condition

Observed Information

	Object is present.	Object is not present
Object is observed.	True Positive (N_{otp})	False Positive (N_{ofp})
Object is not observed.	False Negative (N_{ofn})	True Negative (N_{otn})
	N_{tp}	N_{tn}

General Performance Measures

- N_{otp} (True Positive)
  - The number of positive observations from N_{tp} positive true-condition cases
- N_{ofn} (False Negative)
  - The number of negative observations from N_{tp} positive true-condition cases
- N_{otn} (True Negative)
  - The number of negative observations from N_{tn} negative true-condition cases
- N_{ofp} (False positive)
  - The number of positive observations from N_{tn} negative true-condition cases

$$N_{tp}=N_{otp}+N_{ofn} \text{ and } N_{tn}=N_{ofp}+N_{otn}$$

General Performance Measures

- True positive Fraction (TPF)
  - The ratio of the number of positive observations to the number of positive true-condition cases.

    $TPF = N_{otp}/N_{tp}$ -> Sensitivity
- False Negative Fraction (FNF)
  - The ratio of the number of negative observations to the number of positive true-condition cases.

    $FNF = N_{ofn}/N_{tp}$

$TPF + FNF = 1$

	Object is present.	Object is not present
Object is observed.	True Positive (N_{otp})	False Positive (N_{ofp})
Object is not observed.	False Negative (N_{ofn})	True Negative (N_{otn})

General Performance Measures

- False positive Fraction (FPF)
  - The ratio of the number of positive observations to the number of negative true-condition cases.

$$FPF=N_{ofp}/N_{tn}$$

- True Negative Fraction (TNF)
  - The ratio of the number of negative observations to the number of negative true-condition cases.

$$TNF=N_{otn}/N_{tn}$$ -> Specificity

$$TNF+FPF=1$$

	Object is present.	Object is not present
Object is observed.	True Positive (N_{otp})	False Positive (N_{ofp})
Object is not observed.	False Negative (N_{ofn})	True Negative (N_{otn})

General Performance Measures

- Sensitivity
  - The True Positive Fraction TPF
- Specificity
  - The True Negative Fraction TNF
- Accuracy
  - Ratio of correct observation to the total number of examination cases

    $Accuracy=(N_{otp}+N_{otn})/N_{tot}$ (課本有誤)

General Performance Measures

		Disease	
		yes	no
Test	positive	a	b
	negative	c	d

Formulas:

- Specificity = d / b+d
- Accuracy = a+d / a+b+c+d
- Prevalence = a+c / a+b+c+d
- Sensitivity = a / a+c
- Predictive Value:
    - positive = a / a+b
    - negative = d / c+d

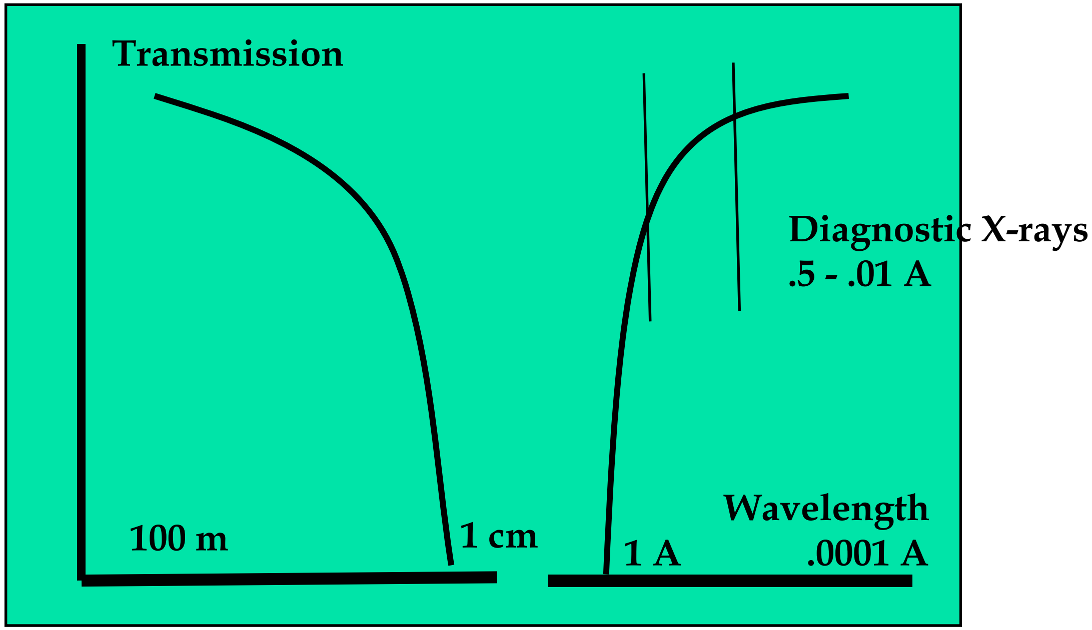
http://www.medstudents.com.br/epidem/epidem2.htm

EM Radiation and Imaging

- Wave concept of EM radiation explains why it may be reflected, refracted, diffracted, and polarized.
- Short EM waves, such as x-rays may react with matter as if they were particles rather than waves.
- These particles are actually discrete bundles of energy.
- Each bundle of energy is called a quantum or a photon.
- Photons travel at the speed of light.
- The amount of energy carried by a photon depends on the frequency of the radiation (I.e. number of vibrations per second).
    - **$E = h\nu$**
- E is the photon energy; h is the Planck's constant = 4.13×10^{-18} keV sec and ν is frequency.
- The particle behavior of photon leads to photoelectric effect and Compton scatter.

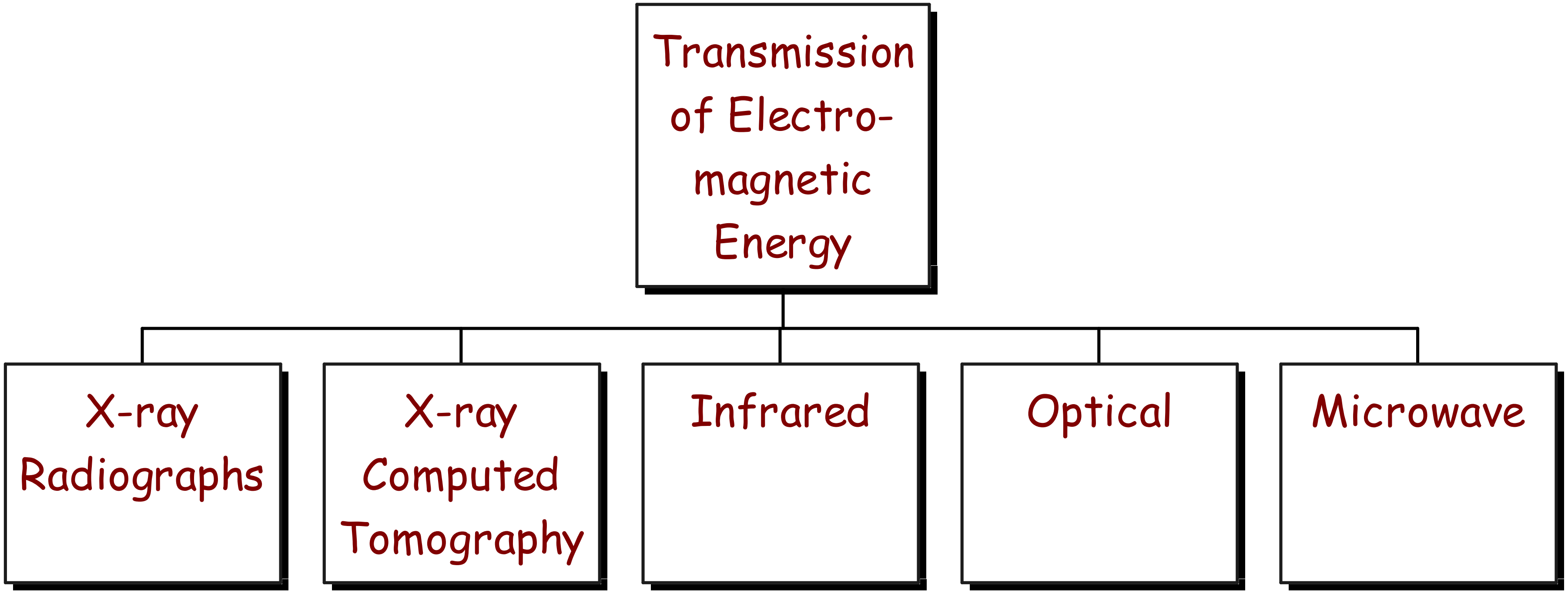
X-ray Imaging

- c=λν   or ν=c/λ
- **Thus, E= hc/λ**
- **where c is velocity of light; hc = 12.4; E is in keV and ν is in A.**
- **E = 12.4/λ keV**



Medical Imaging Thru Transmission

Basic Principle: Radiation is attenuated when passed through the body.



Transmission Imaging

- **Not all wavelengths in electromagnetic radiation spectrum are suitable for transmission imaging for human body.**
- **Resolution of the desired image of human body imposes the restrictions on the use of electromagnetic radiation.**
- **There are two important considerations when selecting an electromagnetic radiation for imaging human body:**
  - **Resolution: For a useful image, the wavelength must be under 1.0 cm. Higher wavelengths will not provide useful resolution in the image. Wavelength should be shorter than the resolution of interest.**
  - **Attenuation: The radiation should be reasonably attenuated when passed through human body. Too much attenuation will result in poor signal-to-noise ratio. If it is completely transmitted, it will not provide any meaningful structural details in the image.**